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# Conservation guidelines for the endangered Brown-eared Pheasant based on the geographic information system and the MaxEnt model

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We analyzed the synchronous relationship between forest cover and species distribution to explain the contraction in the distribution range of the brown-eared pheasant (*Crossoptilon mantchuricum*) in China. We consulted ancient texts to determine this pheasant's historical distribution from 25 to 1947 CE. Based on this species' habitat selection criteria, the history of the forests, ancient climate change records, and fossil data, we determined that the brown-eared pheasant's historical distribution included the three provinces of Shaanxi, Shanxi, and Hebei. It once inhabited an area of about 320,000 $km^2$, as calculated by the minimum convex polygon method (MCP) in ArcGIS 10.0. The current species distribution covers 46,800 $km^2$ of the Shaanxi, Shanxi, and Hebei provinces, as well as Beijing city, while Shanxi remains the center of the distribution area. This pheasant's distribution range has decreased by 85% over the past 2,000 years. We used the Mean Decrease Accuracy (MDA) index to assess the importance of the evaluation of 13 environmental factors using the Random Forests (RF) measure from the R 3.0.2 software platform. The results showed that vegetation is the most important determinant influencing distribution. We built a corresponding correlative relationship between the presence/absence of brown-eared pheasant and forest coverage and found that forest coverage in the north, northeast, central, and southeast areas of the Shanxi province were all less than 10% at the end of the Qing Dynasty (1911 CE). Our MaxEnt model indicated that the brown-eared pheasant had retreated to the western regions of Shanxi (AUC = 0.753) and that the historical distribution area had reduced synchronously with the disappearance of local forest cover in Shanxi. Wild brown-eared pheasant populations are stable in the Luliang Mountains, where forest coverage reached 13.2% in 2000. Consequently, we concluded that the distribution of this species is primarily determined by vegetation conditions and that forest cover was the most significant determining factor. To guarantee stable growth in the population and consistent distribution of the brown-eared pheasant, we suggest that forest coverage should be at least 48% in the natural reserves where the brown-eared pheasant is currently distributed.

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# Conservation guidelines for the endangered Brown-eared Pheasant based on the Geographic Information System and the MaxEnt Model

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# Abstract

We analyzed the synchronous relationship between forest cover and species distribution to explain the contraction in the distribution range of the brown-eared pheasant (*Crossoptilon mantchuricum*) in China. We consulted ancient texts to determine this pheasant's historical distribution from 25 to 1947 CE. Based on this species' habitat selection criteria, the history of the forests, ancient climate change records, and fossil data, we determined that the brown-eared pheasant's historical distribution included the three provinces of Shaanxi, Shanxi, and Hebei. It once inhabited an area of about 320,000 km$^2$, as calculated by the minimum convex polygon method (MCP) in ArcGIS 10.0. The current species distribution covers 46,800 km$^2$ of the Shaanxi, Shanxi, and Hebei provinces, as well as Beijing city, while Shanxi remains the center of the distribution area. This pheasant's distribution range has decreased by 85% over the past 2,000 years. We used the Mean Decrease Accuracy (MDA) index to assess the importance of the evaluation of 13 environmental factors using the Random Forests (RF) measure from the R3.0.2 software platform. The results showed that vegetation is the most important determinant influencing distribution. We built a corresponding correlative relationship between the presence/absence of brown-eared pheasants and forest coverage and found that forest coverage in the north, northeast, central, and southeast areas of the Shanxi province were all less than 10% at the end of the Qing Dynasty (1911 CE). Our MaxEnt model indicated that the brown-eared pheasant had retreated to the western regions of Shanxi (AUC = 0.753) and that the historical distribution area had reduced synchronously with the disappearance of local forest cover in Shanxi. Wild brown-eared pheasant populations are stable in the Luliang Mountains, where forest coverage reached 13.2% in 2000. Consequently, we concluded that the distribution of this species is primarily determined by vegetation conditions and that forest cover was the most significant

determining factor. To guarantee stable growth in the population and consistent distribution of the brown-eared pheasant, we suggest that forest coverage should be at least 48% in the natural reserves where the brown-eared pheasant is currently distributed.

# Introduction

The issue of species distribution is of fundamental interest to ecologists [1]. Since the first studies using species distribution models (SDMs) appeared in the 1980s, the number of published studies using SDMs has increased exponentially [2], particularly those studies investigating changes in species distribution as a result of climate change [3]. The aim of these models is to geographically represent the environmental niche of a target species and to extrapolate these models to represent potential real world distributions [4]. SDMs are useful tools for analyzing species–environment relationships [5] and include such approaches as machine learning models (*e.g.*, MaxEnt and GARP), regression models (*e.g.*, GAMs, GLMs, MARS, and BRT), and bioclimatic envelope models (*e.g.*, Bioclim), all of which are now widely used [6].

The MaxEnt model is currently the most commonly used model for probability predictions related to species distribution. MaxEnt is a general purpose method that uses presence-only occurrence data in niche modeling [7]. By relating known species occurrences and distributions to environmental variables, the MaxEnt model offers predictions of current and future potential ranges of species [8]. By maximizing the entropy of the probability distribution, MaxEnt fulfills the constraint that the expected values of environmental variables under the estimated distribution match their empirical averages [9]. Comparative studies have consistently shown that MaxEnt has excellent performance and outperforms many other methods (such as GAMs, GLMs, and GARP) in estimating potential species distributions, particularly when sample sizes are small [9]. This approach produces a map for the predicted distribution based on the environmental variables in each grid cell in the study area and has better predictive performance than other models [10]. Overall, MaxEnt is considered an effective means by which we can estimate potential species distributions.

Environmental variables, such as climate change, land use, the percentage of vegetation cover, and characteristics of the vegetation can exert direct or indirect effects on a species [11]. Climate change has reportedly led to habitat loss and fragmentation and, in turn, range contraction for many species [12]. Vegetation is one of the most widely used indirect indicators of the distribution of terrestrial animal species [13]. It is likely that historical changes to vegetation may influence species distributions and reduce the geographic ranges of animals, leading to smaller, isolated species groups. This can result in a higher risk of extinction. Therefore, understanding how species respond to vegetation changes is crucial for helping conservation managers identify and implement appropriate management strategies given these vegetation changes.

