Original Research

Potential Suitable Habitat Distribution and Conservation Strategy for the Siberian Crane (*Grus leucogeranus*) at Spring Stopover Sites in Northeastern China

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Abstract

The wetlands where the migratory waterfowl stop during their migration, also called stopover wetlands, are important nodes where migratory waterfowl supplement their energy and food. The Siberian crane *(Grus leucogeranus)*, a wetland obligate endangered species, is highly dependent on a series of stopovers on the migration route. Although some conservation measures have been adopted in China, it is still necessary to develop an appropriate management strategy to preserve this endangered species at different stopover areas. This paper used maximum entropy modeling to evaluate habitat suitability for the migration of the Siberian crane. We found that vegetation community type and water depth are the most important factors affecting the distribution of the Siberian crane during the migration period. For Siberian crane migration, the most suitable water depth does not exceed 60 cm, the desirable land cover type is swamp, the most suitable community is *Phragmites-Sparganium*, the most suitable vegetation coverage is from 8% to 35%, the distance from a residential area is over 2800 m, and the distance from a road is over 2000 m. On this basis, some specific conservation strategies are proposed for better protection and management of the Siberian crane's habitat. These results can serve as a reference point for the preservation and management of the potential habitats of similar endangered waterfowl.

Keywords: wetland, Siberian crane (*Grus leucogeranus*), habitat, conservation strategy, stopover

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Introduction

Wetlands are one of the ecosystems that have the most abundant biodiversity, providing water, food, shelter, breeding sites and habitat for waterfowl [1, 2]. Wetlands that are distributed on the migratory routes of birds are called stopover wetlands. They are important energy and food supply stations for migratory waterfowl and have important ecological significance in maintaining the population quantity and stability of migratory waterfowl species [3]. However, many of the world's wetlands have been degraded or have disappeared due to climate change, water pollution, and human disturbance [4-6]. The degradation and loss of stopover wetlands has a strong impact on the waterfowl population during migration – especially the changes that occur at important international stopover sites [7, 8]. Strict measures should be taken to conserve waterfowl habitat. In addition, habitat suitability assessment is fundamental to conservation planning.

Previous studies of migratory birds were mainly focused on the effects of habitat [4, 9] and the selection of breeding areas and wintering grounds [10-13]. Research on the ecological selection of stopover areas is seldom documented [3, 14]. The habitat suitability assessment of the stopover areas of migratory waterfowl may aid in understanding why waterfowl choose certain sites. Species distribution models have become important tools to assess habitat suitability in recent years.

Species distribution models (SDMs) use environmental factors and geographic information to interpret and predict the occurrence probability of species [15]. The MaxEnt (maximum entropy model) developed by Phillips et al. in 2006 is a model that estimates the probability density of the occurrence of species, which is utilized to infer and predict the potential geographical distribution of species [16]. MaxEnt avoids the shortcomings of the subjectivity of mechanism models and the difficulty of obtaining input data of regression models. It is extremely suitable for the evaluation of habitat suitability for rare and endangered species with limited occurrence data [13, 17, 18]. Therefore, MaxEnt has been widely applied to quantify the relationship between species distribution and environmental factors and to predict the potential distribution of species [19]. The model can also be used to evaluate habitat suitability for species, such as in some waterfowl habitat evaluation [13, 20, 21].

The Siberian crane is a wetland obligate waterfowl. It prefers to wade and forage on the tubers of submerged aquatic macrophytes by using its long beak in soft mudflats with water saturation or shallow water. However, in recent years, due to the overexploitation of wetland resources through activities such as reclamation, grazing, and oil drilling, the living habitats of Siberian cranes have been reduced or destroyed [9, 22, 23]. The number of Siberian cranes is continuously decreasing. Therefore, the habitat requirements of Siberian cranes should be clarified, and suitability of habitat for the species should be assessed to make scientific decisions to better preserve the valuable species. In this paper, we use the MaxEnt model to understand the Siberian crane's distribution and habitat selection and to guide future conservation efforts. Our objectives were to: (1) explore how the Siberian crane responds to different environmental determinants during spring migration, (2) determine the spatial distribution of potentially suitable habitats for the crane, and (3) provide suggestions for local wetland managers to effectively protect crane habitat.

