Management reference for nature reserve networks based on MaxEnt modeling and gap analysis: a case study of the brown–eared pheasant in China

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Abstract

Management reference for nature reserve networks based on MaxEnt modeling and gap analysis: a case study of the brown–eared pheasant in China.— Nature reserve designs and networks are important for wildlife and habitat conservation. Gap analyses are efficient and reliable tools for prioritizing habitat conservation efforts, especially when considering endangered species. We propose a conservation plan for the brown–eared pheasant, *Crossoptilon mantchuricum,* by identifying protection gap areas based on 14 existing nature reserves. A total of 45 locality sites and 11 environmental variables were selected according to the characteristics of habitat use of the brown–eared pheasant and applied to a maximum entropy (MaxEnt) model to obtain the species distribution. The MaxEnt model results showed a high prediction accuracy. The gap analysis results revealed that the Luliang Mountains in Shanxi and the Xiaowutai Mountains in Hebei had protection gaps. We found 458 km^2 of optimum habitat and 1,390 km^2 of moderately suitable habitat within the national nature reserve range. However, almost 1,861 km^2 of the optimum habitat and 17,035 km^2 of the moderately suitable habitat were unprotected, equivalent to 9.0% and 82.1%, respectively, of the total suitable habitat. Most of the unprotected area comprised moderately suitable habitat for brown–eared pheasant and should be prioritized in future conservation efforts. There are nine nature reserves along a north–to–south range in the Luliang Mountains that form a wildlife habitat corridor. To maintain the integrity, originality, and continuity of these habitats and thus protect brown–eared pheasants, local conservation departments should be strengthened to improve provincial nature reserve management and successfully carry out conservation efforts.

Key words: Brown eared pheasant, GAP analysis, MaxEnt model, Nature reserves, Suitable habitat

Resumen

Referencia para la gestión de las redes de reservas naturales basada en la creación de modelos MaxEnt y el análisis de deficiencias: un estudio del faisán orejudo pardo en China.— La planificación de reservas naturales y la creación de redes son importantes para la conservación de los hábitats y la fauna silvestre. Los análisis de las deficiencias son instrumentos eficientes y fiables para establecer un orden de prioridad entre las iniciativas de conservación de hábitats, en especial por lo que respecta a las especies en peligro de extinción. Proponemos un plan de conservación para el faisán orejudo pardo, *Crossoptilon mantchuricum,* mediante la determinación de las zonas con una protección insuficiente en las 14 reservas naturales existentes. En total, se seleccionaron 45 localidades y 11 variables ambientales en función de las características del uso del hábitat del faisán orejudo pardo, y se utilizó un modelo de máxima entropía (MaxEnt) para obtener la distribución de la especie. Los resultados del modelo MaxEnt mostraron una elevada precisión de predicción. Los resultados del análisis de las deficiencias revelaron que en las montañas Luliang, en Shanxi, y las montañas Xiaowutai, en Hebei, la protección era insuficiente. Encontramos 458 km^2 de hábitat óptimo y 1.390 km^2 de hábitat moderadamente adecuado dentro de los límites de la reserva natural nacional. No obstante, casi 1.861 km^2 del hábitat óptimo y 17.035 km^2 del hábitat moderadamente adecuado no estaban protegidos, lo que equivale al 9,0% y el 82,1%, respectivamente, del hábitat adecuado total. La mayor parte de la superficie sin protección estaba formada por hábitat moderadamente adecuado para el faisán orejudo pardo y debería considerarse prioritaria en las iniciativas futuras de conservación. Hay nueve reservas naturales a lo largo

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de un eje norte–sur en las montañas Luliang que forma un pasillo ecológico. Para mantener la integridad, originalidad y continuidad de estos hábitats y, por tanto, proteger el faisán orejudo pardo, deberían reforzarse los departamentos locales de conservación con miras a mejorar la gestión de la reserva natural a escala provincial y poner en práctica eficazmente las iniciativas de conservación.

Palabras clave: Faisán orejudo pardo, Análisis de deficiencias, Modelo MaxEnt, Reservas Naturales, Hábitat adecuado

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Introduction

Nature reserves are used to protect populations and habitats of endangered species, such as the brown–eared pheasant, *Crossoptilon mantchuricum*. However, the home range of a species should not be restricted by reserve borders because nature reserves cannot encompass all suitable habitats. For example, Shota (2015) studied suitable habitats of the crested ibis, *Nipponia nippon*, which overlapped minimally with a conservation area on Sado Island. Moreover, some designated reserves cannot fully protect endangered species, although reserves should be accurate, efficient, and cost–effective (Prendergast et al., 1999). Therefore, habitat suitability should be evaluated before release because it is vital to planning more effective reserves (Shota et al., 2015). In addition, forecasting range shifts and suitable habitats for a species using various environmental factors can provide an invaluable reference for selecting protected areas and planning conservation (Hole et al., 2009).

Species distribution models, such as maximum entropy (MaxEnt), random forest, and genetic algorithms for rule–set production models, are widely used to study conservation reserves. MaxEnt modeling uses presence–only occurrence and environmental data to predict suitable habitat of a particular species after assessing combinations of environmental variables and their interactions based on the maximum entropy principle (Phillips et al., 2006). MaxEnt modeling is currently one of the most commonly used models for probability–based predictions of suitable habitat distributions. Comparative studies have found that MaxEnt modeling is relatively good at predicting the potential distribution of a species and mapping areas that meet the environmental requirements (Elith et al., 2006). It has excellent performance and consistently outperforms many other methods, including GARP (genetic algorithm for rule–set production modeling), particularly when using sample sizes (Peterson, 2003).

