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Coupling the Occurrence of Correlative Plant Species to Predict the Habitat Suitability for Lesser White-fronted Goose (*Anser erythropus*) under Climate Change: A Case Study in the Middle and Lower Reaches of the Yangtze River

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Abstract: Climate change and human activities influence species biodiversity by altering their habitats. This paper quantitatively analyzed the effects of climate change on a migratory bird. The Lesser White-fronted Goose (LWfG), a species which migrates via the middle and lower reaches of the Yangtze River region, is an herbivorous species of high ecological value. It is an endangered species threatened by climate change and human activities, so comprehensive information about its distribution is required. To assess the effectiveness of conservation of the LWfG under climate change, both climate variables and human activities are often used to predict the potential changes in the distribution and habitat suitability for LWfG. In this work, the current scenario and the Global Circulation Models (GCMs) climate scenarios were used to simulate the future distribution of the species. However, besides climate change and human activities, the spatial pattern of plants surrounding the wetland is also known to be closely related to the distribution of LWfG. Therefore, the distribution model results of six plant species related to LWfG's diet selection were used as environment variables to reflect the changes of suitable LWfG habitat. These environmental variables significantly improved the model's performance for LWfG, since the birds were clearly influenced by the plant distribution factors. Meanwhile, the suitable habitat area decreases by 2070 in GCM models under two representative concentration pathways scenarios (RCP2.6 and RCP8.5). More appropriate management and conservation policies should be taken to adapt to future climate change. These adjustments include modifications of the size, shape and use of the conservation area for this species.

Key words: habitat suitability modeling; climate change; Maxent; Lesser White-fronted Goose; MODIS; the Yangtze River

1 Introduction

Over the past several decades, climate change and habitat loss have been the most dramatic alterations affecting biodiversity by leading to reduced areas of suitable habitats (Butchart et al., 2010; Ren et al., 2016). Environmental pollution has been a problem which also influences the protection of biodiversity. Biodiversity loss has been increasing since the second half of the 20th century, and is likely to continue in the future (Seddon et al., 2014). Rapid climate change is widely recognized as a great threat to biodiversity

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and it interacts with other environmental factors (Ramirez-Villegas et al., 2014). Numerous lines of evidence show that biodiversity changes may increase the extinction risk of already endangered species (Moritz et al., 2008; Seddon et al., 2014). Many endangered species are confined to habitats which are decreasing, less physiologically tolerant to environmental changes and less able to migrate/disperse to track climate change (Strange et al., 2011; Araujo et al., 2012). Therefore, the relationships between climate change, human influences and the ecosystem should be scientifically understood before formulating and implementing strategies for conserving biodiversity (Díaz et al., 2006; Remme et al., 2016).

The Lesser White-fronted Goose (LWfG) breeds in the Arctic tundra of the Palearctic from northern Scandinavia to the Chukotka Mountains in East Siberia (Rokas et al., 2003; Nijman et al., 2010). It has seen drastic population declines throughout most of its range during the 20th century, and the species is now classified as Vulnerable in the IUCN Red List (Baillie et al., 2004). The Eastern main subpopulation of LWfG (nesting from the Taimyr Peninsula eastward and wintering in China) is the largest and most threatened subpopulation, but it has experienced a decline from more than 20000 individuals at the beginning of the last century to 14000 breeding pairs in 2004 (Nisbet, 2008). Most of them are distributed in the Middle and Lower Reaches of the Yangtze River, which is an important international wintering habitat for many East Asian migratory birds (Liu et al., 2015; Yuan et al., 2015). Previous studies have documented serious threats to the population of water birds in these areas, especially in Dongting Lake Wetland (Yuan et al., 2014). For this reason, the region is considered to be a key priority for biodiversity conservation.

Habitat suitability models (HSM or species distribution models) are useful tools for predicting the suitability of a location for a given species or group of species based on observed affinities with environmental conditions (Vierod et al., 2014; Anderson et al., 2016). Several studies have reviewed the reliability of HSMs and found that they have been applied to a variety of scientific and applied issues (Magurran, 2007; Culmsee et al., 2014; Sánchez-carnero et al., 2016). To be valid, an HSM must be robust (Elith et al., 2006; Marmion et al., 2009). By providing realistic estimates of the impacts of climate change and human influences, some species found in unsuitable habitats or those not observed in suitable habitats may be explored (Magurran, 2007). For some migratory birds, building the models based on the variables that are unrelated to habitat change is often difficult. A good comprehension of the modeling techniques requires careful choice of the convictive variables and appropriate model building. Some approaches to HSM are limited by the environmental variable data that are available. The most widely used data in the historical literature are the WorldClim-Global Climate Data. We agree that these data show an excellent performance in plants HSM, since most plant species are influenced by climate change directly. However, such climate data cannot provide the full information about migratory birds, such as LWfG, and the effect of true habitat changes and proper conservation plans should be also offered (Moreno et al., 2011; Maleki et al., 2016). The occurrence and distribution patterns of LWfG are related not only to climatic and topographic variables but also to the characteristics of the habitats where the birds live. Among the factors which influence distribution, food is most likely to determine the distribution of LWfG. Therefore, food plant distribution modeling results could be used in LWfG HSM to assess the habitat suitability of their living areas.