Materials and Methods

Study Area

Momoge National Nature Reserve (MNNR) is located at N 45°42′25″-46°18′0″, E 123°27′0″~124°4′33″ in the western Songnen Plain in Jilin Province, China (Fig. 1). It covers an area of 1440 km². The average elevation is approximately 142 m above sea level. MNNR is the most important stopover area along the East Asian-Australasian Flyway in northeastern China, attracting approximately 95% of all Siberian cranes globally to replenish their energy from April to May each year [9, 24]. According to the satellite tracking results, the MNNR is a long-term refueling stopover site during the Siberian crane migration [24, 25] due to its abundant wetland types and numerous lakes and rivers. MNNR is a Ramsar site and was founded in 1981 with the major purpose of protecting endangered waterfowl, such as *Grus leucogeranus, Grus japonensis, Grus grus,* Oriental white stork and *Grus monacha.*

The study area belongs to the continental temperate monsoon climate zone and is characterized by an average annual temperature of 4.9ºC and average annual precipitation of approximately 400 mm. Four rivers (the Nen, Tao'er, Erlongtao and Huerda) flow through Momoge Reserve. Due to drought and reservoir construction, only the Nen and the Tao'er flow into the MNNR. Eighty percent of the MNNR is composed of inland salt marshes [26].

Observation of the Occurrence of Siberian Cranes

During April and May 2018, we used a monocular telescope (Nikon MONARCH 82ED-A) to observe the cranes along with MNNR administration staff. The staff has considerable fieldwork experience and knows where to find the cranes. In combination with the MNNR administration staff's daily monitoring routes and points, we used fixed-point observation and line transect sampling methods to determine 20 sites where Siberian cranes occur during spring migration (Fig. 1). Because we were unable to reach the Siberian cranes, the occurrence sites were estimated based on the
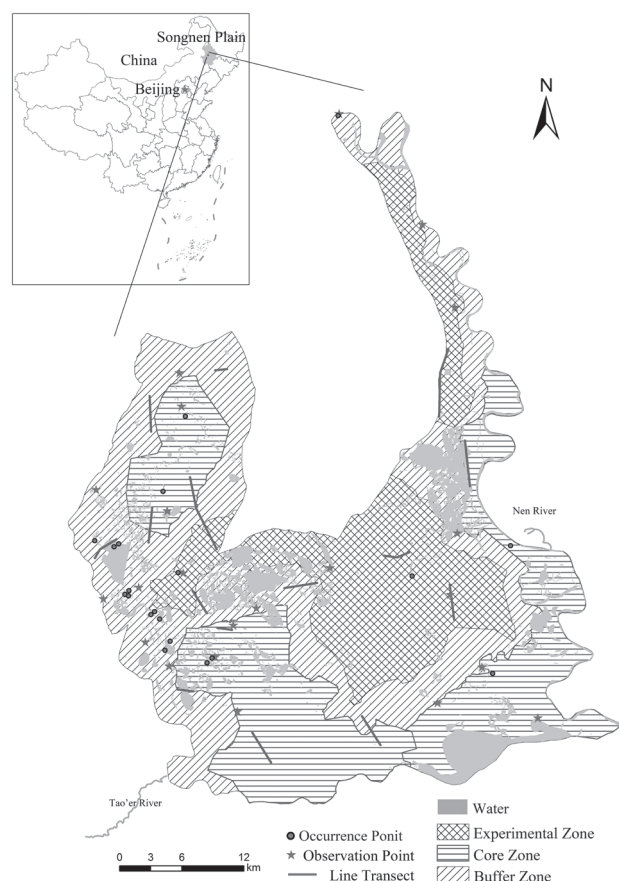
Fig. 1. Locations of the MNNR and occurrence points of Siberian cranes.

directions and distances between the observing locations and the rangefinder telescope. The coordinates of these points were sorted into Excel tables and imported into ArcGIS 10.3 and then converted into the ASCII format required by the MaxEnt software.

Environmental Variables

Previous studies have shown that land cover, human disturbances, vegetation coverage, vegetation communities and water depth are the key factors affecting the habitat requirements of Siberian cranes in Momoge wetlands [9, 22, 27]. No bioclimatic predictors were used because these datasets were usually coarsely scaled and more suited to regional or continental SDMs. We also sampled 126 sites across the MNNR through a field survey. The geographical coordinates, vegetation cover, vegetation types, and average water depth at each sampling site were recorded using a handheld GPS. The sampling sites were spatially scattered to avoid autocorrelation issues.