Gap analysis is relatively popular for evaluating reserves and biodiversity. It is useful for identifying sites that should be protected but that currently fall outside existing conservation networks (Burley, 1988). The ability to identify gaps in an existing reserve network is a simple and appealing concept in conservation management (Prendergast et al., 1999), and gap analysis provides a fast and comprehensive coarse–filtered approach to the protection and conservation of biodiversity (Scott et al., 1993). It uses geographic information system (GIS) technology to identify protection gaps in reserves and offers a powerful and efficient approach to managing reserves and practically guiding reserve selection (Prendergast et al., 1999). GIS is used for its ability to store thematic data layers and can perform complicated spatial analyses and overlap layers such as vegetation, elevation, and climate maps, which can be superimposed to conduct various spatial analyses (Scott et al., 1993). Therefore, areas of importance identified by gap analyses must be examined carefully for their biological qualities and management needs. Gap analysis also provides a quick assessment of vegetation that has already disappeared and associated species to provide focus for further biodiversity maintenance (Scott et al., 1993). GIS gap analysis models have been widely used to plan and evaluate animal diversity conservation and management (Edwards et al., 1996). Their rationale follows a conventional approach of selecting and reconfiguring reserves that can easily be adopted and used by conservation managers (Prendergast et al., 1999).

The brown–eared pheasant is an endangered, mountain–dwelling pheasant endemic to China (Liu et al., 1991). It is listed as a vulnerable globally threatened species (IUCN, 2015). It is a typical mountain bird (Johnsgard, 1999) that inhabits coniferous and mixed coniferous–broadleaf forests (Li et al., 2010) at an altitude of 800 to 2,600 m (Xu et al., 1998; Pang et al., 2009; Zheng, 2015). Due to limited flight ability, wild pheasant populations depend on local areas for appropriate habitat. The brown–eared pheasant is found in three isolated populations: the western population in the Huanglong Mountains of Shaanxi, the central population in the Luliang Mountains of Shanxi, and the eastern population in the Xiaowutai Mountains of Hebei and Beijing (Zheng, 2015).

Most endangered wildlife conservation is achieved via networks of protected areas in the form of reserves (Prendergast et al., 1999). Eight national nature reserves [Huanglong Shan (HLS), Hancheng (HC), Luya Shan (LYS), Pangquanguo (PQG), Wulu Shan (WLS), Heicha Shan (HCS), Xiaowutai Shan (XWTS), and Baihua Shan (BHS)] and six provincial nature reserves [Weifenhe (WFH), Lingjinggou (LJG), Fenheshangyou (FHSY), Yunding Shan (YDS), Xuegongling (XGL), and Jinhua Shan–Heng Lingzi (JHS–HLZ)] were instituted to protect the brown–eared pheasant and its suitable habitat.

In this study, we used a MaxEnt model and GIS gap analysis of the existing reserve networks to assess conservation success, identify protection gaps, and provide advice to improve the protection of this rare and endangered species. Proper management of nature reserve design and networks is pivotal in population rehabilitation and habitat restoration. We addressed two important questions: (1) what are the current conservation achievements and are there protection gaps? and (2) how can protection gaps be addressed in future management plans for nature reserves?

Material and methods

Study area

According to the Site Record Database for Chinese Galliformes (Zhang & Ding, 2007), the current distribution area of the wild brown–eared pheasant population was calculated using the minimum convex polygon method in ArcGIS ver. 10.0 (Esri, Redlands, CA, USA). This population is divided into three areas: the Huanglong Mountains in Shaanxi, the Luliang Mountains in Shanxi, and the joint region of the Xiaowutai Mountains in Hebei and Beijing.

The brown–eared pheasant is non–migratory and has a dispersal distance of 5.7 km (Wang et al., 2006).

The study area mapped out was 20 km and included its current distribution area (fig. 1). The reliability and accuracy of the model predictions should be improved when the model is extrapolated to a larger study area (Phillips, 2008; Phillips et al., 2009). We selected this research area to cover the potential range capacity and help identify potential habitats of this species.

Distribution data sources

The localities and distribution data of the brown–eared pheasant were obtained from the Site Record Database for Chinese Galliformes. We compared the geographic coordinates of these sites with modern occurrences in ArcGIS 10.0 (Xi'an 80 coordinate system). Long–term studies have been conducted on the brown–eared pheasant, and there is relatively sufficient information on its life history and biological needs (Li et al., 1990; Liu et al., 1991; Zhang et al., 2000). We selected 45 locality sites based on ecological and biogeographical features, including the vegetation and geomorphic preferences of this species, with the aim of predicting areas of suitable habitat similar to its actual niche.

