



The Path Forward: Conservation of Climate Change-Affected Breeding Habitat of Red-crowned Cranes near Zhalong Reserve, China

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ABSTRACT

The endangered red-crowned crane (*Grus japonensis*, RCC) has the smallest population of all Chinese cranes, and is also susceptible to climate change because of its large body size, short migration distance, and specialized diet. We examined climate change-induced RCC habitat shifts and suggested some purposeful, resolute and crucial improvements needed to protect appropriate areas that ensure the RCC's long-term survival. Based on monitored data of nesting locations and climate variables gathered from 2014 to 2017 around Zhalong Reserve on the Songnen Plain in northeast China, we used four General Circulation Models in Maxent modeling to project changes, including suitability and fragmentation, in RCC breeding habitat up to the year 2050. Based on climate change, we predicted a decline in 2050 of suitable and sub-suitable habitat from the current 26.2% to 14.3%-19.7% in the study area, but an even larger loss (from 71.3% to 27.3%-32%) of suitable habitat in Zhalong Reserve. The predictions also showed a northward movement of RCC habitat and a loss of current suitable habitat southeast of Zhalong Reserve, resulting in a discrepancy between future habitat areas and currently protected areas. In addition, climate change will further fragment RCC habitat, thus decreasing habitat suitability and carrying capacity, especially within Zhalong Reserve. Our study indicated that the most suitable breeding habitat is currently restricted to the Reserve. This finding partially explains that the low rate of RCC population growth is likely because of the limit of RCC's expansion due to spatial patterns of suitable habitat. We confirmed that temperature, rather than precipitation, had the most impact on RCC breeding. To cope with climate change, we recommend that new refuges be designed within the study area and the transformation of wetland to farmland in the area be banned. Also, organic agriculture methods and crop species that consume less water than rice should be adopted to mitigate the adverse climate changes that accompany global warming and will contribute to RCC habitat degradation.

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Authors' Contribution

MG planned this research. SP, ZG, W Wen, GL, HL and QF performed field surveys and data collects. MG, W Wang analyzed the data. MG wrote the article.

Key words

Breeding habitat, Climate change, *Grus japonensis*, Habitat shift, Migratory bird, Phragmites, Red-crowned crane, Wetland

INTRODUCTION

Climate change may result in habitat loss or fragmentation and may cause shifts in population ranges and phenological changes that degrade species fitness at habitat and genetic levels (Parmesan, 2007; Brook, 2008; Peacock, 2011). Global mean surface temperatures have been increasing since the late 19th century, with 0.2 to 0.3 °C increases over the past 40 years (Nakićenović and Nebojša, 2000). Many birds in Britain had moved farther north an average of 18.9 km during a 20-year span (Thomas and Lennon, 1999), and some North American

birds had experienced significant abundance shift with the average velocity of distribution centroids by 5.89 km yr⁻¹ (Huang *et al.*, 2017). Climate change projections indicate that species' range shifts over the next century will likely be significant (Hole *et al.*, 2009), especially at high latitudes and in the northern hemisphere (Rubolini *et al.*, 2010; Bitterlin and Buskirk, 2014). Climate change has already caused widespread alterations to species populations and ecological communities (Roberts *et al.*, 2014). Temperature is the dominant abiotic factor directly affecting insect phenology (Bale *et al.*, 2002), thus also making insectivorous birds significantly sensitive to temperature change, even more so than to precipitation (Pearce-Higgins *et al.*, 2015). Higher temperatures may impact the energy birds expend to maintain homeostasis (Both *et al.*, 2009). Temperature changes could have

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significant implications on the phenology and life histories of migratory species, as well as on their food choices (Peñuelas and Filella, 2001; Heimonen *et al.*, 2015), such as when the arrival of migratory species coincides with peak food availability (Both *et al.*, 2009; Thackeray *et al.*, 2010).

Migratory species are sensitive to environmental changes and are considered objective indicators of global change (Takuji *et al.*, 2016). Range-restricted species are particularly vulnerable to climate change because they often have poor dispersal abilities and limited food resources. Thus, they have been identified as species with immediate and high probabilities of extinction caused by recent climate change (Parmesan, 2006; Crabtree and Ellis, 2010). In general, avian phenology is sensitive to climate change, especially given certain characteristics of body size, diet, and migration distances (Hedenström, 2006; Lehikoinen *et al.*, 2010). With its large body size, the red-crowned crane is one such species affected by climate change because of both its absolute need of Phragmites-dominant vegetation to provide its specialized dietary and habitat requirements (Li and Yang, 1999; Su and Zhou, 2012) and its short migration distance, which is intra- continental (Takuji *et al.*, 2016).

