RESEARCH

A potential distribution map of wintering Swan Goose (*Anser cygnoides*) in the middle and lower Yangtze River floodplain, China

An An[1,2] , Yong Zhang[3], Lei Cao[1,2*], Qiang Jia[4] and Xin Wang[1]

Abstract

Background: Reliable information on the distribution of target species and influencing environmental factors is essential for effective conservation management. However, ecologists have often derived data from costly field surveys. The Swan Goose (*Anser cygnoides*), a vulnerable Anatidae species, winters almost exclusively in China's Yangtze River floodplain, but wintering numbers have been steadily decreasing. To better safeguard this unique species, modern modeling approaches can be used to quantify and predict its suitable wintering habitat. Specifically, a potential wintering distribution map of this species is critically important.

Methods: This study used the maximum entropy approach to model a distribution map of this species. In total, data from 97 up-to-date sites were extracted from 1263 survey sites (excluding duplicate data). After eliminating spatial autocorrelation, 11 environmental variables, including factors related to climate, land structure, vegetation, and anthropogenic activities, were used for model prediction.

Results: The prediction distribution map shows that the population has concentrated mainly in the boundary area of Anhui, Hubei, and Jiangxi provinces, especially along the Yangtze River. Modeling results suggest that areas within the middle and lower Yangtze River floodplain, such as those in Hunan and Hubei provinces and the eastern coastal area of Zhejiang Province, demonstrate a potential level of "medium" suitability for this species to winter.

Conclusions: Results from this study provide fundamental information for the restoration and management of the Swan Goose. Our "visualized" potential distribution map can assist in planning optimal conservation strategies, and consequently may help to increase the number of wintering populations in China.

Keywords: Swan Goose, Species distribution map, Maxent, Ecological conservation management

Background

Wetlands play an important role in ecological diversity, and waterbirds are key bio-indicators for wetland health assessments (Wang et al. 2018). Many natural wetlands have been lost in China over the last 50 years with the rapid economic development that has taken place in the 20th century (An et al. 2007). In particular, between 1990 and 2010 almost 30% of China's natural wetlands have vanished (Cyranoski 2009). In recent decades, 19% of inland wetland habitat has been lost in eastern China (Gong et al. 2010). Wetlands in China support huge numbers of migratory waterbirds, and China's remaining wetlands are undergoing extensive degradation due to increasing land reclamation, pollution, and anthropogenic disturbances, leading to a dramatic decrease in the number of wintering Anatidae species (Lu 1996a; Cao et al. 2008a; Wang et al. 2017). Over the last several decades, policymakers and environmental managers have implemented numerous measures for waterbirds conservation in China, such as building up national nature reserves, designating key wetlands as Ramsar Sites (those designated as internationally important wetlands), conducting long-term waterbird surveys,

*Correspondence: leicao@rcees.ac.cn
[1] State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China
Full list of author information is available at the end of the article

An *et al. Avian Res*   (2018) 9:43

Page 2 of 10

and carrying out public education initiatives (The State Forestry Administration 2015; Zeng et al. 2018). To a certain extent, these efforts have all been successful; however, waterbirds still face increasing pressure from many different directions (Yang et al. 2011; Wang et al. 2017, 2018). Thus far, the conflict between waterbirds conservation and economic development has not only been a local issue but a national concern (Cao and Fox 2009). There has long been a consensus of opinion that a sustainable solution is urgently needed in the form of a rectified management plan.

One of the prerequisites for developing a long-term, efficient management plan to resolve the conflicts between waterbirds conservation and anthropogenic demands is to gather reliable information regarding the current wintering sites and habitat usages of species under consideration (Wisz et al. 2008). Such an overview can help us identify species distribution patterns and behavior across wetlands and consequently aid in the improvement of habitat management and restoration (Franklin and Miller 2010). However, without adequate information, current policies used to allocate funds for the construction of nature reserves as well as ecological monitoring initiatives will fail to subsidize the cost of implementing species protection measures while allowing migratory connectivity.

The Swan Goose (*Anser cygnoides*) breeds in western and central Mongolia, northeastern China, which borders both China and Russia, while breeding also occurs in Sakhalin as well as areas close to the Russian mainland (Kear 2005). However, this species almost exclusively winters in China, namely, between southern and eastern China, at a number of seasonal recessional wetlands along the middle and lower Yangtze River floodplain (Lu 1996b; Fox et al. 2008; Zhang et al. 2011). The latest population size of this species was estimated to range from 60,000 to 78,000 (Wetlands International 2012), and it has been categorized as a vulnerable species (the International Union for Conservation of Nature (IUCN)). Although there have been some studies on distribution changes and the population status of wintering Swan Goose populations in China, annual survey data were the only supportive evidence used in these studies (Zhang et al. 2011; Wang et al. 2012; Zhao et al. 2012), and such empirical data may inadvertently lead to subjective results. Thus far, no such efforts have included advanced technological tools, such as modeling, which is based on empirical data as well as habitat information at large spatial scales that are used to determine the population distribution of Swan Goose populations throughout China. Accordingly, conservation managers critically require a prospective species distribution map to identify as yet unidentified zones that are likely to be used by

Swan Geese for long-term habitat conservation and restoration planning.

In recent years, species distribution models have been increasingly used to predict the potential habitats of many species. Such tools may be used to associate empirical counting data to environmental variables. They are based on statistical or theoretical responses to calculate and infer reasonable predictions (Guisan and Thuiller 2005). In some cases, both "present" and "absent" data are required for model development (Corsi et al. 2000; Guisan and Zimmerman 2000; Elith 2002; Scott et al. 2002). However, in most cases, not all species "absent" data are recorded, making the maximum entropy method indispensable because it only requires "presence-only" data, which has been frequently used to forecast potential species distributions (Phillips et al. 2006).

In this study, we investigated factors associated with the distribution of Swan Goose populations in the middle and lower Yangtze River floodplain, China, and introduced a new prediction map to determine prospective habitats that this species may utilize within their wintering area by employing the maximum entropy modeling method. The objective of this study was to provide consultative information to use for habitat conservation and species preservation measures of Swan Goose populations. Findings from our study may also contribute to the development of China's "ecological redline policy".