Land Cover

We generated a land cover map by classifying remotely sensed data. Landsat 8 OLI image (WRS-2 path 120 row 28) from May 21, 2018, was acquired from

the U.S. Geological Survey website (http://glovis. usgs. gov/). Before the image was classified by land cover type, 1:100,000 topographic maps were used to correct the image, and the root mean squared error was controlled within 0.5 pixels. Furthermore, the GF-2 images obtained from the China Center for Resource Satellite Data and Application (http://218.247.138.119:7777/DSSPlatform/productSearch.html) were used as supplemental data. The land cover was divided through visual interpretation into 7 types: 1-swamp, 2-cultivated land, 3-residential area, 4-woodland, 5-water body, 6-saline-alkali land and 7-grassland. The accuracy of the visual image classification was evaluated at 126 field sampling points, and the accuracy was 89.6%.

Human Disturbances

Human disturbances included distance to road and distance to residential areas. The roads were obtained from Google Earth and GF-2 images by visual interpretation. The residential areas were extracted from the Momoge Wetland land cover map. The Euclidean distances to roads and residential areas were calculated using the Spatial Analyst toolbox in ArcGIS 10.3.

Vegetation Coverage

This paper estimates the vegetation coverage of MNNR based on the NDVI method for dimidiate pixel model [28]. The NDVI value was derived from the Landsat 8 OLI image and was calculated in Envi 5.3 software.

Vegetation Communities

The original vegetation community map was provided by the MNNR administration, and then we updated the map with remote sensing images and field survey data. Vegetation community types are divided into 12 types: 1-*Phragmites communis-Scirpus yagara* community, 2-paddy field, 3-dry land, 4-*Carex-Calamagrostis angustifolia* community, 5-*Phragmites communis-Typha angustifolia* community, 6-*Typha angustifolia-Calamagrostis angustifolia* community, 7-woodland, 8-*Leymus chinensis-Suaeda glauca* community, 9-*Leymus chinensis* community, 10-*Phragmites communis-Leymus chinensis* community, 11-*Leymus chinensis-weeds* community, and 12-water body.

Water Depth

The modified normalized difference water index (MNDWI) was used to extract the water surface, and the DEM data and field survey data were used to divide the water area into water depths. DEM is the abbreviation of Digital Elevation Model. It is in raster format with each cell value representing the elevation (m) a.s.l. The data was acquired from the

U.S. Geological Survey website (http://glovis. usgs. gov/). The Siberian crane prefer shallow water ranging from 0 to 60 cm, and we divided the water depth into 4 consecutive grades: 1:~0 cm, 2: 0-30 cm, 3: 30-60 cm, and 4: >60 cm.

To reduce the influence of multiple collinearity on the MaxEnt model, the correlation test of the environmental variables was carried out in R 3.0.1 (http://www.r-project.org/), and the factors with high correlation (r>0.8) were eliminated. The results showed that the above six environmental factors were all aligned with the requirements. Therefore, the following factors (Fig. 2) were used to build the model: (1) land cover types, (2) distance to residential area, (3) distance to roads, (4) vegetation coverage, (5) vegetation communities and (6) water depth. Finally, using the ArcGIS 10.3 platform, each factor layer was projected into the WGS 84 coordinate system and converted into raster format with a cell size of 30 m.

Model Construction and Verification

The species occurrence point data and the environmental variable data were imported into the MaxEnt software (3.4.1). Seventy-five percent of the species occurrence data points were randomly selected to establish the model, and the remaining 25% of points were selected for model validation. The average value of the 15 replicate simulations by subsample run type was taken as the final simulation result. Other parameters were set as follows: "maximum number of background points" was 10,000, "maximum iterations" was 500, the "convergence threshold" was set as 0.00001, and the regularization multiplier was set as 1.