The RCC has the smallest population of all the Chinese crane species and is a globally endangered species, listed in the Convention on Migratory Species (CMS) Appendix 1 and CITES Appendix 1 (IUCN, 2012). It is also a first-level protected species in China (Ma and Tang, 1998; Wang, 2011). The RCC was found in 2 separate populations: the continental and the island populations (Su and Zhou, 2012). The island population resides in the southeast and northeast of Hokkaido, Japan, and is non-migratory (Masatomi *et al.*, 2001; Masatomi *et al.*, 2007). The continental population is migratory, breeding in northeast China and far southeast Russia from March to October. From October to March they reside on the Yellow Sea coast in eastern China and the central section of the Korean Peninsula (Johnsgard, 1983; Ma *et al.*, 2009). This species faces serious threats from habitat loss and deterioration, and habitat fragmentation. Its population has declined sharply and estimates show only 1800 individuals remaining (Su and Zhou, 2012). The RCC is a phragmites-dependent species in summer and prefers large and integrated phragmites patches in a marsh. Containing a large phragmites patch, the Zhalong National Nature Reserve is the largest breeding ground for the migratory RCC population. Almost 300 RCCs, or one-sixth of the total population, breed in the Zhalong Reserve (Wang, 2011; SFA, 2014).

Climate change is rapidly becoming one of the main threats to biodiversity. Indeed, species are already

responding to climate change by shifting their distribution, and this may eventually cause spatial mismatching among population ranges, suitable habitats, and locations of protected areas (Santangeli *et al.*, 2016). Yet, as RCC is a species likely impacted by climate change, there is a lack of knowledge of climate change-induced RCC habitat shifts. These knowledge gaps have resulted in two limitations to RCC conservation: 1) no clear information of RCC habitat spatial patterns for conservation administrators to use to allocate resources and staff during the breeding season and 2) no plans and procedures for coping with the effects of future climate change. Therefore, based on monitoring of both RCC spatial utilization and climate variables, this study focuses on RCC habitat in and around the Zhalong Reserve on the Songnen Plain. The aim is to expose potential dynamics induced by future climate change in order to 1) understand possible spatial pattern and suitability shifts in RCC habitat, given climate and economic scenarios; 2) identify crucial areas in need of protection and update the design of protected areas to ensure RCC's long-term survival while responding to climate change; and 3) provide suggestions for local cultivation methods based on climatic effects and RCC long-term survival.

MATERIALS AND METHODS

Study area

Our study area, in the heart of the Songnen Plain, covered 2,938,126.1 ha, including the Zhalong Reserve in Qiqihaer, China (Fig. 1). Established in 1987, Zhalong Reserve is the largest breeding ground for RCCs migrating between Zhalong and the Yellow Sea coast of China. Also, some smaller groups of RCC were present in suitable habitat on the Songnen Plain outside the Reserve and downstream of the Wuyuer River. This area includes the Nen River catchment, which contains extensive marsh land and Phragmites, thus making it a favored area of RCCs. The entire area is a sub-temperate zone with a continental semiarid and arid monsoon climate. The study area was 140 m above sea level and relatively isolated by raised land to the east, north, and west with 2 railways (Qiha Line and Qibai Line) and 2 highways passing through it. Because of its importance for migratory species, wetland habitat, and biodiversity, Zhalong Reserve was listed as the first Wetland of International Importance in China under the Ramsar Convention in 1992 (Ramsar, 2018). An additional RCC refuge, Wuyuerhe National Nature Reserve, established in 2006, is adjacent to the north edge of Zhalong Reserve. The study covered Qiqihaer, Gannan, Fuyu, Daqing, Duerbote, Tailai, and Longjiang cities in Heilongjiang province. As part of Songnen Plain

in North China, this area is a traditional area of agricultural production and has been designated a grain base by the Chinese central government (Chen and Zhao, 2008; Zhang *et al.*, 2012).