We are interested in the brown-eared pheasant due to its unique characteristics, described as follows.

1) As an endangered Phasianidae bird endemic to China [14], the brown-eared pheasant has been listed as a vulnerable (VU) globally threatened species by the International Union for Conservation of Nature (IUCN) as a result of population decline and habitat fragmentation [15]. Among endangered species, this pheasant has one of the highest priorities for conservation in China [16,17].

2) This species is a Montane bird and is sensitive to climate variation [18]. It lives in coniferous and mixed coniferous-broadleaf forests, where it roosts in tall trees at different elevations in different seasons [14]. This bird is active only between the 800 m and 2600 m elevation range [19,20].

3) It has a well-known biology and life history. Its distribution range has historically been wide and continuous [21]. Its current range includes three discontinuous distribution areas (the Shaanxi, Shanxi, and

Hebei provinces, including Beijing) [22,23]. This historically broad distribution range has declined dramatically in the Shanxi province [14]. Meanwhile, forest coverage in this region has declined sharply [24].

In this study, we aimed to (i) analyze the relationship between regional forest cover and the historical distribution of the brown-eared pheasant and (ii) understand its distribution in response to changes in forest cover.

# Materials and methods

## Sources of distribution data

From the early Western Han Dynasty (156 BC) to the late Qing Dynasty (1911 CE), soldiers decorated their hats using the tail feathers of the brown-eared pheasant as symbols of magnificence and might [25]. Brown-eared pheasants were offered as tributes to kings in the Tang (618-907 CE) and the Song (960-1127 CE) Dynasties. Therefore, regions where brown-eared pheasants were found, together with the corresponding date, were recorded in ancient books and local archives. These history books provided the historical distribution data and time data used in this study.

Historical distribution data and dates were obtained from historical literature (51 ancient books, 149 references, and 7 monographs) (see Table A.1 in Supporting Information). Such data are becoming increasingly available from databases, web sites, and museum collections, providing a rich empirical basis for making predictive maps [26]. We aggregated all of the categories of historical distribution data from 25 to 1947 CE to represent the total historical distribution range of this species. This was a reasonable approach because the species is mostly sedentary, with high-site fidelity and limited dispersal ability, features that prevent full re-colonization.

The names and ranges of some counties in the historical literature have changed over time. We avoided errors by collating records of changes from county annals to obtain their present names. Longitude and latitude were considered to reveal geographical trends in species distribution, which are associated with species population dynamics [27]. The spatial analysis "function-identify" of ArcGIS was used to extract the longitude and latitude of the historical location of modern counties [28] on the basis of China's county-level administrative map. By analyzing the habitat, shape, and life habits of the brown-eared pheasant in written descriptions, the changes in vegetation and climate in these counties' records, and combining suitable habitat characteristics of the brown-eared pheasant, we were able to judge the authenticity of the historical records.

The geographical coordinates and data referring to modern occurrences (1948–2000) were obtained from the Site Record Database for Chinese Galliformes, which includes extensive distributional data. The distribution data were collected from a bird database, monographic research, journals, and other literature sources, ornithology monographs published locally and abroad, and specimens in collections at scientific research institutes and universities, all of which were confirmed by expert evaluation [29]. We checked the longitude and latitude of sites with modern occurrences using ArcGIS10.0 (Xi'an 1980 Geographic Coordinate System).

## Environmental variables

The ecological and biogeographical features (habitat requirements, vegetation characteristics, environmental tolerances, and distribution sites, etc.) of the brown-eared pheasant have been well documented [14,19,23,25,30,31]. We selected 13 environmental variables that are believed to influence the distribution of the brown-eared pheasant (Table 1).

Table 1. List of eco-geographic variables.

| Factor | Environmental variables | Unit |
|---|---|---|
| Factor 1 | Vegetation | |
| Factor 2 | Elevation | M |
| Factor 3 | Aspect | (°) |
| Factor 4 | Slope | (°) |
| Factor 5 | Maximum temperature | °C |
| Factor 6 | Minimum temperature | °C |
| Factor 7 | Annual mean temperature | °C |
| Factor 8 | Annual precipitation | mm |
| Factor 9 | Distance to nearest river | km |
| Factor 10 | Distance to nearest road | km |
| Factor 11 | Distance to nearest residential area | km |
| Factor 12 | Land usage | |
| Factor 13 | Gross Domestic Product | ¥ |

Vegetation information was collected from the Chinese vegetation-type spatial distribution map (1:100 0000). Elevation, slope, and aspect were obtained from a spatial distribution map of geomorphic types in China (1:1,000,000), and land use data were collected from a spatial distribution map of land uses in China (1:100,000) (China's land use database 2000). These data sets were provided by the Data Center for Resources and Environmental Sciences (RESDC) of the Chinese Academy of Sciences (http://www.resdc.cn). We also collected data on the proximity of rivers (China Pyatyi river map 1:100,000), roads (China road map 1:100,000), and villages and towns (China county level administrative region map 1:100,000) for each modern site in which brown-eared pheasants have been sighted. For this purpose, we used a geographic information system (GIS) based on maps downloaded from the National Administration of Surveying, Mapping and Geoinformation, National Dynamic Atlas (http://www.webmap.cn/), which were corrected in ArcGIS10.0 [32] using the Xi'an 1980 geographic coordinate system. Meteorological data were obtained from fine-scaled climate data sets (WorldClim) at a spatial resolution of 2.5 arc-minutes for the period of 1950–2000 (see http://

www.worldclim.org). Four climate variables were used as predictors: the annual mean temperature, the maximum temperature of the warmest month, the minimum temperature of the coldest month, and annual precipitation. Gross domestic product (GDP) data for Shaanxi, Shanxi, Hebei, and Beijing in 2000 were obtained from a GDP database of counties and cities in China (http://zh.wikipedia.org/wiki).

We only extracted data for the 13 environmental factors for the current distribution sites and analyzed their effects on the current distribution of the brown-eared pheasant.

GISs are powerful tools for studying the geographical distribution of species, and they are widely used in the management of nature reserves. We used ArcGIS10.0 to analyze the digital maps and investigate the reasons for the reduction of the geographical distribution of the brown-eared pheasant.