The aims of this study were to explore the importance of plant variables and predict the future spatial pattern of LWfG under climate change in the Middle and Lower Reaches of the Yangtze River. The aims of this paper are: 1) to model the LWfG HSM, map the habitat suitability in the current scenario and predict the potential distribution of LWfG under two Global Circulation Models (GCMs) scenarios, and 2) to examine whether plant distribution improves the predictive performance of the LWfG models.

2 Materials and methods

2.1 Study area

The Yangtze River is the third longest river in the world and the longest river in China (Fig. 1). The Yangtze River is divided into an upper section (from Yibin, Sichuan Province to Yichang, Hubei Province, with a length of 1040 km), a middle section (from Yichang to Hukou, Jiangxi Province, with a length of 955 km) and a lower section (from Hukou to Shanghai, with a length of 938 km). This study was conducted in the middle and lower reaches of the Yangtze River region (approximately 28°30′N–30°20′N, 111°40′E–113°10′E) (Ding et al., 2011; Li et al., 2013). The special geographical location and complex natural environment in these areas lead to an abundance of bird species and ecosystem types. In this area, there are many rare and endangered species (Zhang et al., 2004). Many lakes are connected to the Yangtze River and constitute the wetland ecosystem, including Poyang Lake, Dongting Lake and Tai Lake. During the winter dry season, the water level rapidly decreases and plants growing in the mudflat can provide energy to LWfG (Zhu et al., 2014; Liang et al., 2015a; Liang et al., 2015c; Liang et al., 2015d). Thus, seasonal and regional distributions of the climate can determine the growth of plants and whether the migratory birds can survive in the wintering area.

2.2 Habitat suitability model building

The maximum entropy approach (Maxent) was employed to predict habitat suitability for both LWfG and the key plants (Phillips et al., 2006). This approach is considered to be one of the best performing models for predicting species

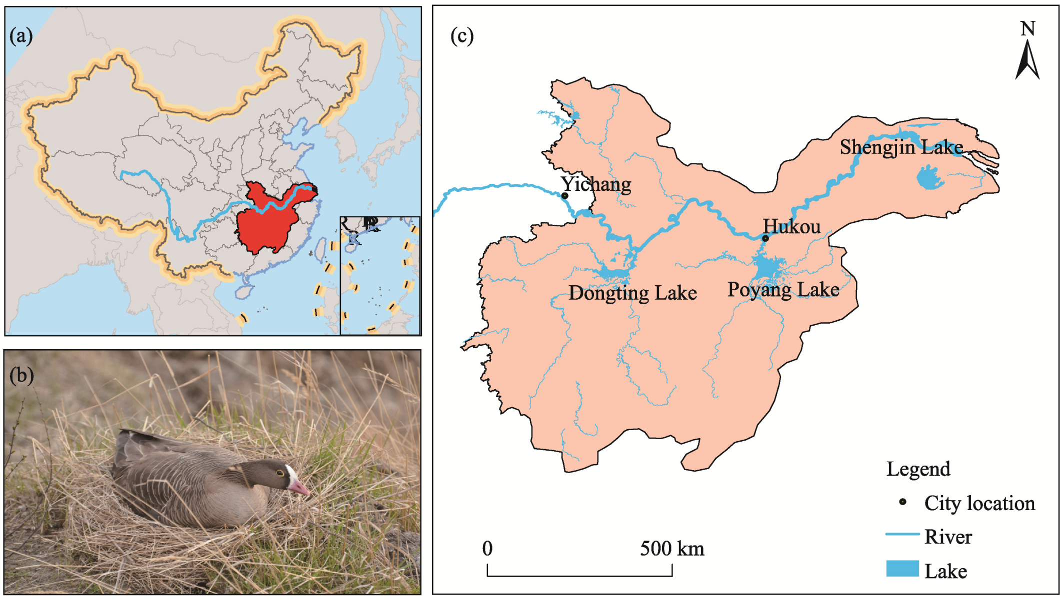

Fig. 1 (a) Map of China and the location of the Middle and Lower Reaches of the Yangtze River; (b) LWfG; (c) Distribution of the main lakes and rivers in the Middle and Lower Reaches of the Yangtze River