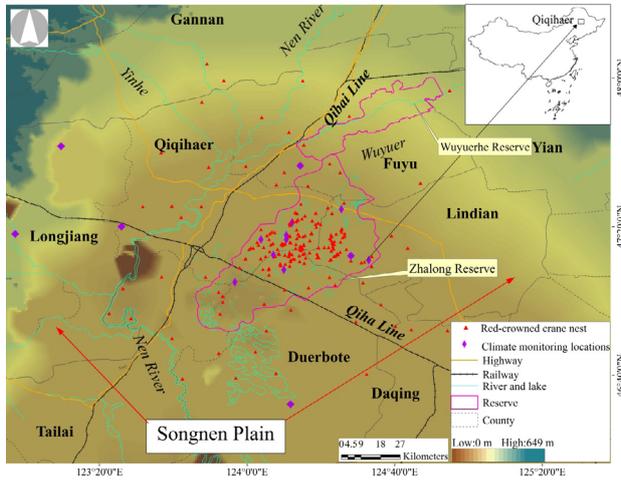


Fig. 1. The Songnen Plain study area including the Zhalong Reserve. Inset shows the study area in northeast China.

RCC presence data

Most cranes are territorial and depend on food resources within their territory. To satisfy trophic needs during breeding, monogamously mated RCC pairs spend most of their feeding time near the nest, while maintaining home range fidelity (Zou and Wu, 2009; Brown, 1969). RCC pairs tend to build their nests around the location of their previous years' nests when habitat changes occurred (Li and Zhao, 1991). So, we recorded nesting locations to reflect both RCC presence and their use of space. Because of their long-term annual monitoring programs and their intimate knowledge of the RCC population, the Reserve staff easily identified RCC nest locations. We located 175 RCC nests in Zhalong Reserve by doing line transect line surveys during routine RCC monitoring from 2014 to 2017. In addition, we obtained 37 RCC nest locations outside of the Reserve but within the study area by conducting face-to-face interviews of local, official wildlife protection staff and residents. Because most RCCs nests in marsh, their nests were difficult to locate using the Global Positioning System. Therefore, we marked each nest location on a Google Earth map and read their latitude and longitude locations from the map.

Environmental variables

Our study included both ecological and anthropogenic variables. We obtained river, lake, and marsh data from the Second National Wetland Survey performed by the

Chinese State Forestry Administration (SFA, 2014), and Zhalong Reserve. That data was supported by satellite images (Landsat 5) which was used to develop a vegetation map of dominant species (*i. e.*, *Phragmites australis*, *Deyeuxia langsdorffii*, *Carex lasiocarpa*, and *Aneurotepidimu chinense*) in the study area. Elevation data in GIS layers were gleaned from a digital elevation model based on 1:50,000 scale topographic maps obtained from the Chinese Academy of Sciences (Geospatial Data Cloud). Regional anthropogenic threats to RCCs included roads, agriculture, and human settlements. To meet data format requirements for modeling, all line and spot data, such as roads and settlements, were transformed to create a raster layer by using EucDistance analysis in Arcgis10.0 (Esri, Redlands, CA, USA), thus transforming the binary data into continuous data. The data for these variables were collected from the National Geomatics Center of China and the Zhalong Reserve Administration Bureau.

Climate data

We applied two sets of climate data in our study. One, compiled using monitoring data gathered by us, was used to identify current habitat suitability. The second, drawn from the Intergovernmental Panel on Climate Change (IPCC; WorldClim Data set) outlines climate predictions we used to project future RCC habitat (Hijmans *et al.*, 2005; Parry *et al.*, 2011). Given the expiration date (1990) of the IPCC's current climate data and to better target real time current climate conditions, we set up 9 meteorological recording spots within Zhalong Reserve to monitor bioclimatic variables from 2016 through 2017, and compiled those variables annually into current bioclimatic variables that coincided with all 19 climate parameters used by the IPCC, such as annual mean temperature, annual precipitation, maximum temperature of the warmest month, and so on. Then, together with additional climate data obtained during the same period from seven national monitoring stations (China Meteorological Administration) within the study area, we interpolated GIS layers of current yearly climate data to a resolution of 30×30 m in our study area using Anuspline 4.3 with latitude, longitude, and elevation variables (Hong *et al.*, 2005; Liu *et al.*, 2008).