Environmental factors 1–12 were unified into 12 digital layers and the resolution was adjusted to agree with meteorological data in ArcGIS10.0 and the Xi'an 1980 geographical coordinate system. Spatial information extraction tools were used to extract habitat factors (*i.e.*, vegetation type, elevation, slope, aspect, highest temperature, lowest temperature, annual mean temperature, annual rainfall, recent distance from a road, recent distance from a river, recent distance from residential areas, and the value of the existing land) from the current distribution points within the 12 digital layers.

The minimum convex polygon method (MCP) is the earliest and most widely used technique for calculating species` home ranges and for comparing data calculation results between different studies [33–36]. MCP has no specific geometric requirements for data space distributions [36], and the sample space correlation does not directly affect the results [37]. In this study, this species' historical and modern range sizes were estimated using a 100% MCP method [38]. The brown-eared pheasant's current distribution is spread across the three areas of Shaanxi, Shanxi, and Hebei-Beijing. We respectively calculated the area of the three distribution areas and used the sum as the current total distribution area. The difference between the historical distribution area and the current distribution area were then compared in ArcGIS10.0 to calculate the shrink back area of the historical distribution of brown-eared pheasants.

## Analysis of environmental variables

We used the Random Forests measure from the R3.0.2 software platform to analyze the importance of the 13 environmental variables and their effect on species distribution. The Mean Decrease Accuracy (MDA) index was used to determine the importance of factors using RF, with larger MDA values indicating greater importance [39].

The historical distribution of the brown-eared pheasant covered all of the Shanxi [14], with Shanxi being the area with the most concentrated distribution of this species, historically and recently. Shanxi was selected as the main study area. Both vegetation and elevation may influence species ranges [40] and are important for explaining species distributions [41]. Shanxi has experienced no major geological upheavals over the past 2,000 years [42]; therefore, its elevation is considered to have remained stable. However, the forest cover has changed substantially according to botanical and ecological data [24].

Consequently, we built a correlative relationship between the presence/absence of brown-eared pheasants and forest coverage in each time period throughout Shanxi to explore forest cover effects on this species. This relationship was analyzed using SPSS19.0. We defined the closest record time of historical distribution point as the cut-off point for occurrence time, the occurrence of the demarcation time as a presence from the last recorded time to 25 CE, and the absence after the demarcation time as the last recorded time to the year 2000. The presence/absence value of the brown-eared pheasant was defined as either 1 or 0, where 1 indicates presence and 0 indicates absence (see Fig. A.1 in Supporting Information). This is considered an effective means by which to estimate the minimum threshold of forest cover necessary for survival of the brown-eared pheasant population.

The data used to describe forest cover in each time period throughout Shanxi (within 25–2000 CE) were collected from monographs [see 24, 42–45] and papers [see 45, 46].

## Modeling approach

SDMs are important tools for predicting species distributions in biogeography, conservation biology, and climate change research [1]. Although there are concerns regarding the reliability of SDMs in forecasting the effects of habitat change related to climate [47], these models can still provide useful information when used carefully [48,49].

Model selection was a pivotal process in choosing the most accurate predictors of the bird's distribution [50]. Due to the limited availability of regional information for determining species distribution areas and the restricted number of environmental variables used in the study of the species' historical distribution, we successfully used a variety of algorithms to model historical biogeographic information, such as MaxEnt, DesktopGarp, and Open-Modeller. The MaxEnt model uses a maximum-entropy approach for modeling species habitats to predict the potential geographic distribution of a species. [51] predicted the nesting habitat distribution of the red-crowned crane using the MaxEnt model. When MaxEnt is used to model a geographical distribution over a certain period of time, the division of time is of great importance in the modeling [28]. We divided the time periods into two groups: 25–1947 CE for the historical period and 1948–2000 CE for the current period.

The MaxEnt model was run with the personality settings for features and regularization. Fifteen replicates were processed; the model was calibrated for each replicate, using a random sample of 75% of the modern distribution data for model training (n = 75). We evaluated this against the remaining 25% for testing (n = 25) randomly generated background points (10,000) within the local range, with a maximum 5,000 times iterations.

The receiver operating characteristic (ROC) is frequently used to test and verify the accuracy of the prediction and the discriminatory power of models [27]. The area under the receiver operating characteristic curve (AUC) score is commonly used to measure the predictive performance of a model [52]. Although some studies have criticized the use of AUC to evaluate model performance [2,53] due to the fact that the AUC value is not affected by a threshold, the evaluation results are fairly objective and are still widely used in the testing of presence-only species distribution modeling [54]. Therefore, we used AUC values to assess the predictive performance of the MaxEnt model.

A larger AUC score indicates a better goodness of fit index (GFI) (usually 1.0 > AUC > 0.5: 1.0 > AUC > 0.9, very good; 0.9 > AUC > 0.8, good; 0.8 > AUC > 0.7, fair; 0.7 > AUC > 0.6, poor; 0.6 > AUC > 0.5, fail) [55]. AUC values above 0.9 are considered to indicate "very good" predictive performance [56]. Generally, AUC values higher than 0.7 are considered to give practicable predictive results [55].

Climate change affects the growth of vegetation [57], which indirectly influences species distribution. The brown-eared pheasant is sensitive to the climatic conditions that influence vegetation. An overall change in climate results in alternating low and high temperatures over a century scale, but temperature changes have been smaller (about 1°C) over the past 2,000 years in China [58,59]. Shanxi is an inland province, with inconspicuous climatic gradients [60]. Therefore, we used Worldclim meteorological data (1950–2000) as our environmental background and historical distribution data (25–1947 CE) in MaxEnt to predict the potential distribution of this species. We compared the predicted potential distribution with the current real distribution in ArcGIS10.0 to verify the historical distribution decrease.