Methods

Study area

The middle and lower Yangtze River floodplain stretches from the Three Gorges Dam and across Hubei, Hunan, Jiangxi, Anhui, and Jiangsu provinces to the estuary in Shanghai, with a total length of 1850 km (Zhao et al. 2012). Wetlands located in this area are important for waterbirds, especially during the wintering season (Scott 1989). Many globally threatened Anatidae species, such as a significant proportion of the Swan Goose population, winter in this region (Cao et al. 2008b). Poyang Lake (5100 km^2), the largest freshwater lake in China, is the most important wintering area for the Swan Goose. Dongting Lake (4350 km^2) and lakes in Anhui Province were once major wintering areas for the Swan Goose, however, only a scattering of the overall population still winters in these area due to changes in lake hydrology and the loss of submerged vegetation, which likely resulted from the construction of the Three Gorges Dam in conjunction with intensive aquacultural activities (Xu et al. 2006; Zhang et al. 2011).

The middle and lower Yangtze River floodplain is under the influence of a subtropical monsoon climate, and the elevation of most of its area is below 50 m. The annual average temperature is 18 °C, while the average winter

An *et al. Avian Res* (2018) 9:43

Page 3 of 10

temperature is approximately 5 °C. Average annual precipitation ranges from 1000 to 1400 mm, mainly occurring from March to August.
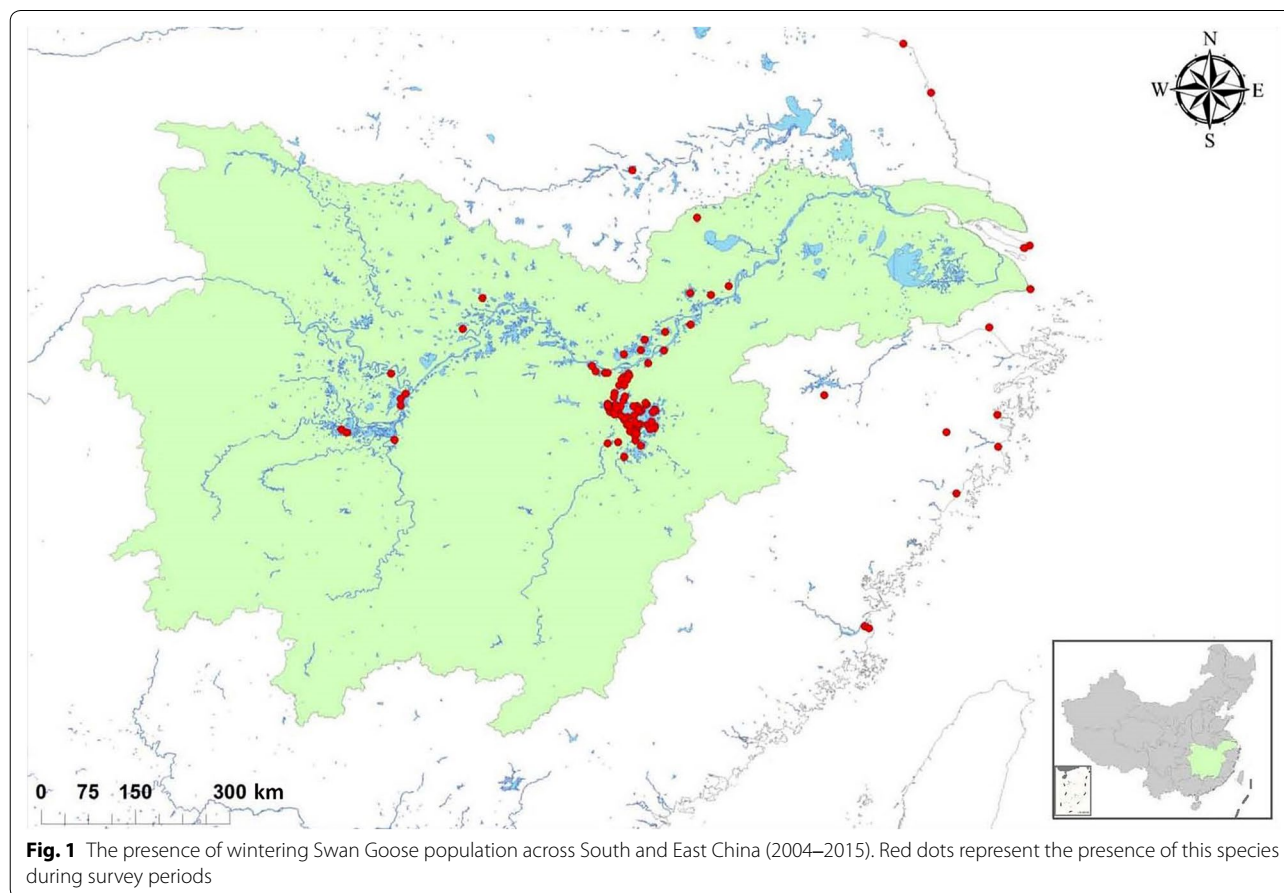
Swan Goose distribution data

Swan Goose distribution records were collected from three major resources: synchronous waterbird surveys conducted throughout the Yangtze River floodplain in February 2004 and 2005 (Barter et al. 2004, 2006) and our field surveys conducted in lakes in Anhui Province between 2007–2015 and Poyang Lake in the winter of 2014/2015 and 2015/2016. Other databases used were based on published articles, specialized reports from relevant organizations, and communication with experts (Cao et al. 2008a, b; Fox et al. 2008; Tu et al. 2009; Zhang et al. 2011; Zhu et al. 2012; Liao et al. 2014; Jia et al. 2016; Wang et al. 2017). In total, data from 97 observed wintering sites were extracted from 1263 survey sites, excluding non-wintering sites and duplicates. Most coordinates taken at these sites were recorded at the observers' position. However, due to the observational scope of optical instruments (such as binocualr), this study presupposed the presence of a Swan Goose population at a radius of

1 km from the position of the observer. We combined observation records during the winters of 2003/2004–2014/2015 with detailed maps to describe the overall occurrence of Swan Goose population (Fig. 1). The distribution data of Swan Goose population used in this study were taken from November to March.