Future climate data used to predict habitat shifts were derived from projections of climate scenarios released by the IPCC (World Clim, 2018). To make the projections more immediate and applicable to crane conservation, we only modeled habitat under climate change scenarios from the present up to year 2050. Because there are 19 General Circulation Models (GCMs) and four Representative Concentration Pathways (RCPs; RCP2.6, RCP4.6, RCP6, RCP8.5) of greenhouse gas concentration in each GCM used by the IPCC, it is difficult to project changes in

every GCM and RCP combination. Therefore, within the objectives of this paper and based on previous climate change-related wildlife habitat studies, we adopted four GCMs: BCC-CSM1-1(BC), CCSM4 (CC), HadGEM2-ES (HE), and MPI-ESM-LR (MP) to project probable climate change shifts (Tuanmu *et al.*, 2013; Li *et al.*, 2014; Gong *et al.*, 2016). Since agriculture is the major industry in this area and it has been designated a base of grain production in China, large-scale, industrial projects have rarely been implemented. Moreover, considering Zhalong's Ramsar designation as a wetland of international importance, we concluded that levels of future greenhouse gas emissions will most likely remain low. Therefore, because of CO₂ and CH₄ emissions generated by agricultural activities (e.g., plowing and fertilization) inherent to grain cultivation, the lowest emission scenario, RCP 2.6 may be too optimistic to reflect actual climate dynamics in the area. Moreover, RCP 8.5 is probably not applicable to agricultural areas. So, as a low emission-oriented economy model, we adopted RCP 4.5 as the most likely scenarios to reflect future climate change in our study area, especially when including wetland conservation.

The IPCC climate data resolution was 30 second (about 900 m). To spatially match the climate data that we interpolated, we set modeling data resolution to 30 × 30 m. Therefore, before modeling we had to convert the IPCC data into a raster with a resolution of 30 meters. To ensure that all GIS data matched, geospatial data was based on the Universal Transverse Mercator grid system using the World Geodetic System 1984 model as the reference.

Habitat modeling

We used Maxent (Phillips and Dudík, 2008) to identify current habitat suitability and habitat shifts in 2050. Maxent is typically used to model the impacts of climate change on habitat suitability by using presence-only data, habitat variables, and climate variables (Gallagher *et al.*, 2013). Combined with current environmental variables and species occurrence, we used Maxent to project habitat and its changes and to predict species distribution, assuming that species presence would be drawn from probable habitat (Phillips, 2008). In our study, species occurrences were all nesting locations indicating RCC presence. The environmental variables were vegetation, rivers, lakes, elevations, current and 2050 climate variables, and the main anthropogenic threats, such as roads and human settlements. Considering our study's aim and for convenience, we based habitat projections on the following assumptions: 1) Climate change will be the principal facilitating factor of RCC habitat shifts in 2050; 2) To reduce the uncertainty of modeling results, other environmental variables (e.g. Phragmites, vegetation,

lakes, rivers) will remain stable in the short term; 3) Based on a recent human population decrease in northeastern China (Li and Xiao, 2015), anthropogenic variables, such as roads and communities, will likely remain static (Chen and Zhao, 2008).

To improve model performance, we used both 10,000 background points for modeling and different random subsamples (70% training and 30% test data) to calculate Area Under the Curve (AUC) test values. The AUC value is widely used as an indicator of a model's ability to discriminate between suitable and unsuitable habitat (Dan and Seifert, 2011). Our models were considered reliable when AUC > 0.75 (Rebelo *et al.*, 2010). The importance of habitat variables was evaluated based on contribution and permutation importance, and the higher a variable's value was, the more important the variable will be.

Habitat suitability, shift, and fragmentation

We ran the Maxent model with both current and future climate and environmental variables to project current habitat suitability, as well as the changes expected by 2050. Given that the habitat projected by Maxent modeling was a raster with a continuous habitat suitability index, all current and future habitats were classified into categorical data for further spatial analysis. Because the range of habitat suitability index was between 0 and 1, we needed a set of thresholds for the habitat classification index. In our models, RCC presence was indicated by nests, so we used the proportion of nests to establish the levels of habitat suitability. Based on previous identifications of wildlife habitat suitability (Wood and Dragicevic, 2007; Xu, 2009), we set the threshold values of our habitat suitability classification index as follows: suitable, habitat containing 70% of the crane nests; sub-suitable, habitat containing 20% of crane nests; and normal, the remaining habitat. Then, to meet the aforementioned criteria, we identified a set of thresholds of suitability values to categorize current habitat into suitable, sub-suitable, and normal habitat. The projected classifications of RCC habitat in 2050 were also based on those thresholds. Here, thresholds of habitat suitability were based on the proportion of species present in habitat with different suitability levels. They can also be used as part of the species' biological characteristics of environmental selection in long-term evolution. So, despite having no data for future RCC nesting, our suitability index was applied to future habitat suitability maps.