Note: Fig. 1. (a) is based on the standard map GS(2019)1654 downloaded from the Standard Mapping Service website of the Ministry of Natural Resources of the People's Republic of China (http://bzdt.ch.mnr.gov.cn/). The base map has no modifications.

distributions with presence-only data, and it has been extensively applied for projecting species ranges and vegetation shifts under current and future scenarios (Elith et al., 2006; Li et al., 2015). Maxent has been tested extensively and found to perform well as a state-of-the-art modeling technique under both current and future conditions (Phillips, 2008; Costa et al., 2010).

We divided the LWfG occurrence dataset into two classes, using 75% of the data for model calibration and 25% of the data for evaluation. According to previous studies on LWfG's diet, food resource availability was the primary factor influencing LWfG distribution (Markkola et al., 2003). Plant distribution and human activities affect the potential distribution of LWfG, while the climate affects the plants that the birds feed on. Therefore, we chose six plant species that are foraged by LWfG (Feng et al., 2014) (Fig. 2). Subsequently, 19 bioclimatic variables and five human influence variables (human density, patch density, distance to residents, distance to road, and land use) were used to project the current and future plant species distribution models. These five human influence variables were proven to be highly related to LWfG distribution (Liang et al., 2015c). To accurately predict the LWfG habitat suitability, we used the results of the six plant species distribution models and five human influence variables to predict the habitat suitability for LWfG. Two GCMs were used to generate probability outputs for each future scenario (Liang et al., 2017). Representative Concentration Pathways (RCPs) are the new standard for modeling emission uncertainty. They represent different concentrations of greenhouse gases (GHGs), or different possible futures based on how much GHGs human industry might emit. Here, RCPs with higher numbers represent a greater degree of radiative forcing (in terms of W m^{-2} over preindustrial levels) that the scenarios are expected to produce by 2070 (i.e., the radiative forcing of RCP8.5 is greater than that of RCP2.6) and, hence, they represent a future scenario with more emissions. Finally, expert opinion and historical data were applied as the threshold to define the presence-absence distribution of LWfG habitats, and we reclassified LWfG habitats into five classes (marginally, lower, moderately and highly suitable habitats and other areas) using "Natural Breaks" (Jenks) tool, and "Natural Breaks" finds the "best" way to split up the ranges based on the characteristics of the distribution. Units with similar values would have the same class (Liu and Li, 2008).

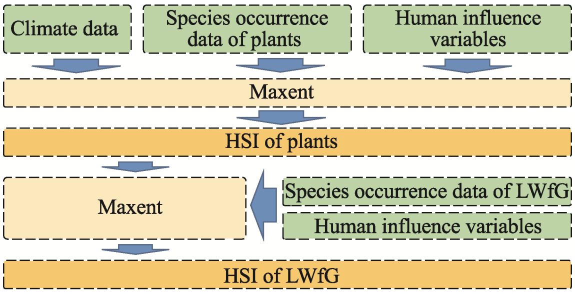

Fig. 2 Flow chart of LWfG habitat suitability modeling

Several indexes frequently used for the evaluation of HSM performance were calculated based on true positive, false positive, true negative and false negative rates, including Cohen's κ (Cohen, 1960), TSS (true skill statistic) (Allouche et al., 2006), area under receiver operating characteristic curve (AUC) (Hanley et al., 1982) and others. In this study, AUC was employed to evaluate the model performance. To validate the model performance, we developed HSM for LWfG in the current scenario with 19 bioclimatic variables and five environmental variables, and compared the AUC values.

2.3 Data sources and variables selection

As a key factor influencing the results, species occurrence data play an important role in HSM. To ensure that LWfG actually existed in the area defined by the data, bird and field surveys were conducted. Seventy-two occurrence records of LWfG in the middle and lower sections of the Yangtze River were collected from various data sources, including newspaper and government websites, published articles and reports from relevant organizations. In the winters of 2005–2013 (December to February of the following year), field surveys were carried out in Dongting Lake, Poyang Lake, and Shengjin Lake to determine the locations of LWfG occurrence, and a total of 9 surveys were conducted. The plant occurrence records came from the National Specimen Information Infrastructure (http://www.nsii.org.cn/), the Chinese Virtual Herbarium (http://www.cvh.org.cn/), the Global Biodiversity Information Facility (http://www.gbif.org) and the literature. The six plants chosen because they can be important to LWfG's diet were *Carex heterolepis*, *Heleocharis migoana*, *Alopecurus aequalis*, *Cynodon dactylon*, *Polygonum criopolilanum*, and *Eleocharis valleculosa* (Table 1) (Cohen, 1960; Markkola et al., 2003).