# Results

## Historical distribution of the brown-eared pheasant

There are historical records of brown-eared pheasants occurring in 13 Chinese provinces (Shaanxi, Shanxi, Hebei, Beijing, Henan, Anhui, Hubei, Sichuan, Fujian, Guangdong, Liaoning, Heilongjiang, and Gansu). Our research results determined that the historical distribution range of the brown-eared pheasant has been Shanxi, the east and center of Shaanxi, and the west and center of Hebei, a total area of about 320,000 $km^2$. According to the Site Record Database for Chinese Galliformes, the current distribution area of this species includes Huanglongshan in Shaanxi, the Luliang Mountains in west Shanxi, the XiaoWutai Mountains in Hebei, and parts of the Baihua Mountains in Beijing, and covers only about 46,800 $km^2$ (Fig. 1).

**Figure 1. Changes in the distribution range of the brown-eared pheasant in China.** Labels in the map: N, north; NE, northeast; E, east; SE, southeast; SW, southwest; W, west; NW, northwest; C, central. The background is based on the "spatial distribution map of geomorphic types in China (1:1,000,000)" (Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (RESDC) http://www.resdc.cn).

The distribution area has decreased considerably, with 85% of the original distribution area being lost over the past 2,000 years. The most serious reduction in the historical distribution area has occurred in Shanxi.

## Decrease of forest cover in the Shanxi province

The Random Forests results (Table 2) showed that Factor 2 (elevation MDA = 16.1723629) and Factor 1 (vegetation MDA = 15.3178893) had larger MDA index values than the other 11 factors; Factors 4, 5, 7, and 11 (slope, distance to nearest residential area, maximum temperature, and annual mean temperature) had intermediate index values, while the other seven factors had low index values. Elevation and vegetation were therefore considered to be the main factors affecting the distribution of this species. There has not been any significant change in elevation in Shanxi over the last 2,000 years; therefore, this study only analyzed the influence of vegetation on species distribution.

Table 2. Importance-evaluation of environmental factors by RF.

| Factor | Mean Decrease Accuracy (MDA) |
|---|---|
| Factor 1 | 15.3178893 |
| Factor 2 | 16.1723629 |
| Factor 3 | 0.8026194 |
| Factor 4 | 13.3896091 |
| Factor 5 | 7.7163924 |
| Factor 6 | 2.6618293 |
| Factor 7 | 6.1517868 |
| Factor 8 | 1.1159693 |
| Factor 9 | −0.2180437 |
| Factor 10 | 3.1519641 |
| Factor 11 | 10.4198686 |
| Factor 12 | 3.7342411 |
| Factor 13 | −1.192471 |

Figure 2 shows that the area covered by forests has decreased markedly in Shanxi ($R^2$ = 0.747), with forest coverage declining continuously from the reported 50% in 25 CE to 4.8% in 1948, followed by a recovery to 13.2% by 2000.

**Figure 2. Variation of forest cover throughout the Shanxi province.** The amount of forest coverage in the northern (Datong area), northeastern (Wutai area), central (Taiyuan area), southeastern (Changzhi area), and western (Luliang Mountains) of Shanxi has declined annually ($R^2$ = 0.747). The north and southeast areas have

suffered the most serious declines; however, there is still a relatively high amount of forest coverage in the western part of the Shanxi province.

The forest coverage in the northern (Datong area), northeastern (Wutai area), central (Taiyuan area), southeastern (Changzhi area) and western (Luliang area) regions of Shanxi has declined annually. In all of these regions, forest cover exceeded 10% before the Ming Dynasty (1368 CE), but the northern, northeastern, central, and southeastern regions have declined to 0.6%, 5.0%, 4.5%, and 0.5% forest cover, respectively, over the late Qing Dynasty (1911 CE), followed by a recovery to about 5% by 2000. In addition to the general decline in forested areas, there was a notable sudden decline, likely associated with the Western Jin Dynasty (316 CE), and a decline to 20% in the later period of the Northern Wei Dynasty (534 CE) in northern Shanxi, followed by a recovery back to 60% until the end of the Tang Dynasty (907 CE). The most dramatic changes occurred in northern and southeastern Shanxi, which experienced some of the most serious declines. The forest has remained relatively intact in western Shanxi. The forest cover was maintained at about 10% during the late Qing Dynasty in the Luliang Mountains, which remains the primary distribution area for this species.

Figure 3 indicates that the presence value of the brown-eared pheasant was 1 in all of the districts of the Shanxi province when forest coverage of the historical distribution was greater than 10%, and the max-median of the forest cover was 48%. The value was zero in northern, northeastern, central, and southeastern Shanxi when the forest coverage rates were less than 10%. This species is still present in the western areas where forest coverage rates are over 10%. It is likely that there will be a regional extinction when less than 10% of the forest coverage area remains. Thus, we speculate that 10% forest cover is probably the minimum threshold for maintaining the brown-eared pheasant population, and 48% forest cover is likely to guarantee stable growth in the population and distribution of the brown-eared pheasant.

**Figure 3. Correlative relationship between the presence/absence value of brown-eared pheasants and forest coverage in the Shanxi province.** Brown-eared pheasants appeared in all districts of Shanxi when the forest coverage was greater than 10%, and the max-median of the forest cover was 48%. There has been local extinction in northern, northeastern, central, and southeastern regions when the forest cover rates were less than 10%. The western areas of the province have always occupied the main distribution area of this species due to the fact that forest coverage has remained above 10%.

## MaxEnt model results

The prediction accuracy of the MaxEnt model was AUC = 0.753. Figure 4 shows the prediction probability map for the brown-eared pheasant distribution. The historical distribution of this species covered most of the Shanxi province, whereas its modern distribution has been mainly restricted to the Luliang Mountains. The red areas, which indicate a probability of presence > 0.9, have mainly been concentrated in the panhandle of the western, central, and northern areas of Shanxi. This predicted range mostly overlapped with the true modern distribution. The blue and pink areas, which indicate a probability of presence < 0.7, included the northern, northeastern, eastern, southeastern, and southwestern areas of Shanxi and were all areas that were included in this species' historical distribution range. However, there have not been any new reports of this species in these locations. The prediction results of the potential distribution of the brown-eared pheasant were consistent with historical facts. Our model results support observations of a reduction in the historical distribution of this species.