Environmental variable selection

Biotic and abiotic factors, such as satellite–derived vegetation, geomorphic type, climate, and presence of roads and rivers, have been used in ecological models of species spatial distributions. In addition, researchers have investigated the effects of climate change on the suitable habitats of endangered species to develop a predictive distribution model using species distribution modeling (Li et al., 2010). We selected 11 environmental variables (vegetation, elevation, aspect, slope, maximum temperature of the warmest month, minimum temperature of the coldest month, annual mean temperature, annual precipitation, distance to the nearest river, distance to the nearest road, and distance to the nearest residential area) that influence the distribution of the brown–eared pheasant as the MaxEnt model environmental predictors of model habitat suitability (table 1). These environmental variables have been used to analyze the habitat choice of brown–eared pheasants in several studies (Li et al., 2009, 2012). The brown–eared pheasant is highly sensitive and vulnerable to climate change (Liu et al., 1991; Li et al., 2010). Climatic variables were presumed to effectively characterize the habitat suitability of the brown–eared pheasant across a large spatial scale. All environmental variables were recorded directly as quantitative data at a resolution of 2.5 arc/min. We extracted the attribute data of the environmental factors using ArcGIS 10.0 from 11 environmental layers.

We used Student's *t*–test to evaluate significant differences among the 11 environmental factors in SPSS ver. 19.0 (IBM, Armonk, NY, USA). In addition, we used a recently developed modeling technique, TreeNet, in SPSS ver. 19.0 to assess major environmental preferences and authenticate the veracity of the suitable habitat predicted in MaxEnt Model ver. 3.3.

MaxEnt model

Species distribution modeling can provide a measure of determining potential suitable habitats for species in study areas not covered by biological surveys (Corsi et al., 2000). MaxEnt modeling is a machine learning process that uses presence–only data (Rebelo & Jones, 2010) and environmental variables (Phillips et al., 2006), and it has become a convenient tool for conservation planning. Sample data should cover the ecological conditions throughout the range of a species (Wisz et al., 2008), but MaxEnt modeling has excellent predictive abilities with good accuracy using low sample sizes (Wisz et al., 2008).

We used 45 sites for the presence data and 11 environmental variables for the predicted background in the MaxEnt model. In this experiment, we used 15 replicates. For each replicate we calibrated the model using a random sample of 75% of the modern distribution data for model training (n = 75); these data were evaluated against the remaining 25% for testing (n = 25) 10,000 randomly generated background points within the local range with a maximum of 5,000 iterations.

We used two statistical analyses to quantify different aspects of the model's performance (Elith & Graham, 2009). Omission and receiver operating characteristic plots with their respective areas under the curve (AUCs) are commonly used to measure the predictive performance of models (Pearce & Ferrier, 2000). The omission range is from 0 to 1, where lower omission values are indicative of higher prediction accuracies (Kang, 2010). As a threshold–independent method, the AUC ranges from 0 to 1, where 0.5 indicates randomness, 1 indicates perfect discrimination and 1.0 > AUC > 0.9 indicates very good predictive performance (Swets, 1988; Fielding & Bell, 1997).

MaxEnt models produce a continuous raster with suitability values from 0 to 1 representing habitat suitability within the study area.

Gap analysis

The choice of threshold is important for ultimately determining protection gaps. The threshold should be defined based on the objectives of the model (Hernandez et al., 2006), while accounting for the precision and quality of the data (Rebelo & Jones, 2010). We required two threshold values to define the optimal, moderately suitable, and unsuitable habitat categories.

MaxEnt modeling provides threshold values based on a variety of statistical measures. We plotted the logistic suitability output to place the limit for moderate suitability as the limit between the geometric and arithmetic increases. This threshold was used to define the minimum probability of suitable habitats and reclassify our model.

We determined the limit for optimum suitability as the point at which suitability stabilized along the logistic curve. The suitability values were based on recent occurrence data. Using the species habits and characteristics, the purpose of the map was to differentiate between optimum habitat and moderately suitable habitat from total suitable habitat. From this,

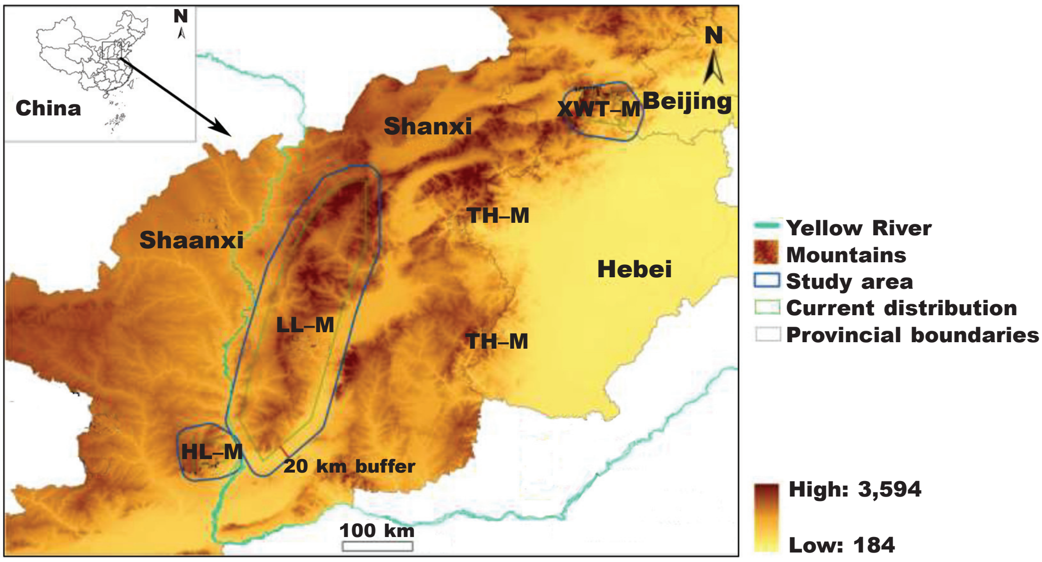

Fig. 1. Map of study area in China. Background data were based on the Spatial Distribution Map of Geomorphic Types in China (1:100,000) (Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences–RESDC). The total study area comprised three areas: the Huanglong Mountains (HL–M) in Shaanxi, the Luliang Mountains (LL–M) in Shanxi, and the Xiaowutai Mountains (XWT–M) in Hebei and Beijing. TH–M indicates the Taihang Mountains.