The importance of environmental factors was analyzed using jackknife analysis, and the model performance accuracy was evaluated by area under the curve (AUC) of the receiver operator characteristic (ROC). The AUC value ranged from 0-1; larger AUC values indicate higher prediction accuracy of the constructed model and better predictions [19].
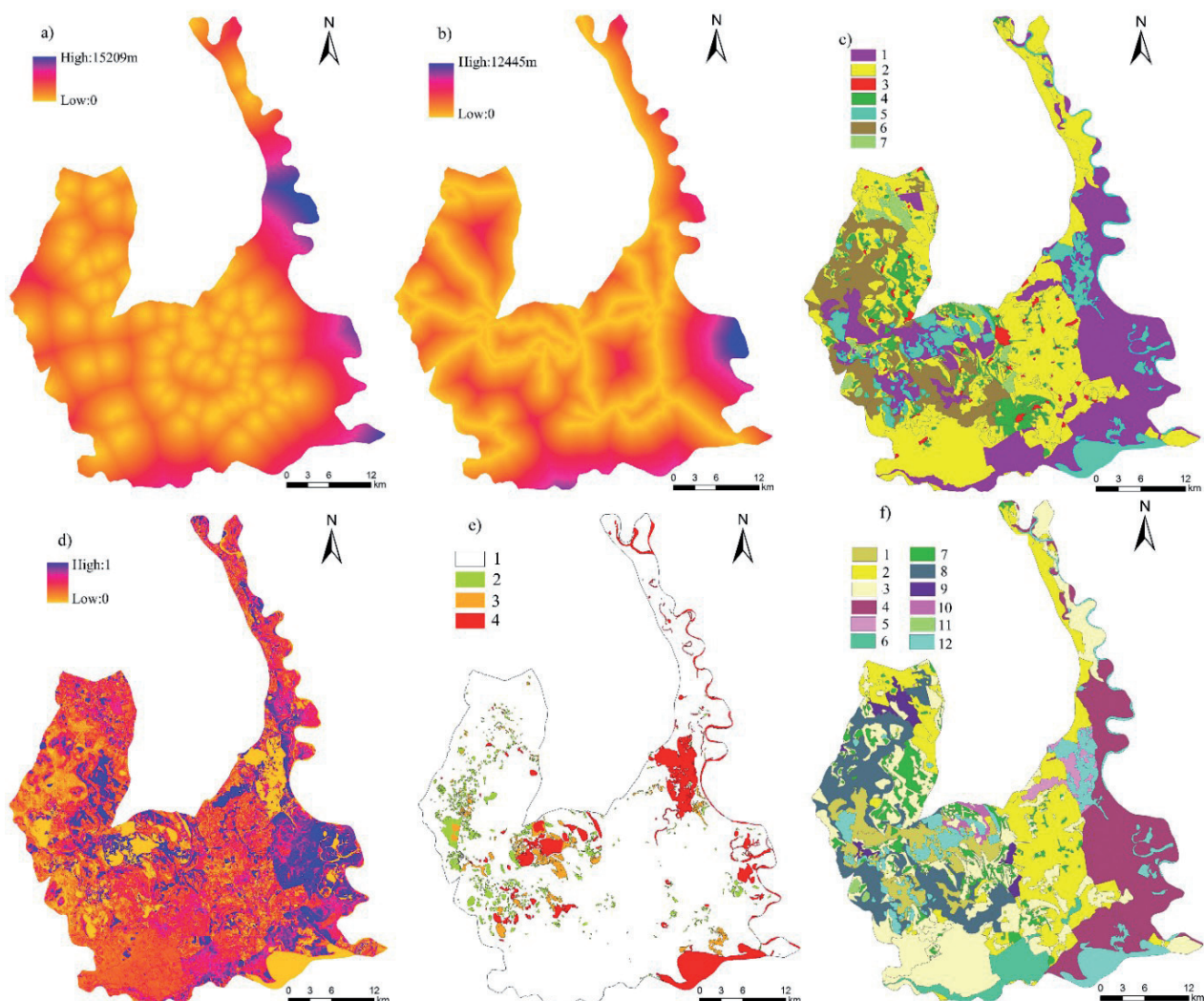

