Land-use and climate change accelerate the loss of habitat and ecological corridor to Reeves's Pheasant (Syrmaticus reevesii) in China

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Abstract

Human activity and climate change are widely considered to be main responsible for Galliformes bird extinction. Due to a decline in population, the Reeves's Pheasant (Syrmaticus reevesii), a member of the Galliformes family, was recently elevated to first-class national protected status in China. However, determining their factor on extinction and provide remedy is challenging owing to the lack of long-term data with high spatial and temporal resolution. Here, based on national field survey we used habitat suitability models and integrated data on geographical environment, road development, land-use and climate change to predict potential changes from 1995 to 2050 in the distribution and connectivity of Reeves's Pheasant habitat. Furthermore, ecological corridors were identified using the Minimum Cumulative Resistance (MCR) model. The priority of building ecological corridors was then determined by combining the ecological source and the network cost-weight importance index. The study results indicate that both intensified land-use and climate change were associated with the increased habitat loss of the Reeves's Pheasant. In more recent decades, road construction and land-use changes have been linked to a rise in local extinction, and future climate change is predicted to cause the habitat to become even more fragmented and lose 89.58% of its total area. The ecological corridor for Reeves's Pheasant will continue to decline by 88.55%. To counteract the negative effects of human activity and climate change on Reeves's Pheasant survivorship, we recommend taking immediate action. This includes bolstering cooperation amongst provincial governments, restoring habitats, and creating ecological corridors amongst important habitat.

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Abstract

Human activity and climate change are widely considered to be main responsible for Galliformes bird extinction. Due to a decline in population, the Reeves's Pheasant (*Syrmaticus reevesii*), a member of the Galliformes family, was recently elevated to first-class national protected status in China. However, determining their factor on extinction and provide remedy is challenging owing to the lack of long-term data with high spatial and temporal resolution. Here, based on national field survey we used habitat suitability models and integrated data on geographical environment, road development, land-use and climate change to predict potential changes from 1995 to 2050 in the distribution and connectivity of Reeves's Pheasant habitat. Furthermore, ecological corridors were identified using the Minimum Cumulative Resistance (MCR) model. The priority of building ecological corridors was then determined by combining the ecological source and the network cost-weight importance index. The study results indicate that both intensified land-use and climate change were associated with the increased habitat loss of the Reeves's Pheasant. In more recent decades, road construction and land-use changes have been linked to a rise in local extinction, and future climate change is predicted to cause the habitat to become even more fragmented and lose 89.58% of its total area. The ecological corridor for Reeves's Pheasant will continue to decline by 88.55%. To counteract the negative effects of human activity and climate change on Reeves's Pheasant survivorship, we recommend taking immediate action. This includes bolstering cooperation amongst provincial governments, restoring habitats, and creating ecological corridors amongst important habitat.

Keywords: Reeves's Pheasant, habitat, ecological corridor, conservation prioritization

Concise cover letter

Reeves’s Pheasant (*Syrmaticus reevesii*, Phasianidae, Galliformes) is endemic to China and is categorized as Vulnerable on the IUCN Red List. It was once widely distributed and relatively common. Because of habitat loss and fragmentation, some populations have been extirpated. In order to address the issue of habitat fragmentation for Reeves's Pheasant, the construction of ecological corridors has been proposed. However, at present the causes of habitat loss and priority areas for ecological corridor building have not been identified. In this work, we leverage a multidisciplinary approach, incorporating expertise from ecology, zoology, and geography, to shed light on the impacts of human activity and climate change on the habitat and ecological corridors of the Reeves's Pheasant. Our findings indicate that the loss of important habitant and ecological corridor of Reeve's Pheasant to change in human activity was significant in three decades, while the local extinction sensitivity to climate change was much significant in past and future, and Guizhou and Shanxi populations are faces highest risk of extinction in future. By unraveling these factors leading to the extinction of the Reeves's Pheasant, our research contributes to the foundational understanding of the priority areas for the restoration of habitat and ecological corridors.Our findings indicate that the loss of important habitant and ecological corridor of Reeve's Pheasant to change in human activity was significant in three decades, while the local extinction sensitivity to climate change was much significant in past and future, and Guizhou and Shanxi populations are faces highest risk of extinction in future.