Fig. 1. Mapa de la zona de estudio en China. Los datos de referencia se basaron en el Mapa de distribución espacial de los tipos geomórficos en China (1:100.000) (Centro de datos para recursos y ciencias ambientales de la Academia China de Ciencias–RESDC). La superficie total de estudio estaba dividida en tres zonas: las montañas Huanglong (HL–M), en Shaanxi; las montañas Luliang (LL–M), en Shanxi; y las montañas Xiaowutai (XWT–M), en Hebei y Beijing. TH–M indica las montañas Taihang.

we defined three levels of habitat suitability: optimum habitat, moderately suitable habitat, and unsuitable habitat. We identified protection gaps by overlaying the habitat suitability and nature reserve layers in ArcGIS 10.0. Suitable habitats located outside the nature reserves were defined as protection gaps.

The boundary map of the national nature reserves was obtained from the College of Nature Conservation at Beijing Forestry University, and detailed information was downloaded from the Ministry of Environmental Protection of the People's Republic of China (table 2). The locations of the six provincial nature reserves were labeled due to their unclear boundaries. The total size of these six provincial nature reserves was approximately 1,457.56 km^2 based on information provided by Ministry of Environmental Protection of the People's Republic of China.

Results

Model performance and evaluation

The ecological niche of a species is determined by numerous biotic and abiotic factors. The *t*–test results showed that all 11 environmental variables differed significantly ($P < 0.001$) among the 45 sites (table 3). The 45 sample sites represented different habitat conditions of the brown–eared pheasant. We gave full consideration to the 11 environmental backgrounds in the MaxEnt model, which allowed the model to acquire accurate suitable habitats to evaluate habitat preference. The suitable habitat distribution determined from this model therefore tended to be more complete than the TreeNet model.

TreeNet and MaxEnt predicted that the habitat preference of the brown–eared pheasant was coniferous and mixed coniferous–broadleaf forests with gentle slopes on sunny south–facing aspects at high altitudes (table 4). The results of both models were similar, although they had levels of success in evaluating the range of suitable climate and distances differed.

The TreeNet model yielded a conservative estimate of the optimum temperature of −15°C to 36°C independent of rainfall. In addition, the brown–eared pheasant preferred habitats far from residential areas and roads, and rarely depended on rivers. The MaxEnt model was robust in selecting the preference range, with a temperature range of −20°C to 35°C, and a closer distance to rivers, roads, and residential areas of > 0.5 km. These habitat preferences are in agreement with the known ecological characteristics of the brown–eared pheasant.

Table 1. The sources of environmental variables used for modelling habitat suitability for the brown–eared pheasant. Aspect definition: 360 degrees divided into eight pieces, each 45 degrees: north, 0–22.5º and 337.5º–360º; northeast, 22.5º–67.5º; east, 67.5º–112.5º; southeast,112.5º–157.5º; south, 157.5–202.5º; southwest, 202.5º–247.5º; west, 247.5º–292.5º; northwest, 292.5º–337.5º, respectively.

Tabla 1. Fuentes de variables ambientales utilizadas para establecer el modelo de idoneidad del hábitat para el faisán orejudo pardo. Definición de aspecto: 360 grados divididos en ocho partes, cada una de 45 grados: norte, 0º–22,5º y 337,5º–360º; noreste, 22,5º–67,5º; este, 67,5º–112,5º; sudeste,112,5º–157,5º; sur, 157,5º–202,5º; sudoeste, 202,5º–247,5º; oeste, 247,5º–292,5º; noroeste, 292,5º–337,5º, respectivamente.

Environmental variables	Layer	Website	Unit
Vegetation	China vegetation type spatial distribution map	http://www.resdc.cn	Dimensionless
Elevation	Spatial distribution map of geomorphic types in China		m
Aspect			º
Slope gradient			º
Maximum temperature of the warmest month	WorldClim (1950–2000)	http:// www.worldclim.org	ºC
Minimum temperature of the coldest month			ºC
Annual means temperature			ºC
Annual precipitation			mm
Distance to nearest river	China pyatyi river map	http://www.webmap.cn/	km
Distance to nearest road	China road map		km
Distance to nearest residential area	China county level administrative region map		km

The MaxEnt model was accurate in predicting the ecological niche of the brown–eared pheasant even though we included only 45 samples. All of the training omission indexes were < 0.10, and all of the test omission indexes were < 0.35 (table 5). These values indicate that the MaxEnt model has very high prediction accuracy. The AUC results revealed a training average AUC of 0.9575, a test average AUC of 0.8985, and an AUC standard deviation of 0.0406, indicative of good model prediction performance (table 6).The MaxEnt model predicted a continuous raster from 0.00 to 0.94 that represented a suitable brown–eared pheasant habitat, shown as the green area in figure 2, which was mainly located in the Luliang Mountains in Shanxi and the Xiaowutai Mountains in Hebei. The results included a large area of suitable habitat that extended beyond its known distribution.