Fig 2. Factors affecting habitat selection of the Siberian crane: a) distance to residential areas, b) distance to roads, c) land cover, d) vegetation coverage, e) water depth, f) vegetation communities.
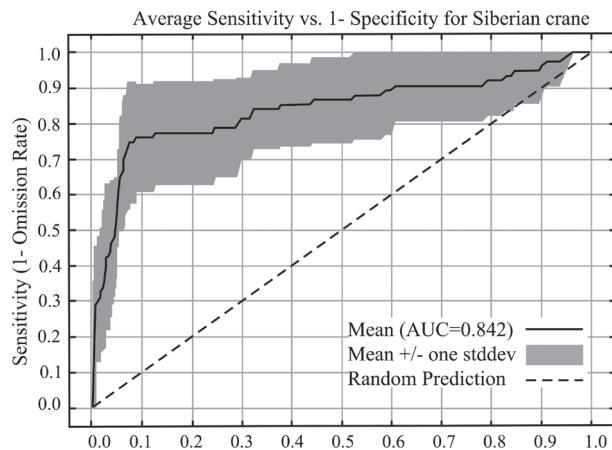
Fig. 3. ROC curve of MaxEnt prediction.

Results and Discussion

Model Performance

The ROC curve (Fig. 3) shows that the AUC value is 0.842, indicating that the simulation results of the MaxEnt model are relatively accurate.

Suitable Siberian Crane Habitats During Spring in MNNR

To map the potential habitats of the Siberian crane, the maximum test sensitivity and specificity values were applied to determine the cutoff point for the model [29, 30]. This threshold maximizes the number of cases where the model erroneously assigns unsuitable habitat and misses suitable habitat. Then, we divided the habitat map into suitable (≥threshold value) and unsuitable (<threshold value) based on the equal training sensitivity and specificity logistic threshold.

The optimal cutoff value was 0.3258. The total area of suitable habitat (Fig. 4) for the Siberian crane during spring in MNNR was 87.55 km^2, of which 37.3 km^2 (or 42.6% of the total area) was in the core zone; 41.36 km^2 (47.24%) was in the buffer zone; and 8.89 km^2 (10.15%) was in the experimental zone.

The Relationship Between Habitat Suitability and Environmental Factors

The Jackknife analysis of the model tested the contribution of each potential environmental variable to the spring migration habitat distribution of the Siberian crane in the MNNR. As shown in Table 1, the vegetation community, water depth and vegetation coverage were the main factors affecting the distribution of the Siberian crane, accounting for 94.4% of the total contribution rate.

The Jackknife test also showed (Fig. 5) that the vegetation community and the water depth have a greater impact on the prediction results; that is, the distribution probability of the Siberian crane is more sensitive to these factors.

The response curve of environmental variables to predicted probability contribution is shown in Fig. 6. The results showed that the most suitable water depths for the Siberian crane were between 0-30 cm and that 30-60 cm was also an appropriate depth. The probability of occurrence at 0-30 cm water depth exceeds 0.8 and goes down to 0.7 at a relatively deep water depth.
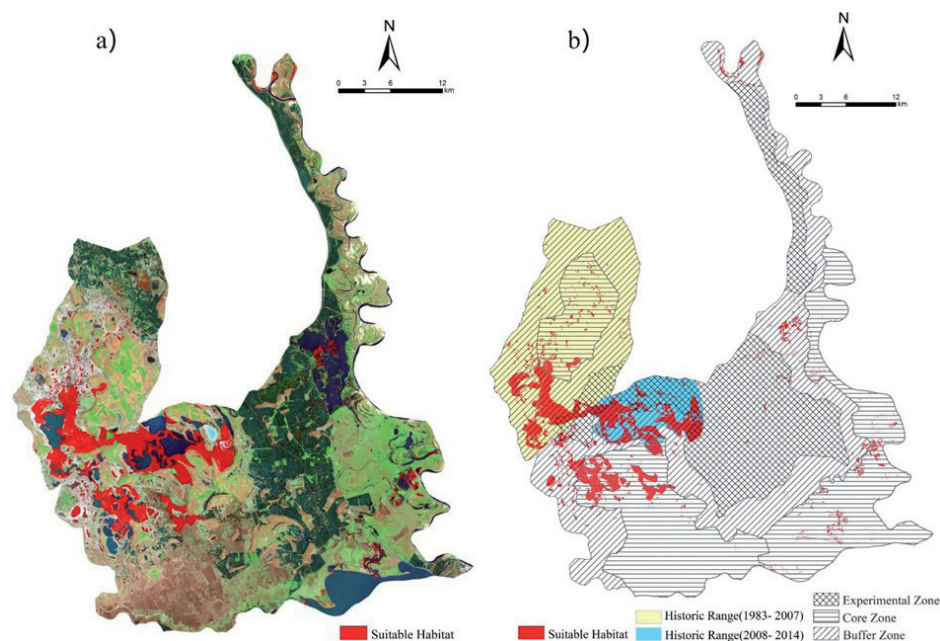

Fig. 4. Potential habitats map of the Siberian crane: a) Landsat 8 image overlap map (R-7 G-5 B-3, time: 2018.5.21); b) historic range overlap map.