1. Introduction

Global biodiversity has been declining rapidly since modern times (Rahbek & Colwell, 2011), posing significant threats to natural ecosystems and biodiversity conservation (Hooper et al., 2012). Land-use and climate change are considered to be two primary factors contributing to range shifts and local extinctions of animals in their natural habitat (Dirzo et al., 2014). Applications of various methods to quantitative relationships between local extinction of endangered species and anthropogenic or climatic factors have been important in different periods (Wan et al., 2019). Based on research findings， take different strategies aim to prevent the decline of species' populations and loss of habitat by constructing protected areas (PAs) to safeguard forest ecosystems, biodiversity and cultural resources, creating corridors to enhance opportunities for migration and increase genetic diversity (Pringle, 2017; Wu et al., 2023). However, the challenges associated with protecting and maintaining biodiversity are dynamic, and success must be constantly re-evaluated to ensure that both short-term and long-term changes in the habitat distribution in response to climate and land-use change (Li et al., 2024).

China is one of the countries with the most diverse bird populations, hosting 1445 bird species, 93 of which are found only in China (Zheng, 2017). However, numerous bird habitats have been fragmented or lost due to climate and land-use changes (Ubachs, 2016). Currently, 118 bird species in China are endangered (Jiang et al., 2023). Understanding the factors that led to the extinction of birds at different times and building efficient ecological networks to protect against habitat fragmentation in regional reserves is considered to provide a theoretical foundation and practice basis for conserving bird biodiversity (Huang & Tang 2021; Chen et al., 2024). Ecological corridor can greatly enhance opportunities for bird dispersal and contribute to the preservation of biodiversity (Colyn et al., 2020). At present, three main approaches to constructing ecological corridors were summarized: the graph-based network approach (Minor & Urban, 2008); the minimum cumulative resistance (MCR) model (Liu et al., 2021; Peng et al., 2019); and circuit theory (Peng et al., 2017). However, current approaches to constructing ecological corridors, which consider protected areas or forests as ecological source areas, do not inherently account for the habitat needs of each species (Peng et al., 2019). In addition, they only treat land-use as ecological resistance, leading to simplified resistance surfaces (Peng et al., 2019).

The Galliformes are among the most threatened groups of birds due to direct exploitation for food, habitat loss, and cultural practices (Keane & McGowan 2005). According to Grainger et al. (2018), 27% of species in this group are globally considered threatened. Reeves's Pheasant (*Syrmaticus reevesii*) belongs to the Galliformes, and it is a flagship species for conservation initiatives in certain mountain ranges in Central China where it was previously abundant (Tian et al., 2020). Due to the growing impact of human activities and climate change, the habitat of Reeves's pheasant has become more and more fragmented (Feng et al., 2015). The previously continuous population of Reeves's pheasant has now been fragmented into two isolated geographic subpopulations, which are also patchy and scattered (Zhou et al., 2015). Due to habitat loss and rapid population declines, the species is listed as "Vulnerable" on the IUCN Red List (IUCN, 2020) and as a first-class protected animal in China. In order to address the issue of habitat fragmentation for Reeves's Pheasant, the construction of ecological corridors has been proposed (Han et al., 2022; Lu et al., 2023). However, the specific area for corridor construction has not been determined.

The restoration of habitat success should prioritize historical records and existing locations to ensure that both short-term and long-term changes in the availability of suitable habitat do not decrease in response to current and future human activities and climate change (Banks-Leite et al., 2020; Li et al., 2024). So that the alterations in habitat and ecological corridors for Reeves's pheasant in response to habitat changes require immediate attention. The objectives of this study are to: (1) Assess habitat changes of the Reeves's pheasant in 1995, 2020, and 2050 under different climatic and land-use conditions and identify the main factors affecting habitat change; (2) identify ecological corridors for the Reeves's pheasant in 1995, 2020, and 2050; and (3) screen important areas for the construction of ecological corridors for the Reeves's pheasant.