Gap analysis of the protection area

Considering that the evaluation index was dependent on the defined threshold, we selected a 10^{th} percentile training presence logistic threshold (0.30) and habitat suitability probability (0.70) to divide the three habitat suitability grades: optimum habitat (0.94–0.70), moderately suitable habitat (0.70–0.30), and unsuitable habitat (0.30–0.00) (fig. 2).

Using ArcGIS 10.0, we found that the suitable habitat range of the brown–eared pheasant across the whole study area covered approximately 20,744 km^2, with an optimum habitat area of 2,319 km^2 and a moderately suitable habitat area of 18,425 km^2. The optimum and moderately suitable habitats were mainly distributed throughout the Luliang Mountains in Shanxi and Xiaowutai Mountains in Hebei. These suitable habitats were continuously distributed throughout the study areas of Shanxi and Hebei–Beijing.

While some of the suitable habitat area was protected by the eight national and six provincial nature reserves, large portions were not protected; we classified these as protection gaps. The gap analysis revealed large protection gap areas in the Luliang Mountains of Shanxi and the Xiaowutai Mountains of Hebei inside the study area. Furthermore, there were large areas of suitable habitat distributed in the north (Shuozhou), northeast (Wutai), and central (Qinyuan) areas of Shanxi outside the study area, as well as some suitable habitat scattered throughout Hebei.

A network of eight national nature reserves was instituted to protect the brown–eared pheasant and its habitat in the total study area (2,640.45 km^2), including four reserves in Shanxi, two reserves in Shaanxi, one reserve in Hebei, and one reserve in Beijing. From our analysis, this network contained

Table 2. List detailing information for eight national nature reserves (the data source was the Ministry of Environmental Protection of the People's Republic of China).

Tabla 2. Lista con información detallada sobre ocho reservas naturales nacionales (la fuente de datos fue el Ministerio de Protección Ambiental de la República Popular de China).

Nature reserve	Area (km²)	Protection object
Huanglong Shan, HLS	817.53	Brown–eared pheasant and its habitats
Hancheng, HC	604.39	Brown–eared pheasant and its habitats
Luya Shan, LYS	214.53	Brown–eared pheasant, larch (*Larix principis–rupprechtii* Mayr.) and spruce (*Picea asperata* Mast.)
Pangquangou, PQG	104.66	Brown–eared pheasant, larch (*Larix principis–rupprechtii* Mayr.) and spruce (*Picea asperata* Mast.)
Wulu Shan, WLS	206.17	Brown–eared pheasant and its habitats
Heicha Shan, HCS	257.41	Forest ecosystems and brown–eared pheasant
Xiaowutai Shan, XWTS	218.33	Temperate zone forest ecosystems and brown–eared pheasant
Baihua Shan, BHS	217.43	Temperate zone secondary forest

approximately 458 km^2 of optimum habitat and 1,390 km^2 of moderately suitable habitat, equivalent to only 2.2% and 6.7% of the total suitable habitat area. There was an area of 1,861 km^2 of optimum habitat and 17,035 km^2 of moderately suitable habitat, equivalent to 9.0% and 82.1% of the total suitable habitat area, located outside the reserves, which should be considered for protection. Moderately suitable habitat should be the main target for protecting currently unprotected areas.

Discussion

Reserve networks

There are 37 national nature reserves in Shaanxi, Shanxi, Hebei, and Beijing, including 16 reserves in Shaanxi, seven reserves in Shanxi, 12 reserves in Hebei, and two reserves in Beijing. These national nature reserves were instituted to protect different forest types and wildlife. Only eight of these national nature reserves were established to protect the brown–eared pheasant.

Four national nature reserves (HLS, HC, XWTS, and BHS) are located in Shaanxi, Hebei and Beijing, and they have a total area of 1,857.68 km^2. We found that HLS and HC covered the entire suitable habitat of the western brown–eared pheasant population in Shaanxi, while XWTS and BHS covered a large portion of the suitable habitat of the eastern population in Hebei–Beijing (fig. 2). Seven national nature reserves are located in Shanxi (LYS, PQG, HCS, WLS, Lishan Reserve [LS], Lingkong Shan Reserve [LKS], and Yangcheng Mang River Macaque Reserve [YCMR]), four of which (LYS, PQG, HCS, and WLS) were established to protect the brown–eared pheasant and its habitat. In the study area, these reserves had an area of 782.77 km^2, which covered a small fraction of the suitable habitat of the central population in Shanxi. The other three national nature reserves (LS, LKS, and YCMR) were established to protect other forests and wildlife outside the study area.

A total of 101 provincial nature reserves have been created to protect forest ecosystems and wildlife, including 31 reserves in Shaanxi, 39 reserves in Shanxi, 19 reserves in Hebei, and 12 reserves in Beijing. Eleven of these are located in the study area: nine in Shanxi, one in Beijing, and one in Hebei. However, only six provincial nature reserves were developed to protect the brown–eared pheasant and its habitat in the study area. Except for JHS–HLZ in Hebei, the others (WFH, LJG, FHSY, YDS, and XGL) are located in Shanxi. Although these provincial nature reserves lack clear boundaries and ideal regulations, they contribute to protecting the habitat of the brown–eared pheasant.