Bioclimatic variables are very biologically meaningful for defining the environmental niche of a species (Yi et al., 2016). Data for nineteen bioclimatic variables in the current and GCM models (RCP2.6 and RCP8.5) under two representative concentration pathways scenarios for 2070 were downloaded from the website of http://www.worldclim.org. A geographical base map of the middle and lower reaches of the Yangtze River region was obtained from National Fundamental Geographic Information System (http://nfgis.nsdi.gov.cn). Land use information for 2000 and 2010 was extracted from the Moderate-resolution Imaging Spectroradiometer (MODIS) annual land use cover product (MOD12Q1). MOD12Q1 was based on the International Geosphere-Biosphere Program (IGBP) classification system that uses a classification algorithm based on decision trees and artificial neural networks. This important data source has been extensively applied to monitoring Land-Use and Land-Cover Change (LUCC) dynamics. The data were divided into 16 classes based on land use. To evaluate the results of land use cover in the future scenario, a cellular automata-Markov chain (CA-MARKOV) model in IDRISI, Andes, v15.0 was used for simulating the land use cover in this study area in 2070, and this approach has been widely used in the field of land use change and urban development simulation (Yuan et al., 2014). FRAGSTATS (version 4.2) was used to calculate the patch area, and the resulting data can be exported to ArcGIS 10.2 to calculate the patch density through the "zonal statistics" tool. Human population density for 2010 was downloaded from the Center for International Earth Science Information Network (Parris, 1995). Because there is much uncertainty in the process of forecasting future human population density, predicting the human population density in 2070 might be difficult. Therefore, we used the data for 2010 in all of the models. Distance to residents and distance to road were calculated by Inverse Distance Weighted (IDW) interpolation. All of these variables were transformed into "asc" format (and resolution transformed to 30 seconds) by ArcGIS 10.2 and imported to the Maxent model software.

Table 1 List of plant species examined and their numbers of occurrences

Plant species	Frequency of occurrences
Carex heterolepis	124
Heleocharis migoana	73
Alopecurus aequalis	375
Cynodon dactylon	161
Polygonum criopolilanum	74
Eleocharis valleculosa	83

3 Results

3.1 Model performance and validation

The AUC values showed that our models could reasonably describe the relationship between the plants and water birds. Each plant distribution model had a high average AUC value (>0.83) for the six plants species (Table 2), and could be used to model the current situation HSM of LWfG (AUC=0.981) (Fig. 3). The validation model's AUC result is also presented in Table 2 in both the current and future scenarios. Overall, the AUC values of models with plant distribution variables were significantly higher than those of the models with the common variables. In LWfG HSM, land-use and patch density contributed more to high suitability areas, and the results showed that five plant species had high contributions to the model distribution results: *Carex heterolepis*, *Cynodon dactylon*, *Heleochairs migoana*, *Alopecurus aequalis*, and *Polygonum criopolilanum* (Fig. 4). This was expected since these plants were selected based on their relevance to the LWfG diet.

3.2 Variable contributions

Response curves, which show the quantitative relationships between environmental variables and the logistic probability of presence (also known as habitat suitability) can contribute to the understanding of the ecological niche of the species (Yi et al., 2016). The responses of 11 variables to LWfG suitability are shown in Fig. 5. On the basis of the response curves, the suitable land use range included water body,

Table 2 AUC values of plant HSM and LWfG HSM

Species	AUC value
Carex heterolepis	0.911
Heleocharis migoana	0.901
Alopecurus aequalis	0.900
Cynodon dactylon	0.872
Polygonum criopolilanum	0.867
Eleocharis valleculosa	0.880
LWfG[a]	0.887
LWfG[b]	0.891
LWfG[c]	0.806
LWfG[d]	0.981
LWfG[e]	0.976
LWfG[f]	0.988

Note: [a] Habitat suitability model in the current situation with bioclimatic variables; [b] Habitat suitability model in the RCP2.6 situation with bioclimatic variables; [c] Habitat suitability model in the RCP8.5 situation with bioclimatic variables; [d] Habitat suitability model in the current situation with plant distribution variables; [e] Habitat suitability model in the RCP2.6 situation with plant distribution variables; [f] Habitat suitability model in the RCP8.5 situation with plant distribution variables.