**Figure 4. Distribution probability map of brown-eared pheasants predicted by the MaxEnt model.** The gray triangles indicate the historical localities of brown-eared pheasants (25–1947 CE). The black points represent the current distribution (1948–2000 CE). Red areas indicate potentially suitable distributions, pink

areas indicate moderately suitable habitat, and blue areas indicate unsuitable habitat. Western Shanxi is the concentrated distribution area of the brown-eared pheasant, the distribution probability is 0.9, and the predicted range overlapped with the current distribution. Northern, northeastern, southeastern, and southwestern regions were all within the historical distribution range. However, these areas are no longer suitable habitats for the brown-eared pheasant.

# Discussion

## The historical distribution range of the Brown eared pheasant

The historical records are very important for understanding the overall distribution of the species, but some records could not be used to assess the species distribution. Furthermore, we doubt the accuracy of some of the records because the climate of the provinces was inappropriate for Brown eared pheasant and for some locations there was only a single isolated record. Thus we deleted these dubious records for acquiring accurate results.

The forest is the divide of the warm temperate deciduous broad-leaved forest, and north subtropical evergreen deciduous and broad-leaved mixed forest zones of the Qinling Mountains [61]. The climate and vegetation conditions of the northern and southern slopes of the Qinling Mountains are different, and representing a transitional zone in the bird's distribution[62]. From the historical vegetation and climate data obtained for south China, we found that the tropical and subtropical climate conditions were stable, with constant luxuriant tropical rain forest and subtropical monsoon forest flora since the Mesozoic[63,64]. These areas did not provide a suitable habitat for the Brown eared pheasant, and the species should therefore not be present south of the Qinling Mountains. This was in accordance with the distribution of *Crossoptilon* in a description of China's zoogeographical regions [65].

Fossils pertaining to Brown eared pheasants have been found in Zhoukoudian in Beijing, although they are very rare[66]. Pleistocene fossils of *Crossoptilon jiai sp. Nov* were found in Zhoukoudian [67]. At the same site, the fossil belt (Early Pleistocene) and occipitalia fossils (Late Pleistocene) were suspected to belong to *Crossoptilon harmani* (Data Source: National Infrastructure of Mineral Rock and Fossil Specimen Resources [68]). *Crossoptilon harmani* is a more primitive species [69,70], and has a distant genetic relationship with the Brown eared pheasant[71,72]. Therefore, we did not consider Zhoukoudian Beijing as the historical distribution of the Brown eared pheasant in this study.

Evolution of the Brown eared pheasant occurred in the Pliocene [72], with adults adapting to resist temperatures of -42℃ [14]. Climate change resulted in drought at the end of the Early Pleistocene in northeast China [73]. The climate contrasted between the ice age and an interglacial period[74]. The distribution of panda retracted during the Pleistocene glaciation in the Zhoukoudian area of Beijing[28]. In Liaoning in the Pleistocene interglacial, the climate was subtropical and tropical, with evergreen broad-leaved and evergreen deciduous broad-leaved forests [75]. The climate fluctuations co-occurred with widespread local species extinction [76]. The environment was not suitable for the Brown eared pheasant in this region because of its history of climate and vegetation changes in northeast China. Furthermore, Brown eared pheasants had never been recorded in northeast China [25]. We did not consider Liaoning (Tieling, Shenyang, and Gaizhou) and Heilongjiang (Heihe) as the historic distribution range of this species.

Huating is located in the southeast of the Liupan Mountains in Gansu and has only one record of Brown eared pheasant. Fengxiang and Longxian in Shaanxi are adjacent to Huating county in Gansu province. These sites are isolated and do not share a consecutive distribution with other locations that have historical records of Brown eared pheasant, but they are close to the distribution area of the Blue eared pheasant. Therefore we considered that the three records from these locations were likely to pertain to Blue eared-pheasant.

We obtained a relatively complete distribution records for the Brown eared pheasant by consulting a large number of historical books. Consequently, we considered that the historical distribution range of the Brown eared pheasant included east and central Shaanxi, Shanxi, and west and central in Hebei, which covered 320,000 $km^2$. This historical distribution range overlapped and encompasses the current distribution.

The current distribution exhibits severe fragmentation [14], with three main areas: a west population in the Huanglongshan in Shaanxi, a midland population in the Luliang Mountains in Shanxi, and an east population in Hebei-Beijing[23]. The current distribution is a discontinuous island [21,22] covering 48,600 $km^2$.

Altogether we concluded that most of the historical area was no longer appropriate for this species; its distribution area was diminished by about 85% from 25 to 2000 CE, Shanxi province losing the largest amount of distribution area.

## The main factors leading to the contraction in the historic distribution

Vegetation determines several habitat factors and can be used as an important habitat index for terrestrial animals [77]. The Brown eared pheasant occurs mainly in coniferous and mixed coniferous-broadleaf forests. The species is mostly vegetarian, eating some insects in the breeding season [14]. The MDA value of 13 environmental factors indicated that vegetation and elevation best explained the distribution of this species

(Table 2). Because elevation has not changed in the past 2,000 years [42], but the vegetation cover has changed substantially in Shanxi [24], we consider that this change in vegetation was responsible for the loss of range area.

Shanxi province is the main distribution area of the Brown eared pheasant, with 62.7% of the total historical distribution area and 91% of the current distribution area. Figure 2 shows that Shanxi had lush forests in the past, with 10-70% forest coverage before the Ming Dynasty (1368 CE), and Brown eared pheasants were abundant. However forest coverage gradually diminished from 50% in 25 CE to 4.8% in 1948. The forests were almost completely destroyed in the Ming and Qing Dynasties[24] . When the forest cover rate of Shanxi dropped to 4% at the end of the Qing Dynasty (1911 CE), no more records of Brown eared pheasant were reported in many area[14,43,44,78].

The Brown eared pheasant probably became locally extinct because of forest destruction in many parts of its former range. For example, the north, northeast, central, and southeast areas of Shanxi were important historical distribution areas of this species. Before the Ming Dynasty (1368 CE), the historical distribution was broad (Fig 1), and forest coverage in these regions exceeded 10% (Fig 2). However, no new records of Brown eared pheasant from these areas were subsequently reported. The forests of west and northwest Shanxi were better preserved than those of other regions[24]. The Luliang Mountains represents the most important current distribution area of Brown eared pheasant in West Shanxi.