Environmental variables

The environmental variables used in this study, which could potentially influence the distribution of Swan Goose populations, were determined by previous studies on geese or other waterbird species. Climate change and anthropogenic activity have long been thought to affect the winter distribution of waterbirds (Zöckler et al. 2008; Clausen et al. 2013). Previous studies have shown that temperature, precipitation, and elevation are highly correlated to geese distribution and abundance (Wisz et al. 2008; Moriguchi et al. 2013; Zhang et al. 2016; Cleasby et al. 2017). Geese are herbivores, and, during the winter, Swan Geese grub in shallow waters and bare areas for submerged *Vallisneria spiralis* tubers (Zhang et al. 2015a). Hence, they could easily be disturbed by frequent anthropogenic activities in open areas close to where

Fig. 1 The presence of wintering Swan Goose population across South and East China (2004–2015). Red dots represent the presence of this species during survey periods

An *et al. Avian Res*   (2018) 9:43

Page 4 of 10

they feed. Moreover, data obtained using the normalized difference vegetation index (NDVI), a proxy for terrestrial net primary production, have typically been used to link the distribution of herbivorous bird species (Cadahía et al. 2017; Suárez-Seoane et al. 2017). Thus, NDVI may be used as a predictor of distribution in prediction models designed for grazing waterbird species (Wu et al. 2014).

In total, we used 13 bioclimatic and 8 environmental variables as predictors in the model (Additional file 1: Table S1). High resolution (from 30 arcseconds to 10 arcminutes) bioclimatic variable layers provided by World-Clim Data (from 1950 to 2000) obtained from weather stations were also used. We downloaded 13 bioclimatic variables at a resolution of 30 arcseconds, including annual mean temperature, mean diurnal range, isothermality (the temperature ratio between the diurnal and annual range), temperature seasonality, minimum temperature of coldest month, annual temperature range, mean temperature of driest quarter, mean temperature of coldest quarter, annual precipitation, precipitation of driest month, precipitation seasonality, precipitation of driest quarter and precipitation of coldest quarter (http://www.worldclim.org). Elevation data were downloaded from the same website as climatic variables. We used 5 monthly mean NDVI values (January, February, October, November and December), which were obtained from the Geospatial Data Cloud of China (http://www.gscloud.cn). In this study, we integrated distance-based site accessibility to represent the degree of anthropogenic disturbance. Site accessibility was calculated as the radius from the road network to the center point of each grid, which was divided into 1 km × 1 km squares. We assumed that the greater the distance the more difficult it would be for people to access a site; in other words, such a site would be subject to less anthropogenic disturbance. This type of indicator is often used to measure anthropogenic pressure on birds (Tavares et al. 2015). All variables were re-sampled to the same spatial resolution (30 arcseconds) and grid cells.

Removing spatial autocorrelation

An assortment of spatial autocorrelation data is combined with ecological and environmental data when values are similar to those nearby (Augustin et al. 1996). Such spatial dependence data may lead to errors during modeling (Moriguchi et al. 2013). To remove spatial autocorrelation data, we randomly selected 1000 grid points throughout the geographical range, and calculated the Spearman's correlation (r) between each variable. We eliminated 10 variables with $r > 0.75$, which were considered to be significantly correlated (Dormann et al. 2013).

These statistical analyses were carried out using R 3.2.3 (R Development Core Team 2011).

Species distribution model

We chose the maximum entropy modeling method (Maxent version 3.3.3 k, Phillips et al. 2006) to predict the potential Swan Goose distribution using presence-only data. The maximum entropy modeling method has been widely used in species distribution prediction studies, and it is broadly considered the most robust and accurate approach (Elith et al. 2006; Hernandez et al. 2006). According to our program settings, 75% of occurrence data were randomly selected to compute 20 replicates for model training, and the remaining 25% of occurrence data were used for model testing.

We evaluated modeling results with receiver operating characteristic (ROC) curves which calculate the area under the curve (AUC). Following random prediction, the AUC value ranged from 0.5 (random accuracy) to 1.0 (perfect discrimination) (Fielding and Bell 1997). An AUC value greater than 0.75 was considered a creditable prediction (Pearce and Ferrier 2000; Elith 2002).

Results

After spatial autocorrelation analysis, we eliminated 7 bioclimate variables and 3 environmental variables which were considered to be significantly correlated to other variables. The eliminated variables were as follow: annual mean temperature (Bio1), temperature annual range (Bio7), mean temperature of driest quarter (Bio9), mean temperature of coldest quarter (Bio11), annual precipitation (Bio12), precipitation of driest quarter (Bio17), precipitation of coldest quarter (Bio19), NDVI of January (NDVI01), NDVI of November (NDVI11) and NDVI of December (NDVI12). Results from our analysis are shown in Tables 1 and 2, and more detailed information is provided in the Spearman's correlation matrix in Additional file 2.

Based on model prediction results, the prospective Swan Goose wintering distribution areas were mainly located in the middle and lower Yangtze River floodplain. The degree of Swan Goose wintering habitat suitability ranged from 0 (blue color) to 1 (red color) (Fig. 2).

We derived the ROC curves and AUC value of wintering Swan Goose from the Maxent model. Our results showed an AUC value of 0.982, which represented a high level of reliability in the Maxent model.

After eliminating highly autocorrelated variables, among a total of 11 variable layers, we used climate, land structure, vegetation, and anthropogenic influence to predict wintering habitat suitability. The most important variables in descending order were elevation (30.9%),

An *et al. Avian Res*   (2018) 9:43

Page 5 of 10

Table 1 Matrix of bioclimate variable correlations

	Bio1	Bio7	Bio9	Bio11	Bio12	Bio17	Bio19
Bio2	−0.02	0.53	−0.2	−0.16	−0.26	−0.36	−0.25
Bio3	0.17	−0.28	0.18	0.31	0.25	−0.18	0.06
Bio4	−0.34	*0.95*	−0.51	−0.63	−0.71	−0.34	−0.52
Bio6	*0.89*	−0.62	*0.86*	*0.99*	0.6	0.49	0.64
Bio14	0.39	−0.38	0.56	0.5	*0.78*	*0.97*	*0.91*
Bio15	−0.16	0.17	−0.22	−0.19	−0.27	−0.63	−0.42

Variables with $r > 0.75$ are considered significantly correlated, and values in italics represent a high correlation between variables

Table 2 Matrix of environmental vegetation variable correlations

	NDVI 01	NDVI 02	NDVI 10	NDVI 11	NDVI 12
NDVI 01	1	0.9	0.8	0.91	0.96
NDVI 02	0.9	1	0.66	0.76	0.86
NDVI 10	0.8	0.66	1	0.9	0.83
NDVI 11	0.91	0.76	0.9	1	0.94
NDVI 12	0.96	0.86	0.83	0.94	1

Variables with $r > 0.75$ are considered significantly correlated

precipitation of driest month (21.6%), isothermality (16.5%), and the vegetation biomass (NDVI) in October (11.9%) (Table 3).