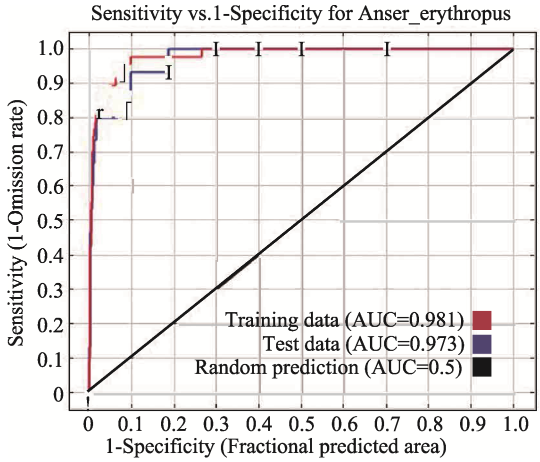

Fig. 3 Profiles of the AUC curves in LWfG habitat suitability model (The red (training) line shows the “fit” of the model to the training data. The blue (testing) line indicates the fit of the model to the testing data, and is the real test of the model’s predictive power)

evergreen coniferous forest, deciduous coniferous forest, wetland and farm land. The suitable human density value ranged from 0 to 0.2, with best score performance at 0.15 in our study, indicating that LWfG preferred sites with lower

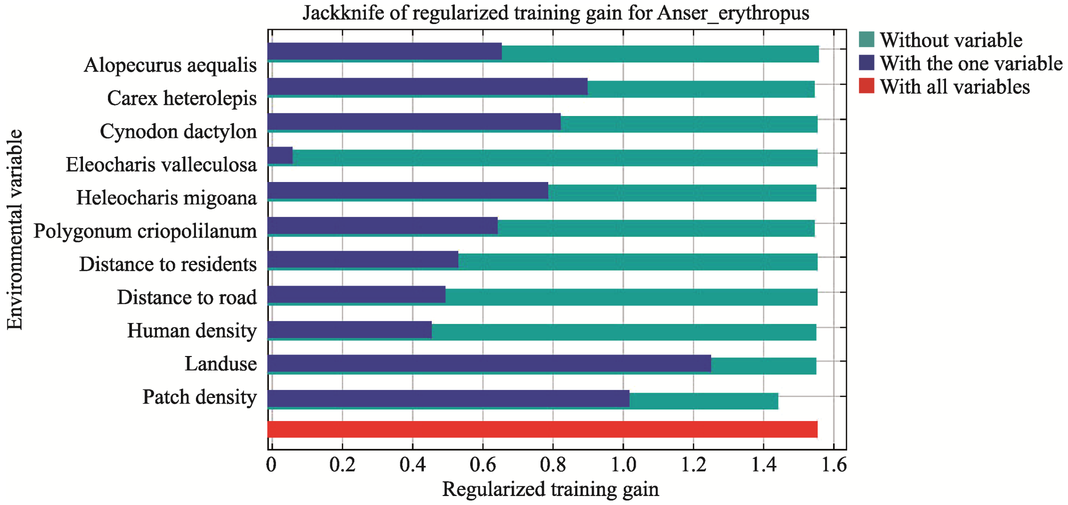

Fig. 4 Jackknife test of variable contribution results for modeling LWfG’s HSM in the current situation

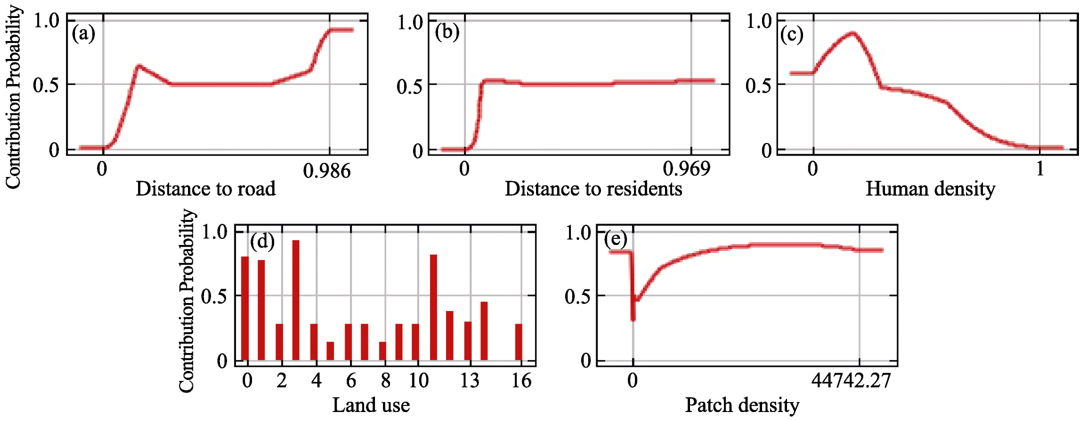

Fig. 5 Response curves of environmental variables in LWfG HSM (the plots’ x axis describes the environmental variables, the plots’ y axis describes the habitat suitability index). (a) Distance to road (b) Distance to residents (c) Human density (d) Land use (e) Patch density

human density, such as lakes and wetlands. For the response curves of distance to road and distance to residents, distances over 300 m seemed to be a better choice for LWfG. More foraged plant distribution and close proximity to wetland are favorable to the presence of LWfG (see Supporting Information).