The northeast, east, central, southeast, and southern areas were the locations of major battlefields in the history of Shanxi[24], and forests were seriously damaged in these locations (Fig 2). The suitable habitat for the Brown eared pheasant had been drastically reduced as a result of forest destruction associated with historical wars and post-war reconstruction. The forest was very seriously destroyed in the north (Datong area) and southeast (Changzhi area), with forest cover extremely low at the end of the Qing Dynasty[44]. In the central basin (Taiyuan), forest coverage was maximal at 70% in 439 CE, then deforestation and tillage resulted in forest loss subsequent to wars, and the Brown eared pheasant disappeared in Taiyuan during the Qing Dynasty[43]. There were many temples in the northeast (Wutai Mountains), where forests survived the wars for a short time, but these were eventually destroyed[78]. The north, northeast, central, and southeast regions all represent historical distribution areas of the Brown eared pheasant. The bird had not disappeared completely in the southeast (Changzhi), at least in the early Qing Dynasty [14], but it had become locally extinct in the northeast and central areas in the Late Qing Dynasty [43,78]. Due to the long-term impact of human activity on forests in Shanxi, especially the large-scale deforestation and destruction in the Ming and Qing Dynasties, a reduction of forest area ensued [79]. The species could not be found at these historical locations following the disappearance of its required habitat. The forest survived in the west and northwest in Shanxi and in the western Luliang Mountains [24], where the Brown eared pheasant can still be found today.

Forest coverage increased to 13.2% in 2000 in Shanxi, where four national nature reserves were established for the conservation of the species and its habitats: Luyashan Nature Reserve, Pangquanguo Nature Reserve, Wulushan Nature Reserve, and Heichashan Nature Reserve. The populations within these protected areas appear to be stable [15,23].

The Brown eared pheasant requires a suitable forest habitat[14,30], with populations declining and local extinction occurring due to habitat loss. The current distribution area is smaller than the historical distribution. Most of this species` original distribution area has disappeared in the past 2000 years at the same time as the forest cover declined sharply. This indicates that the loss of forest resources was synchronous with the reduction of the distribution range of this species, and forest cover decline was closely related to the contraction in its distribution range.

We consider the lower threshold of forest cover for ensuring this species` survival to be at 10% on the basis of figure3. Therefore, we suggest that to guarantee stable growth in the population and distribution of Brown eared pheasant, forest coverage should be 48% in the natural reserves where the Brown eared pheasant is currently distributed.

## MaxEnt model verification

Fig 4 indicates that the MaxEnt model predicted the distribution probability of the Brown eared pheasant mainly occur in west and central area Shanxi. The actual distribution of this species had been really reduced over the 2,000 years, and concentrated in west area of Shanxi. MaxEnt just generates hypotheses about a species distribution, rather than modeling the actual suitability of potential habitats [80]. Surprisingly, there are some gray triangles that fall into the blue and pink areas, which indicate historical records from areas with a lower than 70% predicted probability of harboring this species. The north, northeast, east, southeast, southwest and central regions of Shanxi all had historical reports of Brown eared pheasant from before the Qing Dynasty, but there have been no current reports from these areas. The homochronous forest cover declined in these areas. It is likely that these areas provided suitable habitats for the Brown eared pheasant in historical times. Nevertheless, the predicted result shows that the western and central regions of Shanxi were suitable for the Brown eared pheasant. The current distribution area is concentrated in the Luliang Mountains in western Shanxi.

The predicted result corresponds largely to the current distribution, and confirms that western Shanxi is the main distribution area for this species. The species distribution is shown as having shrunk in accordance with the historical facts.

Climate affects species distributions through its effect on vegetation. Factors other than temperature (e.g., humidity, land use, or extreme climatic conditions) may influence the predicted results. Furthermore, geographic barriers, climatic history, the evolutionary history of the species [80], and its dispersal ability [81] all are related to species distributions, resulting in predictions of species distributions that may differ from their true distributions. Overall, the results of our study showed that the continued reduction in the distribution range of the Brown eared pheasant had been accompanied by the loss of forest cover in Shanxi. The MaxEnt simulation result also confirmed that the historical distribution of this species had been shrinking.

A clear consistency was found between the loss of forest cover and a reduction in the distribution area of the Brown eared pheasant. The Brown eared pheasant is an endemic mountain forest bird that cannot exist without its forest habitat. Hence, the distribution of the Brown eared pheasant is limited by forest cover. We suggest that the lower threshold of forest cover required for ensuring the survival of the Brown eared pheasant in natural reserves is 10%. We expect the population and distribution of this species to remain stable growth when forest cover is greater than 48% in the conservation areas. Further studies are needed to deepen our understanding of the relationship between regional forest cover and species distribution.

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# Supporting information Captions

S1 Table. Sources of information mentioned in the text for the ancient records of Brown eared pheasant (i.e. 51 ancient books, 149 references, 7 monographs).