The response curves of the four most important variables are provided in Fig. 3. Suitable habitats for wintering Swan Goose were plain areas with an elevation ranging from 0 to 500 m and winter precipitation ranging from 40 to 50 mm. The predicted distribution of wintering Swan Goose was positively correlated to isothermality. The potential suitability of isothermality increased with an initial increase in the ratio, and reached a maximum at approximately 23%. Based on NDVI results, vegetation cover was not linearly correlated to the occurrence of wintering Swan Goose; however, this occurrence potentially reached its peak with a NDVI value of approximately 0.15.

To summarize, based on our model prediction results, suitable habitats for wintering Swan Geese were highly concentrated in the boundary area of Anhui, Hubei, and Jiangxi provinces, especially along the Yangtze River. Moreover, among areas located in the middle and lower Yangtze River floodplain, such as in Hunan and Hubei provinces as well as the eastern coastal area of Zhejiang Province, they showed a "medium" potential level of suitability for wintering Swan Geese.

Discussion

In the Maxent model, areas under the ROC curve (AUC) greater than 0.75 are considered useful in the prediction of environmentally suitable niches for Animalia (Phillips and Dudik 2008). Our model, with an applicable AUC value of 0.982, successfully predicted the wintering distribution of Swan Goose populations in South and East China. The potential distribution map highlighted the fact that the occurrence of wintering Swan Goose predominates in Jiangxi Province, mainly around Poyang Lake. This was followed by Dongting Lake in Hunan Province, the southern region of Hubei Province, and the Yangtze River floodplain in Anhui Province, all of which showed a medium potential. The coastal region of Zhejiang Province also showed sufficient potential of the wintering distribution of Swan Goose populations.

Land structure, climate, and anthropogenic disturbance variables are typically recognized as those that strongly influence bird distribution (Zhang et al. 2012). In our results, the most important environmental variables affecting the prospective distribution of Swan Goose were elevation, precipitation of driest month, isothermality, and vegetation biomass in October. Many previous studies have shown that Swan Goose is a herbivorous waterbird species, grazing on recessional grasslands and lakes for submerged tubers (Fox et al. 2008; Zhang et al. 2015a, b). It is commonly believed that grazing wildfowl are sensitive to forage quantity and quality (Ydenberg and Prins 1981; Sutherland and Allport 1994; Cromsigt et al. 2009; Heuermann et al. 2011). Thus, we assumed that vegetation-based variables may play a key role in model prediction.

In our modeling results, however, elevation as a land structure variable proved to be the most important variable in our prediction model. We attributed this fact to the extensive area chosen for our study. In our intent to ascertain the greatest possible prospective potential of Swan Goose wintering area, the cumulative area selected for study included the entire middle and lower Yangtze River floodplain, which includes a total of six provinces. Such a vast territory may, for example, limit the influences of smaller scale vegetation variables. Consequently, variables related to geological land structure, such as elevation, may appear to have a greater contribution during model computing processes than they actually do. Furthermore, we did not consider our results in opposition
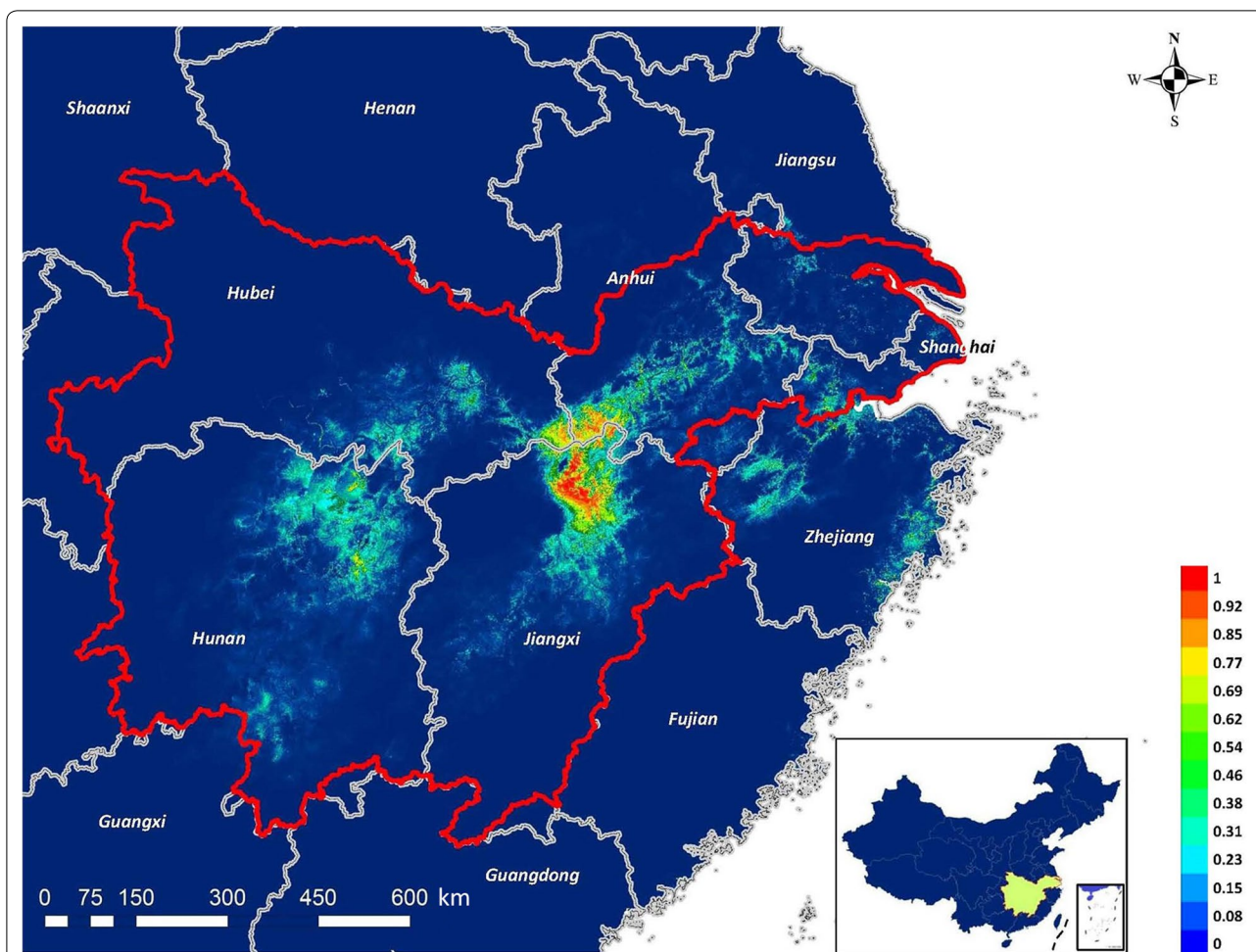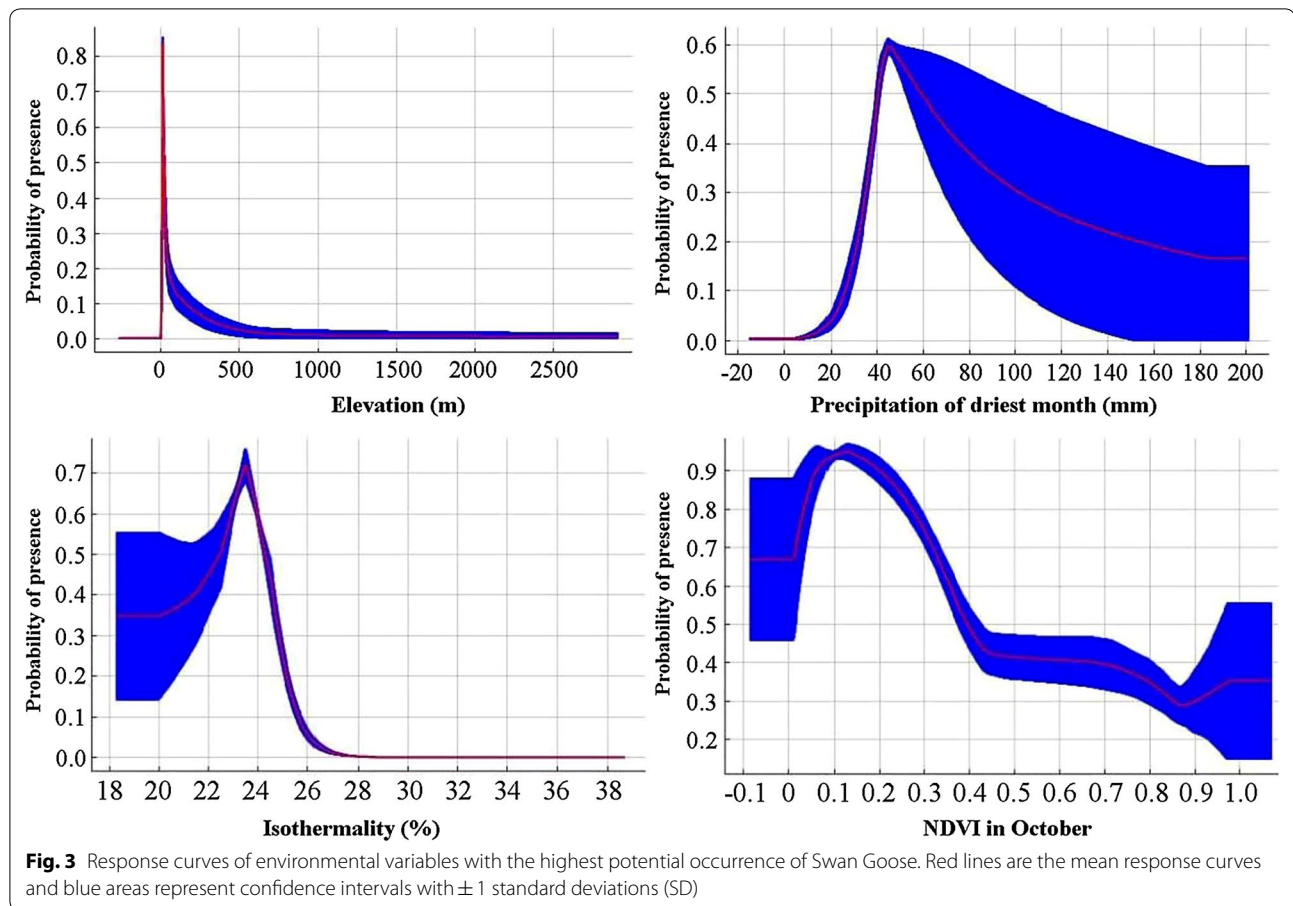
An *et al. Avian Res*   (2018) 9:43