The impact of environmental variables on brown–eared pheasant distribution

The brown–eared pheasant is a forest–dependent species. It mainly feeds on tender roots, stems, leaves, seeds, and fruits (Lu & Liu, 1983). It does not exist outside forests and it inhabits different forests at different elevations depending on the season (Liu et al., 1991). The breeding season lasts from March to July, when the it inhabits the slopes of mixed coniferous–broadleaf forest zones. When the temperature increases in summer, family flocks move to coniferous forests at higher elevations. In autumn and winter, they move to lower altitudes to inhabit sheltered slopes in broad–leaved forest belts. The life history of the brown–eared pheasant determines its choice of altitude and vegetation zone. Overall, this species

Table 3. The *t*–tests of environmental variables. Eleven environmental variables showed high statistical significance (*P* < 0.001) between 45 sites.

Tabla 3. Las pruebas de la t *de las variables ambientales.* Once variables ambientales mostraron una significación estadística elevada (P < 0,001) entre 45 sitios.

Environmental variables	*t*	*P*
Vegetation	32.931	0.000
Elevation	33.962	0.000
Aspect	12.534	0.000
Slope	10.205	0.000
Maximum temperature	118.775	0.000
Minimum temperature	–17.026	0.000
Annual means temperature	29.495	0.000
Annual precipitation	27.296	0.000
Distance to nearest river	10.226	0.000
Distance to nearest road	14.881	0.000
Distance to nearest residential area	12.384	0.000

prefers coniferous and mixed coniferous–broadleaf forests with gentle slopes and sunny south–facing aspects at high altitudes.

Nests and eggs in these forests are destroyed due to grazing by animals and mushroom foraging by local villagers. This directly reduces the reproductive success of the brown–eared pheasant (Zhang & Zhang, 2001). Residential areas with more roads and human interference have forced brown–eared pheasant populations to move to areas with less human interference (Zhang et al., 2004). Brown–eared pheasants usually avoid or cross roads very quickly when they are encountered. Roads do not hinder their movement, but reduce habitat connectivity and canopy density. The risk of becoming prey is higher around motorways (Zhang & Zhang, 2001); therefore, brown–eared pheasants primarily avoid residential areas and roads that are characterized by greater human disturbance.

The brown–eared pheasant is sensitive and vulnerable to climate change (Liu et al., 1991, Li et al., 2010), and temperature and precipitation are important factors in habitat selection. Temperature directly affects its growth, development, reproduction, metabolism, and other life activities (Liu et al., 1991). Brown–eared pheasants choose suitable habitats, avoid adverse environments at different temperatures, and move up or down elevations and slopes with seasonal changes. The brown–eared pheasant lives in semi–arid areas. Precipitation indirectly affects the species' life activities through its effects on vegetation. Excessive rainfall, snowfall, and low temperatures affect the species' survival, especially influencing breeding and reducing its reproductive success (Liu et al., 1991).

The brown–eared pheasant feeds more on fruits and leaves in the spring and summer, while it plucks snow off the ground in the winter and occasionally drinks stream water in the fall when passing mountain springs and streams. Habitats close to rivers offer relatively few refuge areas and have relatively high predation

Table 4. The habitat preference of brown–eared pheasant compared between MaxEnt and TreeNet models.

Tabla 4. Comparación de la preferencia de hábitat del faisán orejudo pardo entre los modelos MaxEnt y TreeNet.

Environmental variables	MaxEnt	TreeNet
Vegetation	Coniferous and mixed coniferous–broadleaf forests	Coniferous and mixed coniferous–broadleaf forests
Elevation	1,500–2,600 m	1,600–2,100 m
Aspect	Southwest	South–southwest
Slope	> 10º	6–16º
Maximum temperature	35ºC	35–36ºC
Minimum temperature	> –20ºC	>–15ºC
Annual means temperature	10–11ºC	6–9ºC
Annual precipitation	100–200 mm	100–300 mm
Distance to nearest river	> 0.7 km	1.5–1.7 km
Distance to nearest road	> 0.5 km	> 0.6 km
Distance to nearest residential area	> 0.65 km	> 0.4 km

Table 5. Omission indexes of training and test of MaxEnt model.

Tabla 5. Tasas de omisión de capacitación y prueba del modelo MaxEnt.

Indexes	Training	Test
Minimum training presence	0.0000	0.1185
10% training presence	0.0741	0.3037
Equal training sensitivity and specificity	0.0963	0.3333
Equal test sensitivity and specificity	0.0592	0.1555
Maximum training sensitivity plus specificity	0.0691	0.3259
Maximum test sensitivity plus specificity	0.0617	0.0889

Table 6. The AUC values of prediction by MaxEnt model repeated 15 times: SD. Standard deviation.

Tabla 6. Los valores del AUC (área bajo la curva) de la predicción realizada con el modelo MaxEnt se repitieron 15 veces: SD. Desviación estándar.