S2. Definition of presence-absence of Brown eared pheasants

S3. Aspect setting

S4. Account for MCP method

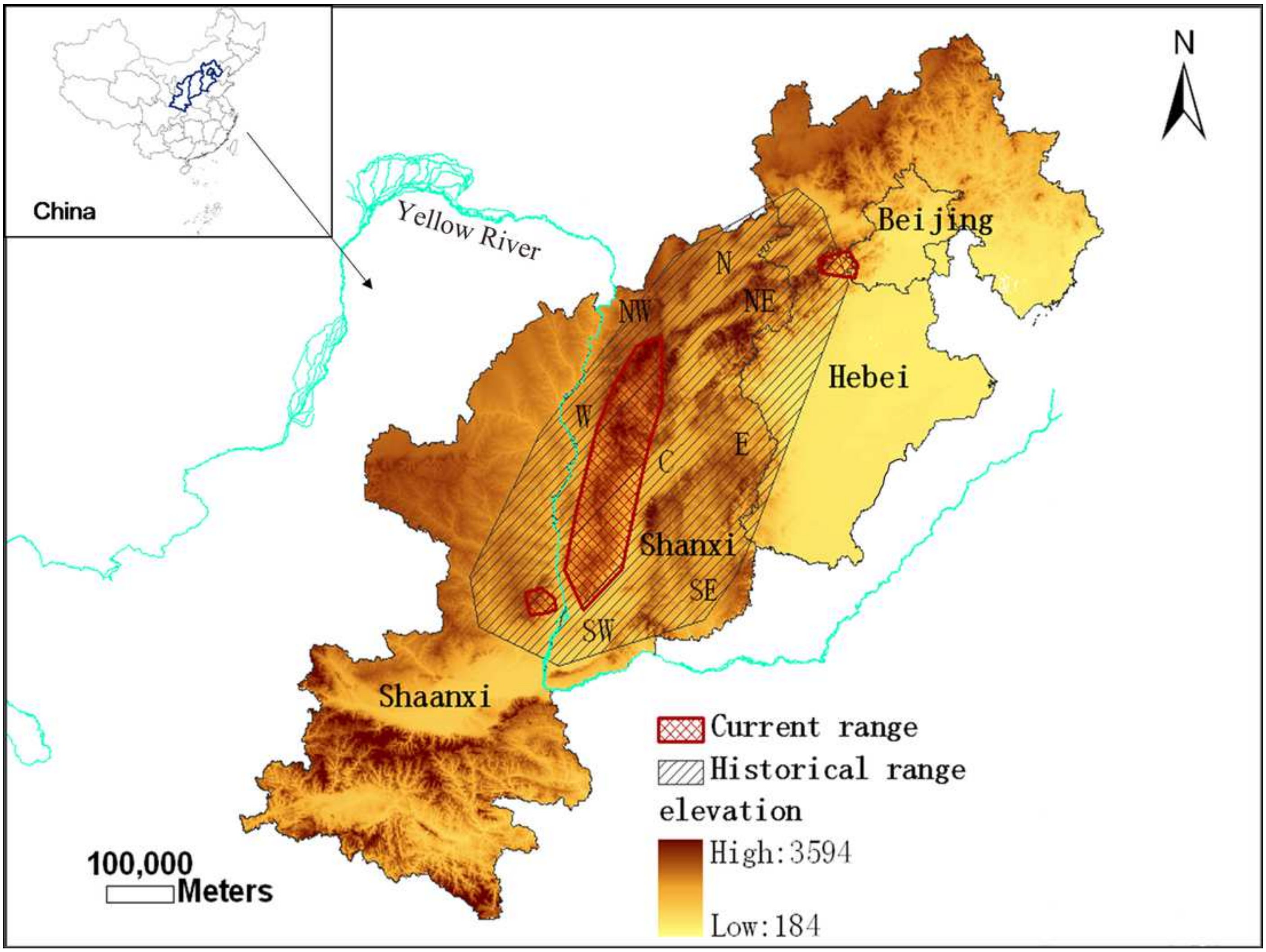
S5. Meteorological data in MaxEnt model

# 1

Changes in the distribution range of the Brown eared pheasant in China

Fig.1 Changes in the distribution range of the Brown eared pheasant in China

Label:N, north; NE, northeast; E, east; SE, southeast; SW, southwest; W, west; NW, northwest; C, central. The background was based on the“spatial distribution map of geomorphic types in China (1:100 0000)” (Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (RESDC) http://www.resdc.cn).