Page 6 of 10

Fig. 2 The potential wintering distribution map of Swan Goose populations in China. Potential probability distribution is shown from high (red) to low (blue). The red line represents the boundary of the middle and lower Yangtze River floodplain

Table 3 Rank in importance of environmental variables (ranked from top to bottom)

Variables	Description	Contribution (%)
Elevation	Elevation from sea level (m)	30.9
Bio14	Precipitation of driest month (mm)	21.6
Bio3	Isothermality: (Mean diurnal range/ Temperature annual range) × 100	16.5
NDVI10	NDVI in October	11.9
Accessibility	Distance from the road network to the center point of each grid	3.9
Slope	Slope of geological formation (%)	3.8
NDVI02	NDVI in February	3.2
Bio15	Precipitation seasonality (coefficient of variation)	2.9
Bio6	Minimum temperature of coldest month (°C)	2.7
Bio4	Temperature seasonality	1.4
Bio2	Mean diurnal range: monthly mean (°C)	1.2

to those derived from traditional theories between waterfowl distribution and food resource abundance. This is because our results showed that wintering Swan Geese prefer lower wetlands, which are typically warmer and may subsequently provide a variety of food resources compared to higher land elevations. Additionally, following elevation, climate variables, such as precipitation of driest month (Bio14) and isothermality (Bio3), also had an important influence on the prediction of Swan Goose distribution. These two variables have been investigated in many studies, demonstrating that higher precipitation and temperature may lead to increasing water levels in wetlands, which would have a negative effect on Swan Goose density due to a decrease in submerged food accessibility (Nolet et al. 2006; Zhang et al. 2015a).