To examine changes in habitat suitability, we first calculated the proportion of suitable and sub-suitable habitat in the entire area. Then to assess the shift of habitat spatial patterns and fragmentation induced by climate change, we chose suitable habitat, important to species survival to reflect the habitat changes between the present

and 2050 based on landscape indices (Hirzel *et al.*, 2006). The landscape indices of suitable habitat were calculated for a simple fragmentation assessment included total area, patch number (PN), mean patch size (MPS), largest patch size (LPS), and proportion (%) of different scales (O'Neill *et al.*, 1988).

RESULTS

Current RCC habitat, suitability and fragmentation

Current suitable habitat with climate, vegetation, and environmental variables preferred by RCC was 269,455.6 ha, which is 9.2% of the total study area. Most of this suitable habitat was inside Zhalong Reserve (168,950.3 ha accounting for 62.7% of the total suitable habitat and 71.3% of the area of the Reserve) (Fig. 2, Tables I and II). Current suitable and sub-suitable habitat accounted for 26.2% of the total study area, most of which was in Zhalong Reserve and in adjacent areas northwest and southeast of the study area. The largest patch of suitable habitat (165,085 ha accounting for 61.3% of the total suitable habitat) occurred mostly in the Zhalong Reserve, thus strongly supporting the integrity of RCC habitat and the carrying capacity of the Reserve (Table II).

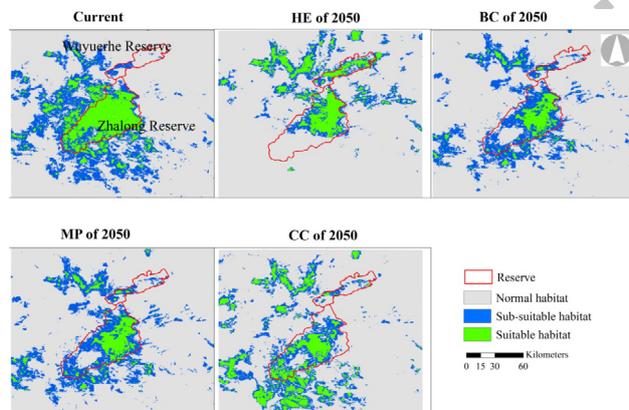


Fig. 2. Current RCC habitat and its suitability to RCC in 2050, as affected by projected climate change in 4 general circulation models (GCMs) in Zhalong Reserve and the study area. GCM abbreviations: BCC-CSM1-1(BC), CCSM4 (CC), HadGEM2-ES (HE), and MPI-ESM-LR (MP).

Shifts of RCC habitat, suitability, and fragmentation induced by climate change

By 2050, the proportion of suitable and sub-suitable RCC habitat will decline from 26.2% to 14.3% -19.7% of the entire study area according to the four GCMs. This means that 6.5%-11.8% of current high quality RCC habitat is predicted to be lost under the impacts of climate change. The HE GCM, rather than the other

GCMs, predicted the greatest loss of RCC habitat, an 11.8% drop in the proportion of suitable and sub-suitable habitat. Given the climate change, Zhalong Reserve may retain the most projected suitable habitat in 2050, but the proportion of the Reserve's suitable habitat will decrease from its current 71.3% to 27.3%-32%. This shows that 39.3%- 44% of current suitable habitat within the Reserve would be lost. Comparatively, the proportional loss of suitable habitat within Zhalong Reserve would be greater than the loss outside the Reserve (Table II). Moreover, we identified a loss of current suitable habitat southeast of Zhalong reserve, and all four GCM scenarios predicted a distinct northward spatial shift of all suitable habitats in 2050.

According to the predicted increase in PN coupled with decreases in MPS and LPS, RCC habitat fragmentation, both in the study area and within Zhalong Reserve, will worsen by 2050 because of climate change. With a reduction in the largest patch of current suitable habitat, the study area's ecosystem function and stability, including within the Reserve, will be weakened.

Model validation with variable importance

Both the training AUC (0.94) and test AUC (0.89) indicated that the results and performance of our model were reliable (Rebello *et al.*, 2010), and that our assumptions of climatic preferences were accurate and valid. The most important climate variables based on contribution and permutation importance were BIO2: Mean Diurnal Range (max temperature–min temperature) and BIO5: Max Temperature of Warmest Month (Table III). Excepting climate factors, vegetation was the most important habitat variable (22.9%) among abiotic and biotic habitat factors, followed by the distance to human communities (12.9%) and distance to roads (8.6%).