3.3 LWfG HSM under current circumstances

The suitable habitat area of LWfG in the middle and lower reaches of the Yangtze River in the current situation is shown in Fig. 6a. For 10.2% of the region, habitat suitability values were higher than 0.6. Based on our field investigation experience, this area was suitable for the survival of LWfG. Most of these areas were distributed around the Yangtze River basin lake groups. In Dongting lake and Shengjin lake, the main wintering ground for the LWfG, the average habitat suitability was higher than 0.8, and 94.6% of the area of these two lakes belong to the high habitat suitability area. Contrary to other studies, our study area belongs to the plains and the difference between the highest and lowest elevation is insignificant, therefore the habitat suitability area is not related to altitude. Meanwhile, some eastern areas show limited occurrence points, but the results still show high suitability in this area, which indicates that these habitats might be suitable for LWfG.

3.4 LWfG HSM in global warming scenarios

The results of habitat suitability simulation for the two GCMs scenarios are illustrated in Fig. 6b and Fig. 6c. The fifth Intergovernmental Panel on Climate Change report (IPCC-5) described four future climate-warming scenarios on the basis of various estimates of total Radiative Forcing (RF) in 2100. RCP 2.6 and RCP 8.5 are two representative scenarios (Padonou et al., 2015). The simulated results of LWfG's habitat suitability in either RCP 2.6 and RCP 8.5 showed that it decreased with climate warming based on the plant variables. Consequently, in addition to a decrease in the habitat quality, climate change would also reduce the area of suitable habitat. Compared with the current situation, the habitat area will become more isolated and the gaps between patches will become greater. In RCP 8.5, the area with habitat suitability greater than 0.30 (we choose these areas as suitable habitat for LWfG (Liu et al., 2013) was reduced by about 33.4% compared to the current situation, and the trend of simulation in RCP 2.6 was the same (Fig. 7). The total habitat area for LWfG would decrease from the current 3.64 million hectares to 2.39 million hectares under the RCP 8.5 climate scenario, a reduction of 34.4%. Under RCP 2.6, the lowest radiative forcing, the habitat area would decrease by 41.5% during the same period.

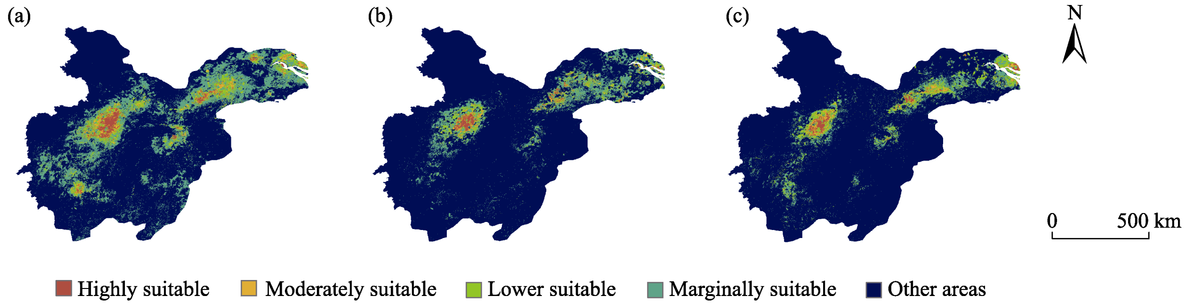

Fig. 6 Suitable habitat distribution for LWfG in the current and future scenarios. (a) Current situation; (b) RCP2.6; (c) RCP8.5.