NDVI has been used as a useful indicator in the analysis of grazing bird density (Zhang et al. 2015a). According to prediction results, the contribution of NDVI in October placed the fourth in modeling results behind

Fig. 3 Response curves of environmental variables with the highest potential occurrence of Swan Goose. Red lines are the mean response curves and blue areas represent confidence intervals with ± 1 standard deviations (SD)

elevation, precipitation, and isothermality. Given that NDVI detection is based on near infrared imagery, it could represent aboveground vegetation richness (Wu et al. 2014). In our study, Swan Goose food sources were often submerged in lakes or mud. NDVI values only partially identify plant cover as animal shelter; thus, this likely represents anthropogenic disturbances more than it does food abundance. It is highly reasonable to presume the abundance of plant richness in national nature reserves where anthropogenic influence is limited (Zhao et al. 2015). This could also be the reason why the contribution of NDVI variables was even better compared to anthropogenic variables in terms of accessibility, which we selected for model prediction. The occurrence of anthropogenic disturbances is often difficult to ascertain, and its degree of influences is difficult to measure. The accessibility variable was calculated using road distance as per fishnet in GIS. Longer distances could signify difficulty in human accessibility from roads to fields. Contrary to our hypothesis, however, accessibility as an anthropogenic variable did not have a strong contribution in the model prediction of Swan Goose distribution. This could be due to many factors. For example, Swan

Goose flocks were always present in the middle of recession lakes, far away from areas that humans congregate. Correspondingly, roads were always far from occupied sites. In the future, direct anthropogenic influence such as the traditional autumn fishery harvest that takes place in these areas, could be integrated into the distribution model to obtain a more precise level of prediction. As for now, however, the geological database remains limited.

Swan Goose winters exclusively in China with the exception of a few vagrant individuals that winter in Japan and Korea (Kear 2005). According to several estimation studies, Poyang Lake (in Jiangxi Province) and Baidang Lake (in Anhui Province) are currently the two most important Swan Goose wintering habitat sites (Zhang et al. 2011; Jia et al. 2016; Wang et al. 2017). It is not surprising that the hotpots in our model prediction map matched survey results.

Our model fortunately found many potentially suitable Swan Goose wintering areas when environmental variables were comprehensively taken into account, such as areas of medium potential suitability in Hunan, Hubei, and Zhejiang provinces. However, actual ecosystem conditions have many uncertainties; thus, due to factors that

An *et al. Avian Res*   (2018) 9:43

Page 8 of 10

may not have been digitalized to variables using current technology, it is reasonable to assume that differences exist between mathematically-computed results and real world conditions. For instance, over the past several years, long-term waterbird fidelity to wintering sites could be a key factor that influences wintering site selection by geese (Hestbeck et al. 1991). Other factors that may affect wintering site selection include land structure changes and interspecific competition (Zhang et al. 2015b).

Furthermore, the Maxent model highly depends on occurrence data and variable inputs. Occurrence data are typically summarized from historical survey data, but it is important to point out that the reliability of historical records may be diminished by rapid urbanization in China. For instance, Shengjin Lake, Anhui Province, was once an important wintering habitat for large Swan Goose populations, but a dramatic decline in their number has been reported in recent studies (Jia et al. 2016). For the future development of the distribution map, new satellite tracking techniques could be incorporated when sufficient sample numbers are available, not only to increase the accuracy of the occurrence site information but also to provide more information on movement patterns. Together with an increase in interdisciplinary progress, more environmental variables may be implemented at finer scale to make the prediction model more dynamic.

One of the major functions of this prediction distribution map is to forecast where wintering Swan Goose populations will occur now and into the future while offering recommendations for conservation managers to formulate better conservation measures in the protection of this species. As an important wintering and stopover area along the East Asian-Australasian Flyway, it is urgent that we improve conservation effectiveness and formulate economical and optimal conservation policies for migratory species (de Boer et al. 2011). This study provides a visual map for conservation managers to use in designing a higher-level strategy by integrating urbanization demands and sustainable development as a whole. Besides establishing nature reserves in areas of hotpots, creating buffer zones and building up ecological migration corridors between urban areas and habitats designated as having a potentially medium level of suitability should also be considered. An increase in the investment of funding for suitable wintering sites is also important to achieve effective conservation measures. For example, some developed countries provide food sources for certain vulnerable migratory species in specific areas to help them survive difficult periods (Martin et al. 2007; Klaassen et al. 2008; Shimada 2009). To achieve an optimal level of conservation for migratory species, especially for the vulnerable Swan Goose, it is critically important to increase our knowledge of migratory connectivity as well as clarify conservation problems. For example, our potential distribution map would make it easier for policymakers to invest in particular areas at specific times to aid in the recovery of Swan Goose populations. Factors including the extent of available winter habitat for conservation, the cost of land acquisition, and the rate of degradation could also be incorporated into optimal conservation strategies to establish conservation zones from which to improve the survival rate of wintering Swan Goose populations.

Conclusions

Our prospective prediction distribution map shows that Jiangxi and Anhui provinces, and Poyang Lake in particular, are irreplaceable as well as being the most suitable areas for wintering Swan Goose populations. Also, areas including the middle and lower Yangtze River floodplain, such as Hunan and Hubei provinces and the coastal area of Zhejiang province, have a potential medium level of suitability as a wintering destination for this species. Results from our study provide fundamental information for the restoration and management of Swan Goose wintering habitat. Our "visualized" prospective prediction distribution map could help in establishing optimal conservation strategies, and could consequently help to increase the number of wintering Swan Geese in China, particularly in habitats with a medium level of suitability after successful restoration takes place. When the application of efficient measures is developed through the involvement of reliable technologies, our national strategy will possess an overall higher level of ecological protection.

Additional files

Additional file 1: Table S1. List of selected environmental variables.

Additional file 2: Table S2. Spearman's correlation matrix of spatial autocorrelation analysis.

Author details
[1] State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China. [2] University of Chinese Academy of Sciences, Beijing 100049, China. [3] Co-Innovation Center for Sustainable Forestry in Southern China, College of Biology and the Environment, Nanjing Forestry University, Nanjing 210037, China. [4] School of Life Sciences, University of Science and Technology of China, Hefei 230026, China.

An *et al. Avian Res* (2018) 9:43

Page 9 of 10

References
An S, Li H, Guan B, Zhou C, Wang Z, Deng Z, Zhi Y, Liu Y, Xu C, Fang S. China's natural wetlands: past problems, current status, and future challenges. Ambio. 2007;36:335–42.

Augustin NH, Mugglestone MA, Buckland ST. An autologistic model for the spatial distribution of wildlife. J Appl Ecol. 1996;33:339–47.

Barter M, Chen L, Cao L, Lei G. Waterbird survey of the middle and lower Yangtze River floodplain in late January and early February 2004. Beijing: China Forestry Publishing House; 2004.

Barter M, Chen L, Cao L, Lei G. Waterbird survey of the middle and lower Yangtze River floodplain (February 2005). Beijing: China Forestry Publishing House; 2006.

Cadahía L, Labra A, Knudsen E, Nilsson A, Lampe HM, Slagsvold T, Stenseth NC. Advancement of spring arrival in a long-term study of a passerine bird: sex, age and environmental effects. Oecologia. 2017;184:917–29.