Table 1. The contribution rate of environmental factors.

Environmental variable	Percent contribution(%)	Permutation importance(%)
Vegetation communities	46.4	30.2
Water depth	33.9	19.3
Vegetation coverage	14.1	37
Land cover types	3.3	8.2
Distance to roads	1.4	0.4
Distance to residential area	1	4.9

Within 2800 meters of the settlement points, the probability of occurrence increased rapidly with increasing distance, rapidly increasing from 0.3 to 0.6 and reaching a peak at 2800 m; the probability then declined rapidly with increasing distance. When the distance reached 6000 m, the probability was only 0.38. Within 500 meters of the roads, the probability of occurrence increased rapidly with increasing distance, increasing rapidly from 0.37 to 0.52, and reaching a peak of 0.52 at 2000 m, and then decreasing with increasing distance, reaching only 0.42 at 6000 m.

The most suitable vegetation coverage for the Siberian crane was 8-35%. When vegetation coverage ranged from 0 to 8%, the probability of Siberian crane presence increased significantly, reaching a maximum of 0.68, and then slowly decreased to 0.65 when the vegetation coverage reached 15%. The probability quickly dropped to 0.45 with the vegetation coverage increasing to 35%.

The most suitable community for the Siberian crane is the Phragmites communis-Scirpus yagara community, and swamp wetlands are the largest available type.

Spatial Distribution of the Potential Habitats of the Siberian Crane

The habitat suitability distribution map (Fig. 4) shows that the potential habitats of the crane are mainly distributed in the central and western parts of the reserve. The majority are located in the core zone and buffer zone of the MNNR, and very few are located in the experimental zone.

The Siberian crane is a large waterfowl and is very sensitive to environmental changes, such as changes in hydrological conditions and the stopover site [31]. In recent years, due to human factors and global climate change, the landscape pattern of the MNNR has undergone serious changes [32]. Due to the population increase and the reclamation of wetlands for farmland, the Siberian crane lost the appropriate hydrological conditions. The core zone in the northwest of the MNNR has been the main stop for the Siberian crane for the past 10 years [31]. Due to wetland degradation, there are only sporadic areas suitable stopover areas for the Siberian crane, and these habitat patches are fragmented. A drainage area has been built in the western buffer zone of the MNNR and now forms a relatively open water area, which can form suitable hydrological conditions for the Siberian crane. From 2008 to 2014, due to the irrigation and drainage of paddy fields, the buffer zone in the middle of the MNNR maintained a certain water surface area and water level and was the main stopover site for Siberian cranes [9, 23]. In recent years, the water intake in the area has been too large, and the water level is too high as a result of a lack of scientific water management; the area is no longer suitable for a large group of Siberian cranes, and the habitat is fragmented [9]. However, the results in Fig. 4 show that the area is still potential habitat for the Siberian crane. If the water level management can be strengthened, the area may still become a stopover site for the Siberian crane. In contrast, the core zone in the middle of the MNNR, due to the retreat of rice fields and the drainage of reservoirs, can form different sizes of ponds to meet the needs of the Siberian crane. Due to the oilfield production facilities and production activities in the eastern part of the MNNR, suitable habitat for the Siberian crane has almost all been lost.