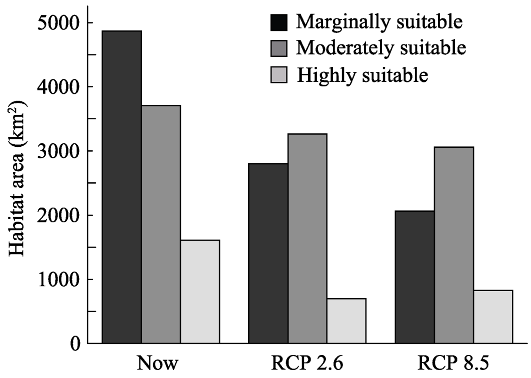

Fig. 7 Habitat area of LWfG in different suitability classes (lower, moderately and highly suitable) based on the consensus forecast from 2 GCMs for the current and two RCPs by 2070

4 Discussion

4.1 Environmental variables

Maxent modeling has been recognized as a useful tool for successful and robust prediction of the richness of the LWfG species and the spatial distribution patterns of individual LWfG (Waser et al., 2007; Camathias et al., 2013). Both the plant and LWfG HSMs accurately predicted the potential spatial distributions of these species (mean AUC>0.8). However, compared with models using only climate variables, the models which also included plant distribution variables performed better. This improvement confirms that, similar to plants (Zimmermann et al., 2007; Wohlgemuth et al., 2008), human influenced climate change and plant distribution are important environmental predictors for the

HSM. Some studies have pointed out that groundwater is one factor influencing the plants, but the predictability of the groundwater is uncertain. Some studies also indicated that thick reeds are unfavorable to LWfG's foraging by inhibiting the growth of plants which are foraged by LWfG (Durant et al., 2004; Zhao et al., 2010). Our results show that in the future scenarios, most of the climate and bioclimatic variables would increase (under global warming), leading to the increase in plant distribution in the area, when environmental variables were incorporated into the LWfG HSM, and changes in the plant-related variables will lead to the decrease in habitat areas (Zhang et al., 2016a). The relationships between these species should be studied further. One possible reason for this is that these environmental variables are closely related to LWfG HSM and it has taken a long time for this system to reach equilibrium. In the future, once the balance is quickly broken, the population of LWfG will decrease sharply (Hua et al., 2015; Liang et al., 2015b; Liu et al., 2015). In the meantime, land cover and human influences had general contributions to the results of HSM, but they are also thought to be among the important variables that influence LWfG, especially after the activation of the Three Gorges Dam (Wu et al., 2013), which led to dramatic changes in land use and ecosystems, and thus changes in the habitat environment of LWfG.

4.2 Potential habitat

Since biologist are more likely to investigate areas where species are abundant, sample collection based on the field surveys are necessary, particularly for birds like LWfG, with a small size and population which decreased rapidly leading to a low chance of finding them (Liang et al., 2015a). Their habitats in China are highly fragmented and scattered, which we know from small nature reserves. The species richness faces a large decrease (especially in the northern Guizhou province, the Dongting Lake and the Poyang Lake) by the 2070s. The prediction of LWfG habitats shows a good accordance with the historical data of occurrences in Dongting lake wetlands, Poyang lake wetlands, Jianghan lake wetlands, middle Yangtze main river wetlands and Anhui lake group wetlands. Our model suggests that some regions in Jiangsu and Shanghai also have high habitat suitability values for LWfG, particularly those wetlands around lakes and rivers including Jiangsu group lakes wetlands, Chongming island wetlands and lower Yangtze main river wetlands. More wetlands should be comprehensively investigated in the future.

4.3 Conservation implications and management

Our results have strong implications for increasing our knowledge about the distribution of LWfG and for its conservation. Conservation planning was established on the basis of specific ecological information, and not on other taxonomic groups taken as a proxy (Ellis, 2012). We showed that variables related to key plant species considerably improved the predictions of the distribution patterns of threatened LWfG. It is a remarkable fact that under the warming climate and continuous human activities, the risks of degradation and reduction of habitat might increase. For example, the greenhouse effect will interfere with rainfall patterns and lead to unusual tidal conditions. Consequently, some plants will grow better, but LWfG prefers to forage on low-growing vegetation, and sometimes the unusual tidal conditions can change the growth cycle of plants, finally resulting in a decrease in the area of suitable habitat for LWfG. There is strong evidence that the irregular fluctuation of the river poses an additional threat to the survival of the LWfG indirectly through wetland plants. East Dongting Lake suffered from drought for a long time in the winter of 2010, causing a decrease in the area of many plants. Furthermore, the number of LWfG in this area in our records was smaller than in other years. A warmer and chaotic climate is likely to occur frequently in the future (Yi et al., 2016). Based on these analyses, making a plant conservation plan may be an effective way to reduce the risk of the LWfG population decrease and to ensure the long-term stability of the LWfG in the changing climate.