Cao L, Barter M, Lei G. New Anatidae population estimates for eastern China: implications for current flyway estimates. Biol Conserv. 2008a;141:2301–9.

Cao L, Barter M, Lei G, Yang Q. Anatidae in the Yangtze floodplain in winter 2004 and 2005. Casarca. 2008b;11(2):146–60.

Cao L, Fox AD. Birds and people both depend on China's wetlands. Nature. 2009;460:173.

Clausen KK, Stjernholm M, Clausen P. Grazing management can counteract the impacts of climate change-induced sea level rise on salt marsh-dependent waterbirds. J Appl Ecol. 2013;50:528–37.

Cleasby IR, Bodey TW, Vigfusdottir F, McDonald JL, McElwaine G, Mackie K, Colhoun K, Bearhop S. Climatic conditions produce contrasting influences on demographic traits in a long-distance Arctic migrant. J Anim Ecol. 2017;86:285–95.

Corsi F, de Leeuw J, Skidmore A. Modeling species distribution with GIS. In: Boitani L, Fuller T, editors. Research techniques in animal ecology. New York: Columbia University Press; 2000. p. 389–434.

Cromsigt JPGM, Prins HHT, Olff H. Habitat heterogeneity as a driver of ungulate diversity and distribution patterns: interaction of body mass and digestive strategy. Divers Distrib. 2009;15:513–22.

Cyranoski D. Putting China's wetlands on the map. Nature. 2009;458:134.

de Boer WF, Cao L, Barter M, Wang X, Sun MM, van Oeveren H, de Leeuw J, Barzen J, Prins HHT. Comparing the community composition of European and Eastern Chinese waterbirds and the influence of human factors on the China waterbird community. Ambio. 2011;40:68–77.

Dormann CF, Elith J, Bacher S, Buchmann C, Carl G, Carré G, Marquéz JRG, Gruber B, Lafourcade B, Leitão PJ, Münkemüller T, McClean C, Osborne PE, Reineking B, Schröder B, Skidmore AK, Zurell D, Lautenbach S. Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. Ecography. 2013;36:27–46.

Elith J. Quantitative methods for modeling species habitat: comparative performance and an application to Australian plants. In: Ferson S, Burgman M, editors. Quantitative methods for conservation biology. New York: Springer; 2002. p. 39–58.

Elith J, Graham CH, Anderson RP, Dudik M, Ferrier S, Guisan A, Hijmans RJ, Huettmann F, Leathwick JR, Lehmann A, Li J, Lohmann LG, Loiselle BA, Manion G, Moritz C, Nakamura M, Nakazawa Y, Overton JM, Peterson AT, Philips SJ, Richardson K, Scachetti-Pereira R, Schapire RE, Soberon J, Williams S, Wisz MS, Zimmermann NE. Novel methods improve prediction of species' distributions from occurrence data. Ecography. 2006;29:129–51.

Fielding AH, Bell JF. A review of methods for the assessment of prediction errors in conservation presence/absence models. Environ Conserv. 1997;24:38–49.

Fox AD, Hearn R, Cao L, Cong PH, Wang X, Zhang Y, Dou ST, Shao XF, Barter M, Rees EC. Preliminary observations of diurnal feeding patterns of Swan Geese Anser cygnoides using two different habitats at Shengjin Lake, Anhui Province, China. Wildfowl. 2008;58:20–30.

Franklin J, Miller JA. Mapping species distributions: spatial inference and prediction. Cambridge: Cambridge University Press; 2010.

Guisan A, Thuiller W. Predicting species distribution: offering more than simple habitat models. Ecol Lett. 2005;8:993–1009.

Guisan A, Zimmerman NE. Predictive habitat distribution models in ecology. Ecol Model. 2000;135:147–86.

Gong P, Niu ZG, Cheng XA, Zhao KY, Zhou DM, Guo JH, Liang L, Wang XF, Li DD, Huang HB, Wang Y, Wang K, Li WN, Wang XW, Ying Q, Yang ZZ, Ye YF, Li Z, Zhuang DF, Chi YB, Zhou HZ, Yan J. China's wetland change (1999–2000) determined by remote sensing. Sci China Earth Sci. 2010;53:1036–42.

Hernandez PA, Graham CH, Master LL, Albert DL. The effect of sample size and species characteristics on performance of different species distribution modeling methods. Ecography. 2006;29:773–85.

Hestbeck JB, Nichols JD, Malecki RA. Estimates of movement and site fidelity using mark resight data of wintering Canada Geese. Ecology. 1991;72:523–33.

Heuermann N, van Langevelde F, van Wieren SE, Prins HHT. Increased searching and handling effort in tall swards lead to a type IV functional response in small grazing herbivores. Oecologia. 2011;166:659–69.

Jia Q, Kazuo K, Chang-Yong C, Hwa-Jung K, Cao L, Gao D, Liu G, Fox AD. Population estimates and geographical distributions of swans and geese in East Asia based on counts during the non-breeding season. Bird Conserv Int. 2016;26:397–417.

Kear J. Bird families of the world: ducks, geese and swans. Oxford: Oxford University Press; 2005.

Klaassen M, Bauer S, Madsen J, Possingham H. Optimal management of a goose flyway: migrant management at minimum cost. J Appl Ecol. 2008;45:1446–52.

Liao B, Liu G, Jin J, Liu F. Number and distribution of large waterbirds in winter of 2013–2014 at Poyang Lake. 2013–2014 Reports of Wetland Research and Monitoring at Poyang Lake. 2014. p. 27–41 **(in Chinese)**.

Lu JJ. The status and conservation needs of Anatidae and their habitat in China. China Ornithological Research. Beijing: China Forestry Publishing House; 1996a. p. 129–42.

Lu J. Distribution and bioenergetics of wintering swan geese (*Anser cygnoides*) in the Yangtze River valley, China. Gibier Faune Sauvage. 1996;13:327–35.

Martin TG, Chadès I, Arcese P, Marra PP, Possingham HP, Norris DR. Optimal conservation of migratory species. PLoS ONE. 2007;2:e571.

Moriguchi S, Amano T, Ushiyama K. Creating a potential distribution map for Greater White-fronted Geese wintering in Japan. Ornithol Sci. 2013;12:117–25.

Nolet BA, Fuld VN, van Rijswijk MEC. Foraging costs and accessibility as determinants of giving-up densities in a swan-pondweed system. Oikos. 2006;112:353–62.