Environmental Factors Affecting the Distribution of the Siberian Crane

Water is the most important ecological factor for Siberian cranes and plays an extremely important role in migration, habitat and feeding. The effects of hydrological conditions on wetland waterfowl are direct or indirect [33]. For example, the water level affects the spatial structure of the wetland, the type of vegetation, the availability of food, and the microhabitat of the habitat [34]. The most suitable water depths for the Siberian crane were between 0 and 30 cm, indicating that the Siberian crane prefers shallow water marsh and wet meadows for foraging. Our results are in line with those of previous studies [9, 22, 27, 31, 35]. However, we also found that 30 to 60 cm is the preferred depth for the Siberian crane during spring, demonstrating that the Siberian crane can feed in relatively deep water where disturbances from humans and livestock are relatively few. In addition, the soil in the deep water area is water-saturated and softer than the water in shallow areas, and the Siberian crane consumes less energy when foraging.
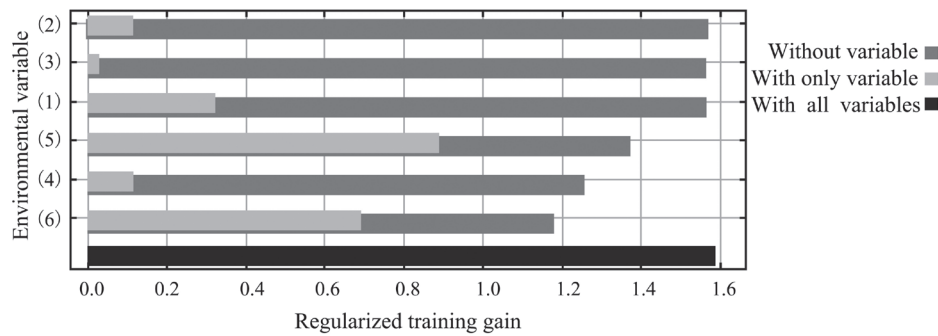
Fig. 5. Jackknife analysis of environmental variables.

The quantity, quality and accessibility of food resources are the decisive factors for whether waterfowl can obtain enough energy and are also the direct cause behind stopover location choice [36]. Our results indicated that the Phragmites communis-Scirpus yagara community was the favorite plant community type for the Siberian crane, which mainly feeds on plants, and the roots and buds are its main food sources. Studies have shown that Scirpusp laniculm is the main source of food [9, 22]. Scirpusp laniculm grows in floodplains,

swamps, paddy fields, riverbanks, lakes, and alkaline meadows, which are often associated with the Phragmites communis-Scirpus yagara community. Our results also showed that the most suitable land cover type for the Siberian crane was marsh.

The various human activities in the wetlands are the main disturbances in the migration and habitat of waterfowls [37, 38]. Strong positive correlations were found between human disturbances and the number of Siberian cranes [12]. The suitable distances to
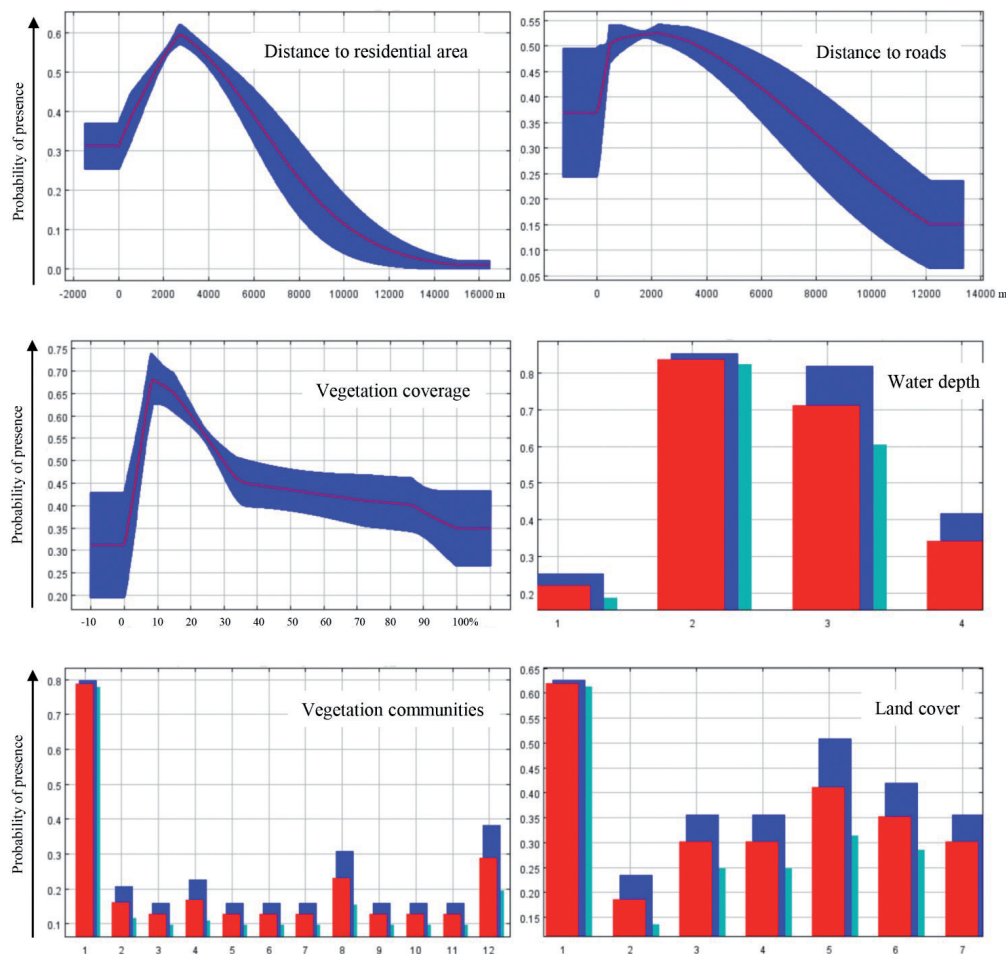