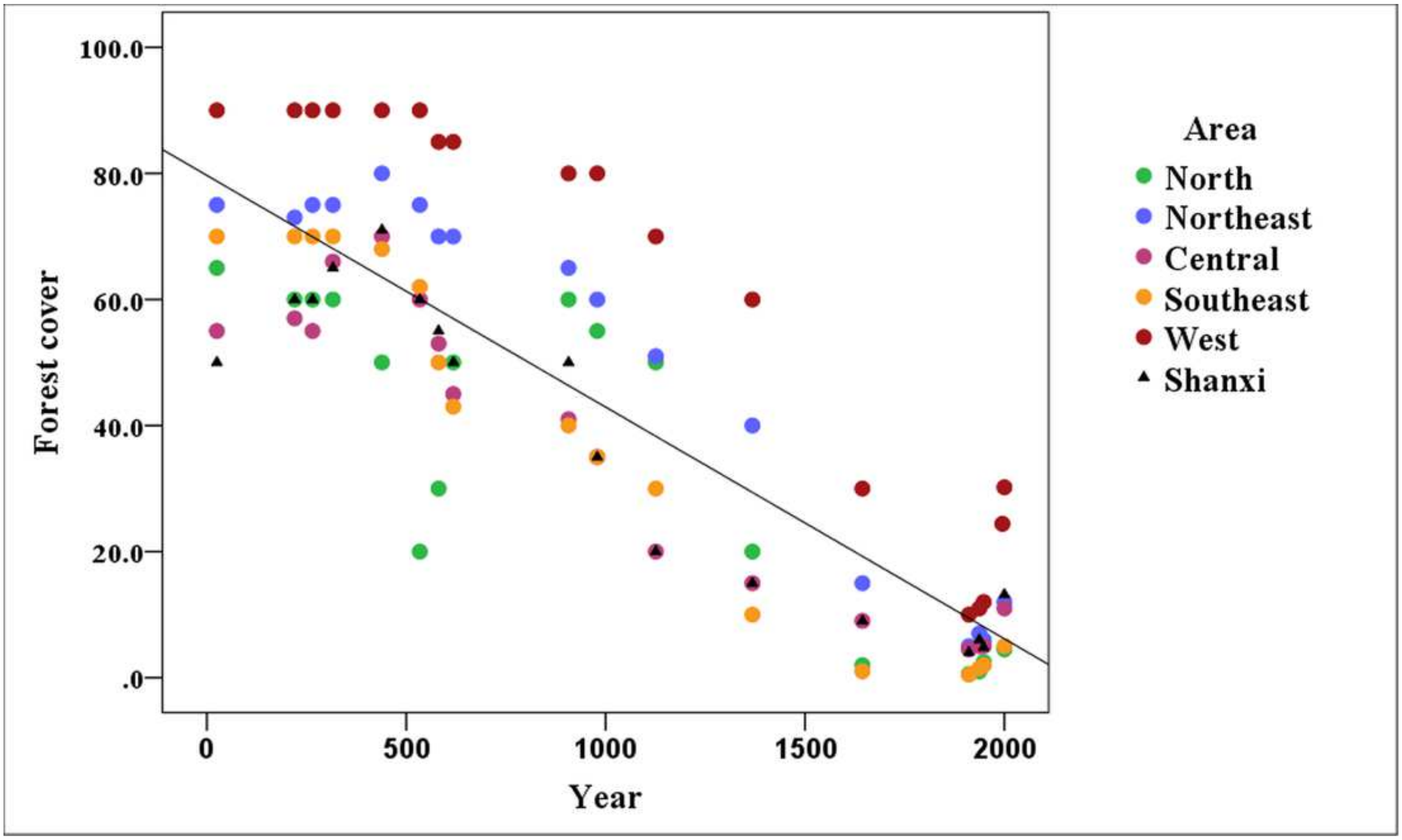


# 2

## Variation tendency of forest cover in all and parts of Shanxi Province

Fig.2 Variation tendency of forest cover in all and parts of Shanxi Province

The forest coverage in north (Datong area), northeast (Wutai area), central (Taiyuan area), southeast (Changzhi area), and west (Luliang Mountains) in Shanxi declined annually (R2=0.747). North and southeast area suffered the most serious declines, however the forest cover still maintain a relatively high level in the west Shanxi.

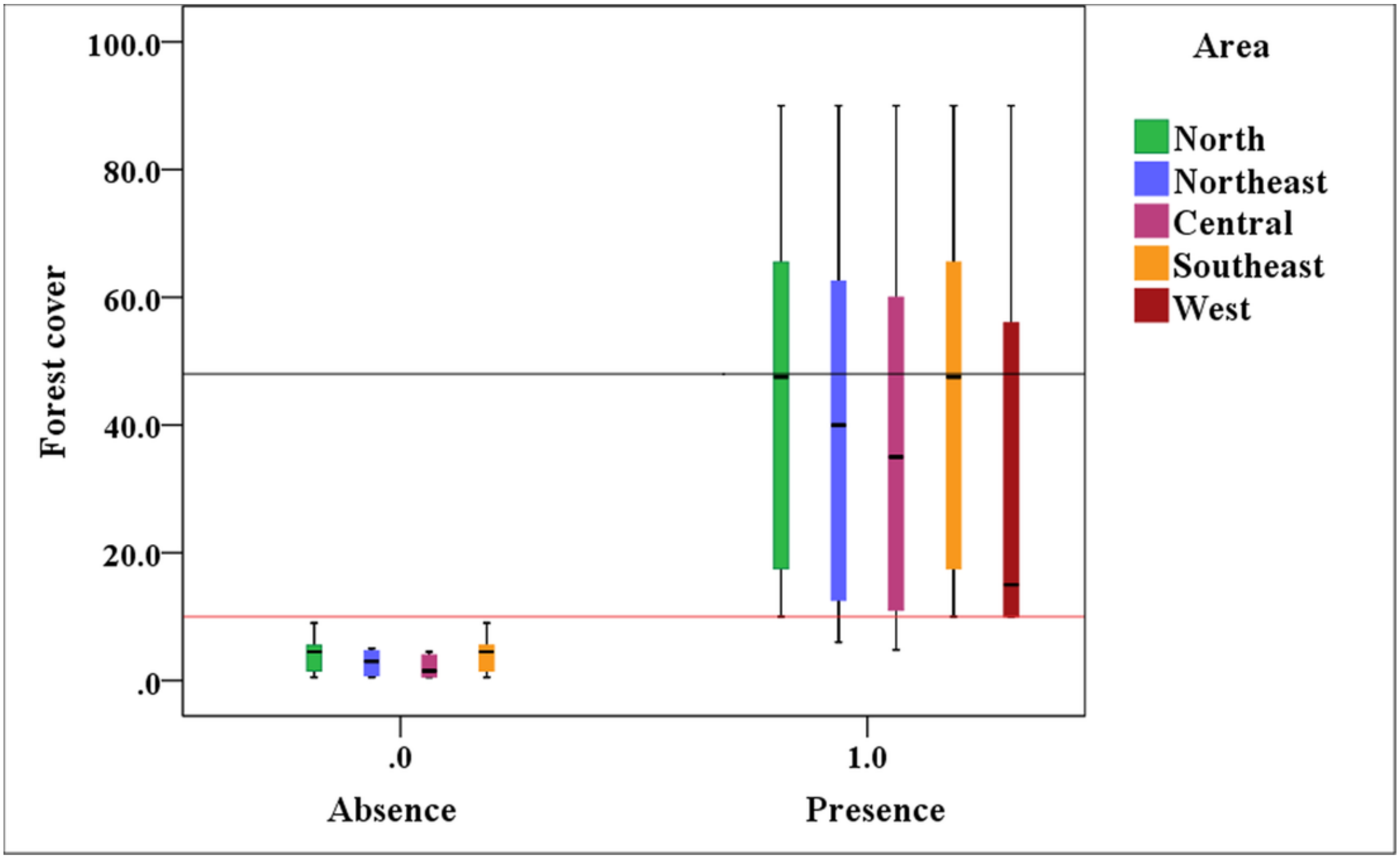


# 3

## The corresponding relationship between the presence-absence value of Brown eared pheasants and forest coverage in Shanxi Province

Fig.3 The corresponding relationship between the presence-absence value of Brown eared pheasants and forest coverage in Shanxi Province.

Brown eared pheasant appeared in all districts of Shanxi, when the forest coverage was greater than 10%, and the max-median of the forest cover was 48%. Its local extinction in north, northeast, central and southeast when the forest cover rates were lesser than 10%. West area always is the main distribution area of this species due to forest coverage stay above 10%.



# 4

Distribution probability map of Brown eared pheasant was predicted by MaxEnt model

Fig.4 Distribution probability map of Brown eared pheasant was predicted by MaxEnt model

The gray triangles indicate the historical localities of Brown eared pheasant between 25-1947 CE. The black points represent current distribution from 1948 to 2000 CE. Red area indicate potential suitable distribution, pink area indicate moderate suitable habitat, blue area indicate unsuitable habitat. West is the concentrated distribution area of Brown eared pheasant, the distribution probability is 0.9, and the predicted range overlapped with the current distribution. North, northeast, southeast, southwest all were historical distribution range. However, there area are no longer suitable for brown eared pheasant habitat.