Pearce J, Ferrier S. An evaluation of alternative algorithms for fitting species distribution models using logistic regression. Ecol Model. 2000;128:127–47.

Phillips SJ, Dudik M. Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. Ecography. 2008;31:161–75.

An *et al. Avian Res* (2018) 9:43

Page 10 of 10

Phillips SJ, Anderson RP, Schapire RE. Maximum entropy modeling of species geographic distributions. Ecol Model. 2006;190:231–59.

R Development Core Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna; 2011. http://www.r-project.org.

Scott DA. A directory of Asian Wetlands, IUCN, Gland, Switzerland and Cambridge, UK. 1989;1–14:1–1181.

Scott JM, Heglund PJ, Morrison ML, Haufler JB, Raphael MG, Wall WA, Samson FB. Predicting species occurences: Issues of accuracy and scale. Washington, DC: Island Press; 2002.

Shimada T. Current status and distribution of Greater White-fronted Geese in Japan. Ornithol Sci. 2009;8:163–7.

Sutherland WJ, Allport GA. A spatial depletion model of the interaction between Bean Geese and Wigeon with the consequences for habitat management. J Anim Ecol. 1994;63:51–9.

Suárez-Seoane S, Álvarez-Martínez JM, Wintle BA, Palacín C, Alonso JC. Modelling the spatial variation of vital rates: an evaluation of the strengths and weaknesses of correlative species distribution models. Divers Distrib. 2017;23:841–53.

Tavares DC, Guadagnin JF, de Moura S, Siciliano DL, Merico A. Environmental and anthropogenic factors structuring waterbird habitats of tropical coastal lagoons: implications for management. Biol Conserv. 2015;186:12–21.

The State Forestry Administration. China wetlands resource master volume. Beijing: China Forestry Publishing House; 2015 **(In Chinese)**.

Tu Y, Yu C, Huang X, Shan J, Sun Z, Wang Z. Distribution and population of the over wintering Anatidae waterfowl in the Poyang Lake. Acta Agric Univ Jiangxi. 2009;4:760–71 **(In Chinese)**.

Wang WJ, Fraser JD, Chen JK. Wintering waterbirds in the middle and lower Yangtze River floodplain: changes in abundance and distribution. Bird Conserv Int. 2017;27:167–86.

Wang X, Fox AD, Cong PH, Barter M, Cao L. Changes in the distribution and abundance of wintering Lesser White-fronted Geese Anser erythropus in eastern China. Bird Conserv Int. 2012;22:128–34.

Wang X, Kuang F, Tan K, Ma Z. Population trends, threats, and conservation recommendations for waterbirds in China. Avian Res. 2018;9:14.

Wetlands International. Waterbird population estimates. 5th ed. UK: Wetlands International Press; 2012.

Wisz M, Dendoncker N, Madsen J, Rounsevell M, Jespersen M, Kuijken E, Courtens W, Verscheure C, Cottaar F. Modelling pink-footed goose (*Anser brachyrhynchus*) wintering distributions for the year 2050: potential effects of land-use change in Europe. Divers Distrib. 2008;14:721–31.

Wu X, Lv M, Jin Z, Michishita R, Chen J, Tian H, Tu X, Zhao H, Niu Z, Chen X, Yue T, Xu B. Normalized difference vegetation index dynamic and spatiotemporal distribution of migratory birds in the Poyang Lake wetland. China. Ecol Indic. 2014;47:219–30.

Xu QJ, Jin XC, Yan CZ. Macrophyte degradation status and countermeasures in China. Ecol Environ. 2006;15:1126–30 **(In Chinese)**.

Yang HY, Chen B, Barter M, Piersma T, Zhou CF, Li FS, Zhang ZW. Impacts of tidal land reclamation in Bohai Bay, China: ongoing losses of critical Yellow Sea waterbird staging and wintering sites. Bird Conserv Int. 2011;21:41–59.

Ydenberg RC, Prins HHT. Spring grazing and the manipulation of food quality by Barnacle Geese. J Appl Ecol. 1981;18:443–53.

Zeng Q, Wei Q, Lei G. Contribution of citizen science towards cryptic specie census: "many eyes" define wintering range of the Scaly-sided Merganser in mainland China. Avian Res. 2018;9:6.

Zhang J, Kissling WD, He F. Local forest structure, climate and human disturbance determine regional distribution of boreal bird species richness in Alberta, Canada. J Biogeogr. 2012;40:1131–42.

Zhang Y, Cao L, Barter M, Fox AD, Zhao MJ, Meng FJ, Shi HQ, Jiang Y, Zhu WZ. Changing distribution and abundance of Swan Goose *Anser cygnoides* in the Yangtze River floodplain: the likely loss of a very important wintering site. Bird Conserv Int. 2011;21:36–48.

Zhang Y, Jia Q, Prins HHT, Cao L, de Boer WF. Effect of conservation efforts and ecological variables on waterbird population sizes in wetlands of the Yangtze River. Sci Rep. 2015a;5:17136.

Zhang Y, Jia Q, Prins HHT, Cao L, de Boer WF. Individual-area relationship best explains goose species density in wetlands. PLoS ONE. 2015b;10:e0124972.

Zhang Y, Prins HHT, Cao L, Zhao MJ, de Boer WF. Variation in elevation and sward height facilitate coexistence of goose species through allometric responses in wetlands. Waterbirds. 2016;39:34–44.

Zhao H, Liu S, Dong S, Su X, Wang X, Wu X, Wu L, Zhang X. Analysis of vegetation change associated with human disturbance using MODIS data on the rangelands of the Qinghai-Tibet Plateau. Rangeland J. 2015;37:77.

Zhao MJ, Cong PH, Barter M, Fox AD, Cao L. The changing abundance and distribution of Greater White-fronted Geese *Anser albifrons* in the Yangtze River floodplain: impacts of recent hydrological changes. Bird Conserv Int. 2012;22:135–43.

Zhu Q, Zhan Y, Liu G, Wu J, Zhan H, Huang Y, Huang J, Zhang B, Hu B, Li Y. Investigation of number and distribution of the waterfowl of Poyang Lake in the winter of 2011. 2012-2012 Report of Wetland Research and Monitoring at Poyang Lake; 2012. p. 57–73 **(**In Chinese**)**.

Zöckler C, Miles L, Fish L, Wolf A, Rees G, Danks F. Potential impact of climate change and reindeer density on tundra indicator species in the Barents Sea region. Clim Change. 2008;87:119–30.