Fig. 6. Response curve of environmental variables to predicted probability contribution: mean of running results in red, standard deviation in blue.

the residential areas and roads were farther than 2000 m. When the distances to these disturbances exceeded 2500 m, the probability of occurrence of the species tended to decrease gradually. This phenomenon indicated that the maximum impact distance of these human disturbances was 2500 m.

The Siberian crane is naturally alert and prefers to choose open areas with fewer disturbances as its main stopover sites. The optimal vegetation covers for the Siberian cranes were between 8% and 35%, which was similar to the findings of Kong et al. [27]. When vegetation coverage was over 35%, it was no longer an influential factor for the emergence of the Siberian crane, indicating that sparse vegetation is the preferred habitat for the Siberian crane. Lower vegetation coverage enables the Siberian crane to detect enemies earlier.

Implications for the Conservation of the Siberian Crane

Momoge Wetland is an internationally important migration stopover for the Siberian crane. Due to the increasing demand for agricultural products, wetlands are facing unprecedented agricultural and commercial development. It is particularly urgent to use and optimize existing wetland patterns to improve migratory waterfowl's habitat. In conjunction with the findings of this paper, the following suggestions are put forward for better protection and management of the habitat of Siberian crane.

Scientific Supplementary Water

Since the late 1980s, and especially since the 1990s, the local government has built water conservation infrastructure projects such as reservoirs, enclosed lakes and water diversion projects, which have seriously damaged the original hydrological pattern of wetlands. The dryness of the wetlands, which is caused by a lack of water, as well as excessive water saturation, has had a considerable impact on the crane's foraging and perching. Water levels that are too low or too high as well as dramatic changes in water level will directly affect the crane's suitable habitat selection; on the other hand, these will also affect the growth of the crane's food: Scirpus laniculm. Therefore, it is recommended that the MNNR administration make a scientific and rational water replenishment plan to improve hydrological conditions and to establish a long-term water replenishment mechanism for the reserve.

Less Human Interference

The waterfowl habitat in the MNNR is seriously disturbed by anthropogenic activities such as the building of roads and villages and the cultivation of land in the protected area. Roads in the protected area are staggered, and road construction has brought about rapid economic development, but it has also brought serious threats to the quality of waterfowl habitats in the protected areas. The area of cultivated land in the MNNR has increased year after year. Field investigations have found that wetlands have been reclaimed into farmland in the buffer and core zones. These anthropogenic factors pose a tremendous threat to the Siberian crane. It is recommended that MNNR administration managers strengthen publicity for waterfowl conservation awareness and raise people's awareness of the importance of waterfowl biodiversity conservation.

Conclusions

In recent years, with global climate change and the increase in human activities, the wetlands on the migratory route have undergone drastic changes. In this paper we used the MaxEnt model, which was driven by the occurrence points of Siberian cranes, to establish the relationship between the stopover wetland's ecological factors and the habitat selection of the Siberian crane to provide theoretical support for the protection of migratory populations of the Siberian crane. At the same time, this paper provides a reference for the restoration and management of large wading bird habitats in other areas of China.

Acknowledgements

Conflict of Interest

The authors declare no conflict of interest.

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