DISCUSSION

Our study showed that suitable RCC breeding habitat is currently found mainly in the Zhalong Reserve and accounts for 62.7% of total suitable habitat. The spatial pattern of current suitable habitat not only highlights conservation implications of the Zhalong Reserve for the RCC, but partially explains why RCC population growth remains limited compared to the population sizes of other sympatric cranes, such as the Siberian white crane (*Grus leucogeranus*) and the hooded crane (*Grus monacha*), which overall occur in greater numbers than RCC on the Songnen Plain (Su *et al.*, 2000). Because most of the suitable RCC breeding habitat on the Songnen Plain is currently restricted to the Zhalong Reserve (Fig. 2), it has been difficult for the RCC population to expand and grow outside the Reserve.

Table I. Suitability of RCC habitat showing current and 2050 habitat types and proportions of 4 general circulation models (GCMs) using representative concentration pathway 26 (RCP26) with landscape indices of suitable habitat in study area.

	Suitability/ Fragmentation	Current		2050							
				HE		BC		MP		CC	
Habitat type	Suitable habitat (ha)	269455.6	9.2%	180118.6	6.1%	93225.0	3.2%	111042.6	3.8%	213138.3	7.3%
	Sub-suitable habitat (ha)	499969.9	17.0%	241462.8	8.2%	384435.8	13.1%	408809.4	13.9%	365039.1	12.4%
	Normal habitat (ha)	2168700.7	73.8%	2516544.7	85.7%	2460465.4	83.7%	2418274.1	82.3%	2359948.8	80.3%
Suitable habitat	Patch number (PN)	1267		928		555		611		1339	
	Mean patch size (MPS)	212.7		194.1		168.1		181.7		159.1	
	Largest patch size (LPS)	165085		67041.2		43258.6		49481.7		37712.7	
	Proportion of LPS in total suitable habitat		61.3%		37.2%		46.4%		44.6%		17.7%

GCM abbreviations: BCC-CSM1-1(BC), CCSM4 (CC), HadGEM2-ES (HE), and MPI-ESM-LR (MP).

Table II. Proportions and landscape indices of suitable habitat now and in 2050 according to 4 GCMs in Zhalong Reserve.

Area, proportion, landscape indices	Current	2050			
		HE	BC	MP	CC
Total area (TA, ha)	168950.3	75769.2	64628.3	75333.6	67697.3
Proportion in total suitable habitat	62.7%	42.1%	69.3%	65.4%	31.8%
Proportion in area of reserve	71.3%	32.0%	27.3%	31.8%	28.6%
Patch number (PN)	286	148	204	165	265
Mean patch size (MPS, ha)	590.7	511.9	316.8	456.6	255.5
Largest patch size (LPS, ha)	137511.0	66212.2	43239.6	62671.3	37712.7
Proportion of LPS in total suitable Reserve habitat	81.4%	87.4%	66.9%	83.2%	55.7%

GCM abbreviations: BCC-CSM1-1(BC), CCSM4 (CC), HadGEM2-ES (HE), and MPI-ESM-LR (MP).

The people interviewed outside the Reserve confirmed that there were few RCCs in each non-reserve RCC population. Our study demonstrated that temperature, rather than precipitation, was the more important variable and a valuable contributor to modeling permutations (Table III). The importance of temperature in our models supported greater avian sensitivity to temperature than to precipitation (Pearce-Higgins *et al.*, 2015). Also, other studies have identified temperature as some species' dominant abiotic factor affecting behavior, incubation, and mortality (Paladino, 1985; Bale *et al.*, 2002; Long *et al.*, 2012).