Compared with other water birds, the LWfG prefers natural habitats to agricultural land. Hence, the number of LWfG is related to land use and distances to residents and roads. According to the research in East Dongting Lake (Yuan et al., 2015; Zhang et al., 2016b), LWfG is often fed by smallish plants. When the suitability value of some plant grows to a peak level at a specific value, the habitat suitability for LWfG will rise to the maximum value and then decrease. Different from the plant models, LWfG requires unique plants with variable values to meet their daily requirements, and improper values could lead to degradation of the habitat environment and a decrease in the population of LWfG. The other reason why LWfG habitat area decreased is that the plant distribution models showed that the distributions of plants will move to the east, and the original area richness of some plants will decrease, making LWfG unable to adapt to the new habitat. In this view, ensuring proper plant richness and land use planning may be effective ways to reduce the risk of changes in the plant distribution pattern and therefore to ensure the long-term stability of the LWfG in the changing climate.

In addition to climate change, another threat to LWfG was human activity. It should be noted that poisoning and hunting are the main reasons for the decrease in the number of LWfG in the 21st century in China. Hunters are not conscious about the protection of endangered and valued species. Some studies also reported that the impoundment of the Three Gorges Dam (TGD) led to the degradation of vegetation, e.g., the seeds would die after a long-term submersion underwater. Meanwhile, about 30% of plants did not reach their reproductive stages before being submerged (Wu et al., 2013; Jiang et al., 2016).

(Wu et al., 2013; Jiang et al., 2016). Consequently, plants in the wetlands would be inevitably degraded under such serious winter submergence. The impoundment of the TGD could also lead to a change in the LWfG's dietary habits. Both of these reasons have led to the decrease in the number of LWfG in Anhui, Jiangxi and Jiangsu provinces, and mainly in the East Dongting Lakes (Yuan et al., 2014; Zhang et al., 2016b). These influences would have a negative impact on LWfG, although they are not considered in the currently established models. The situation would also become worse if proper conservation measurements were not executed.

The adjustment of the existing protected area is necessary, including modifications of the size, shape and use of the conservation area. For example, in order to maintain the current habitat size in the East Dongting Lake Reserve, an increase in the protected area to the east might be required, especially in the Caisang lakes, which is a very good habitat for migratory birds, and is now rented out for commercial planting of lotus rhizomes by the local government. While the economic benefit has been achieved, habitats have disappeared. In China, many recent eco-conservation programs implemented in this region, such as the "Returning Farmland to Lake", have focused on increasing the areas of lakes and wetlands, but neglected to attach great importance to the availability of food to LWfG. We proposed that plant abundance and diversity should be considered in the plans across the region. Overgrazing will exacerbate wide-scale land degradation, and moderate grazing will be good for LWfG, since this bird prefers to forage around grazing land. For those reserves that may lose most of their LWfG habitats, such as those in the Caisang lakes and Dingzidi, intensive management approaches are necessary for the future protection of LWfG.

5 Conclusion

In this study, HSMs were built for LWfG using Maxent with presence-only data. In contrast to other studies, we used some plant distribution variables by building the distribution patterns of the plants that are foraged by the LWfG in the Yangtze River Basin wetlands in constructing our HSM models. The model had been validated and it performed well based on a high AUC index. The model results indicated that habitat areas would degrade sharply by 2070 under the scenarios of RCP2.6 and RCP8.5. If the habitat areas decrease continuously, this would increase the extinction risk of LWfG. Intensive management strategies, including increasing the nature reserve area, regulating the water in TGD and paying attention to the growing of plants, are suggested to be important for protecting the populations of LWfG in the future.

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气候变化下基于物种与植物耦联机制的小白额雁(*Anser erythropus*)潜在生境及适宜性研究——以长江流域中下游为例

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摘　要：气候变化和人类活动通过改变物种生境而影响物种多样性。小白额雁是长江流域中下游的一种具有较高生态价值的食草型濒危候鸟，受气候变化和人类活动威胁。本文以小白额雁为代表性物种，定量分析了气候变化对长江流域中下游候鸟潜在生境及适宜性空间分布格局的影响。采用Maxent模型模拟了当前情景和全球环流模型（GCMs）气候场景下小白额雁潜在生境及其适宜性分布。研究结果表明，小白额雁分布特征与其栖息地周边植物分布呈显著相关关系；运用Maxent模型模拟小白额雁六种主要食源植物的分布特征，并将其结果作为环境变量，将显著改善小白额雁潜在生境及其适宜性模型的模拟性能；在两种典型浓度情景（RCP 2.6和RCP 8.5）下，2070年小白额雁潜在生境适宜性面积将下降。为应对气候变化对小白额雁的影响，应采取更加合理的管理措施和保护政策，包括调整保护区的大小、形状和用途。

关键词：生境适宜性模型；气候变化；Maxent；小白额雁；MODIS；长江流域