	Training	Test	SD
1	0.9571	0.877	0.0527
2	0.9475	0.9437	0.0147
3	0.9508	0.9404	0.0202
4	0.9574	0.9062	0.0299
5	0.9548	0.9304	0.0162
6	0.96	0.8794	0.0595
7	0.9612	0.8802	0.0449
8	0.9589	0.9155	0.0434
9	0.9511	0.933	0.0177
10	0.9737	0.805	0.0618
11	0.9543	0.9144	0.0466
12	0.9585	0.8914	0.0549
13	0.9588	0.8755	0.055
14	0.9588	0.9176	0.0282
15	0.9601	0.868	0.0636
Averages	0.9575	0.8985	0.0406

risks. Based on the habitat preference analysis, the brown–eared pheasant has little dependence on rivers.

Pheasants tend to choose suitable habitats and avoid adverse environments to improve their chance of survival, and anthropogenic factors and natural conditions determine their distribution. Reserves have been instituted to protect endangered species and their habitats, but the conservation achievements of many of these reserves have been limited. Few reserves or networks have been designed or established using reserve selection and design techniques (Pressey, 1994) before allocating and protecting the land for conservation. This means that reserves designated for certain species may not fully overlap with the species' distribution, resulting in protection gaps.

Protection gaps and conservation implications

The predicted results of the MaxEnt model were similar to the actual ecological niche of the brown–eared pheasant based on the studied environmental preferences. The results of the gap analysis indicated that only 8.9% of the suitable habitat of the brown–eared pheasant is protected by the current eight national nature reserves. The model identified 18,896 km^2 of suitable habitat outside the protected reserves, of which 9.0% was optimum habitat and 82.1% was moderately suitable habitat. The geographical distribution of a species can be limited by factors that fall outside the scope of their optimum habitat, such as limited dispersal abilities, geographical barriers, and predators. Therefore, otherwise moderately suitable habitat may become necessary for the survival of a species. Since moderately suitable habitats constituted the majority of the protection gap areas in our study area, future conservation plans should consider this gap to improve brown–eared pheasant protection efforts.

The current distribution range of the brown–eared pheasant is segregated into three geographical populations: the western, central, and eastern populations. The western population in HLS in Shaanxi is located to the west of the Yellow River, while the central population in the Luliang Mountains in Shanxi is located to the east of the Yellow River. The eastern population in Hebei–Beijing is an isolated island on the east side of the Taihang Mountains (TH–M). The current distribution forms discontinuous islands (Zheng, 2015). Habitat continuity has been highlighted as a biodiversity conservation priority to improve the integrity and vulnerability of a species, which should be prioritized when planning nature reserves (Ginsberg, 1999; Prendergast et al., 1999). However, it is not feasible to connect the three isolated brown–eared pheasant populations. The most practicable conservation measure would be to identify areas of suitable habitat outside the existing nature reserves and improve conservation management by creating additional protected areas in these gaps to increase the integrity and consistency of conservation of each population.

Based on our analysis, the optimum habitats of the brown–eared pheasant were located in the north and east of LYS, northeast of PQG, and north of WLS. The YDS Provincial Nature Reserve is east of the PQG National Nature Reserve (fig. 2). These two reserves

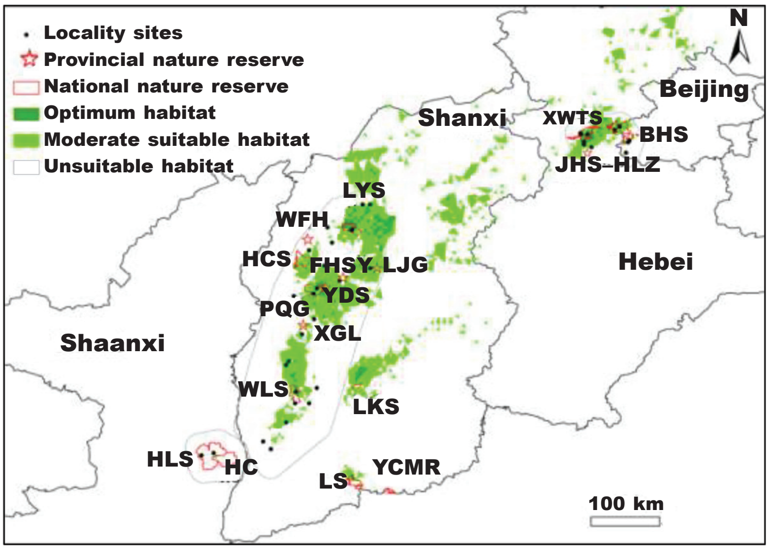

Fig. 2. Protection gap and grade distribution map of habitat suitability produced by the MaxEnt model and ArcGIS ver. 10.0. The green area represents the suitable habitat of the brown–eared pheasant, which covers most of its current distribution area. Large areas distributed in the north (Shuozhou), northeast (Wutai), and central (Qinyuan) areas of Shanxi fell outside the study area. The eight national nature reserves inside the study area were HLS, HC, LYS, PQG, WLS, HCS, XWTS, and BHS. The three national nature reserves outside the study area were LKS, LS, and YCMR. The six provincial nature reserves were WFH, LJG, FHSY, YDS, XGL, and JHS–HLZ.