Global temperatures have increased by 0.75 °C in the past 100 years and rates of future climate changes are projected to increase through the 21st century (Hole *et al.*, 2009). According to the climate change projection for our study area in northeast China, both temperature and precipitation will increase (Zhao, 2007). The projected

northward shift of RCC habitat from the Zhalong Reserve in several of our climate scenarios agrees with general projections for avian species to move northward because of climate change (Thomas and Lennon, 1999; Sparks and Braslavská, 2001; Parmesan, 2007). In addition, with the predicted reduction in suitable habitat and increased habitat fragmentation (Table I), habitat suitability and carrying capacity of this ecosystem will likely be affected. Since most high-quality habitat is currently located within Zhalong Reserve, the impacts of climate change on the Reserve are expected to be much more significant than on other parts of the study area. Coupled with the current design of protected areas within the study area, an obvious spatial mismatch between suitable habitat distribution and the Reserve network could develop by 2050. Since there would be a gap of protected area in the northwest of the study area, priority should be given to the establishment of a new reserve in that area to accommodate future suitable

Table III. Bioclimatic and habitat variables, their contribution, and percent permutation importance in Maxent habitat modeling. Habitat variables and descriptions were taken from Worldclim (www.worldclim.org/bioclim).

Habitat variables	Description	Variable contribution (%)	Permutation importance (%)
BIO1	Annual mean temperature	6.7	6.1
BIO2	Mean diurnal range (mean of monthly (max temp–min temp))	23.6	13.9
BIO3	Isothermality (BIO2/BIO7) (* 100)	0.2	4.2
BIO4	Temperature seasonality (standard deviation *100)	4.5	2.5
BIO5	Max temperature of warmest month	1.3	13.2
BIO6	Min temperature of coldest month	0.1	0.5
BIO7	Temperature annual range (BIO5-BIO6)	0.3	0.3
BIO8	Mean temperature of wettest quarter	0.5	0.4
BIO9	Mean temperature of driest quarter	0.0	0.1
BIO10	Mean temperature of warmest quarter	0.7	3.5
BIO11	Mean temperature of coldest quarter	1.2	0.0
BIO12	Annual Precipitation	1.0	0.1
BIO13	Precipitation of wettest month	0.1	6.9
BIO14	Precipitation of driest month	0.3	0.0
BIO15	Precipitation seasonality (coefficient of variation)	2.1	0.0
BIO16	Precipitation of wettest quarter	0.0	0.0
BIO17	Precipitation of driest quarter	3.5	6.2
BIO18	Precipitation of warmest quarter	1.7	0.6
BIO19	Precipitation of coldest quarter	1.6	1.4
Community	Distance to community	12.9	18.4
Lake	Distance to lake	4.4	8.4
Elevation	Height above sea level	1.0	0.2
River	Distance to river	1.0	5.3
Road	Distance to road	8.6	4.0
Vegetation	Vegetation type	22.9	4.0

or sub-suitable habitat arising from climate change (Fig. 2). Additionally, wetland rehabilitation programs, such as Phragmites planting, should be started now to proactively create future habitat on the Songnen Plain.

An additional impending threat to local RCC habitat may be, because of an increasing demand for food, an increase in grain production that could happen at any time and that would potentially raise ambient temperatures by increasing CO₂ and CH₄ emissions due to land use changes and fertilizer use (Guo *et al.*, 2017). To protect RCC habitat and to restrict CO₂ and CH₄ emissions, thus also mitigating the scale of climate change, transformation of wetland into crop lands must be avoided. Technically, since rice cultivation requires abundant water during its planting cycle, its area of cultivation should be controlled or decreased. To reduce future temperature increases,

soybeans, because of their notable CO₂ sink and low water requirements, should have planting priority and should replace rice production in this area (Jin and Zhu, 2008). Organic agriculture practices would partially reduce the scale of temperature increases because they require less fertilizer and mulch film (Zhang *et al.*, 2008). Indeed, such practices should become the region's future cultivation model.

Because of the RCC's fidelity to their home range (Zou and Wu, 2009; Brown, 1969), our presence data based on nest locations was reliable for modeling, as validated by the high AUC value. While we included temperature and precipitation as variables in our study, we recognized that the impacts of other climatic factors, such as relative humidity, wind velocity, and sunshine duration, are factors deserving investigation in climate change projections. We

encourage subsequent studies to continue long-term climate monitoring and data accumulation and to investigate RCC spatial utilization, thus securing a more robust projection of climate change. Moreover, we noted that the hydrological variables of our study were represented roughly by the land covered by rivers and lakes. Since water is key to the function and dynamics of wetland ecosystems, and water levels should be considered indicators of good breeding environments (Boyce *et al.*, 2005), further study should incorporate more hydrological factors, (e.g. pH levels, water depth, and turbidity) in habitat projections.

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Disclosure statement

The authors declare that there are no conflicts of interest regarding the publication of this article.

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