Fig. 2. Mapa de las zonas sin protección y la distribución de los grados de idoneidad del hábitat, producido por el modelo MaxEnt y ArcGIS ver. 10.0. La superficie verde representa el hábitat adecuado del faisán orejudo pardo, que abarca la mayor parte de su área de distribución actual. Las extensas zonas distribuidas en el norte (Shuozhou), el noreste (Wutai) y las áreas centrales de Shanxi (Qinyuan) estaban fuera de la zona de estudio. Las ocho reservas naturales nacionales dentro de la zona de estudio eran HLS, HC, LYS, PQG, WLS, HCS, XWTS y BHS. Las tres reservas naturales nacionales fuera de la zona de estudio eran LKS, LS y YCMR. Las seis reservas naturales provinciales eran WFH, LJG, FHSY, YDS, XGL y JHS–HLZ.

are roughly connected and cover a large area of suitable habitat. Reserve networks must be configured to optimize their conservation potential (Prendergast et al., 1999), and expanding the current reserves is both necessary and feasible. We suggest that the protected area should be extended to include suitable habitat within 15 km northeast of LYS and 16 km north of WLS to improve current conservation efforts for the brown–eared pheasant.

Suitable habitat in the Luliang Mountains of Shanxi is almost continuously distributed (fig. 2). Five provincial nature reserves (WFH, LJG, FHSY, YDS, and XGL) are located among the four national nature reserves (LYS, PQG, WLS, and HCS). These provincial nature reserves are crucial to link protected habitats, especially FHSY and XGL, which are located in a narrow band of suitable habitat. The nine reserves are distributed from north to south in the Luliang Mountains, forming a wildlife habitat corridor that supports population dispersion and gene exchange within the central brown–eared pheasant population.

Well–designed boundaries and effective management systems are important for constructing provincial nature reserves. To maintain the integrity and continuity of suitable brown–eared pheasant habitat, local conservation departments should strengthen and improve their management of provincial nature reserves to optimize conservation effects. In addition, the organizational structure of provincial reserves should be clarified, including boundary confirmation, the institution of regular monitoring patrols, and implementation and improvement of habitat protection. In particular, it is essential to maintain local ecological wildlife corridors to sustainably develop the region.

The Luliang Mountains are the main distribution area of the brown–eared pheasant. Although there are four national nature reserves and five provincial nature reserves in this area, a large area of suitable habitat remains unprotected. To ensure the stable development and continued growth of the brown–eared pheasant, protection measures against deforestation are urgently required to protect its suitable habitat, such as prohibiting logging in the Luliang mountains.

Furthermore, some suitable habitat is located in the north (Shuozhou) and central (Qinyuan) areas of Shanxi outside the study area. The brown–eared pheasant historically inhabited Qinyuan County (He & He, 1990; Liu et al., 1991), and this area should be considered for reintroduction to help rejuvenate the population of this endangered species.

The protection gap area in the eastern population in Hebei–Beijing is continuous (fig. 2), with suitable habitat fragments in 10– to 24–km intervals. Two national nature reserves (XWTS and BHS) and one provincial nature reserve (JHS–HLZ) form a close triangle. This region has dense vegetation cover and little human disturbance due to bans on hunting, logging, and travel to maintain the integrity and connectivity of suitable habitat and ensure genetic exchange between the brown–eared pheasant populations in Hebei and Beijing. Implementing further protections in this area is feasible.

Since the 1980s, the Chinese government has initiated large–scale tree planting, reforestation, and nature reserve programs to improve the survival rates of species that rely on forest landscapes, such as the brown–eared pheasant. In this study area, two counties (Laiyuan and Laishui) in Hebei Province and five counties (Yangqu, Loufan, Jixian, Xingxian, and Shilou) and two districts (Lishi and Xinfu) in Shanxi Province have provincial nature reserves to protect local forest and wetland ecosystems, as well as larch, *Larix principis–rupprechtii* Mayr., and pine, *Pinus tabuliformis,* forests and local wildlife. Ten provincial nature reserves [Tianlongshan (TLS, outside the study area), Yunzhongshan (YZS), Hejiashan (HJS), Renzushan (RZS), Tuanyuanshan (TYS), LJG, FHSY, YDS, XGL, and WFH] were created to protect the brown–eared pheasant and forest ecosystems in Shanxi. Only five of the provincial nature reserves (LJG, FHSY, YDS, XGL, and WFH) covered some of the suitable habitat in our study area, offering limited protection of suitable brown–eared pheasant habitat. We found that the western and eastern population habitats were better protected than the central population, and the suitable habitat of the central population in Shanxi urgently requires further protection.

Brown–eared pheasant populations in nature reserves are stable and even increasing (Zheng, 2015). However, outside reserves, habitat loss and degradation due to urban development (Zheng, 2015) is the main cause of their decline. Therefore, it is crucial to strengthen the protection and management of suitable habitats outside nature reserves.

Our models identified previously unknown protection gaps and determined good candidate areas for additional conservation. If conservation planners predict suitable habitat before designing reserves, give full consideration to the integrity and continuity of suitable habitat, and cover a relatively reasonable habitat range when planning nature reserves, then more suitable brown–eared pheasant habitat can be protected. In addition, the protection and management of provincial and other nature reserves are crucial for promoting steady brown–eared pheasant population growth. Our results may encourage conservation managers to use distribution modeling before beginning nature reserve construction projects (Hernandez et al., 2006) by conducting additional field surveys and informing the selection and management of protected areas in future conservation programs.

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