2. Method

2.1 Species data collection

This study constructed the Reeves's Pheasant distribution database for the two periods of 1995 and 2020 in China, based on field surveys and documentation. Following the approach below, we first excluded counties or municipalities where there was convincing evidence that the species had not been recorded for more than 25 years according the historical distribution of Reeves's Pheasant, current reports, staff of county or municipal forestry bureaus to gather detailed information about Reeves's Pheasant for each county (Zhou et al., 2015; Tian et al., 2022). This approach ensured complete coverage of the habitat area and the feasibility of completing field surveys within the time and budget constraints. We then divided the maps into grid cells of 100 km * 100 km. Last identified 49 counties or municipalities for field surveys and to minimize spatial autocorrelation, ensured that the distance between sites was at least 20 km (F. Dormann et al., 2007; Zhou et al., 2015).

During the breeding season (March to June) of 2018 and 2019, when the birds were easier to identify, we conducted systematic surveys of Reeves's Pheasant in the study area using similar protocols employed by Zhou et al. (2015) in the same area. Line transects of 850–3,600 m in length were randomly distributed within the survey area. A fixed width of 50 m on each side of the line transects was surveyed to assess abundance by direct sightings and indirect evidence (e.g., feathers, nest sites, wing-whirring sounds, etc.) of the presence of Reeves's Pheasant. A total of 219 line transects were surveyed. Excluded occurrence locations within 1 km to avoid pseudo-replication and spatial autocorrelation using R 4.3.1, as the average maximum home range of Reeves's Pheasant measures 1.05 km^2 (Zhou et al., 2017; Tian et al., 2020). A total of 171 occurrence locations were recorded in 2020. The GPS coordinates of all field survey locations were captured with an accuracy of within 10 meters using GPSMAP 60CSX by Garmin Inc.

Reeves's Pheasant data was acquired from GBIF in order to build 1995 occurrence data; only counties and cities with comprehensive historical record previous to 1995 were kept (Zhou et al., 2015). Additionally, current distribution data was overlaid to ensure comprehensive coverage of the Reeves's Pheasant distribution in 1995. As mentioned earlier, we excluded data for distributions within 1 km. A total of 196 occurrence locations were recorded in 1995.

2.2 Data sources and preparation

The data used in this paper are as follows: (1) Temperature and precipitation data of 12 months were downloaded in 1995 and 2020 respectively. Using the ‘biovars’ function in the R package ‘dismo’ (Evans, 2019) in R v4.1.2 (RCoreTeam, 2020), we estimated mean annual temperature (bio1), mean temperature of the warmest quarter (bio10), mean temperature of the coldest quarter (bio11), mean annual precipitation (bio12), precipitation of the driest quarter (bio16) and precipitation of the wettest quarter (bio17) for 1995 and 2020. Bioclimate in 2050 is mean values for the years 2041 to 2060. All of the above bioclimatic data were obtained from the WorldClim (https://worldclim.org/) at a spatial resolution of 30 s. These variables were selected due to their recognized significance in defining climate space for species (Elsen et al., 2020; Asamoah et al., 2021). (2) The 2050 land-use data from the Global PFT-based land projection dataset under SSPs-RCPs, with a spatial resolution of 1 km, the dataset aligns with the latest IPCC coupled socioeconomic and climate change scenario SSP-RCP (Chen et al., 2022), which is consistent with our simulations of future probability of species presence and calculations of future climate change intensity. Land-use data of 1995 and 2020 from the European Space Agency (http://maps.elie.ucl.ac.be/CCI/viewer/), with a spatial resolution of 300 m, in ArcGIS 10.7. The land-use data was reclassified to conform to the 2050 land-use categorization units. (3) We used 1995 and 2020 road data obtained from the Resource and Environment Science Data Centre of the Chinese Academy of Sciences (https://www.resdc.cn/). (4) Additionally, we utilized the digital elevation model from the Chinese Academy of Sciences Resource Environmental Data Center (https://www.resdc.cn), which has a spatial resolution of 300m. After conducting multiple experiments, we adjusted the resolution of these raster data to 300 m * 300 m.

2.3 Habitat identification

To reduce the uncertainty associated with predictions based on a single model and increase the effectiveness of conservation efforts, we adopted the ensemble modeling approach based on multi-model predictions (Jones-Farrand et al., 2011) for the occurrence and suitable habitat. Use the 2020

Reeves's Pheasant occurrence data to identify habitat areas for 2020 and 2050. This can help reflect the spatial distribution changes of the Reeves's Pheasant in response to varying degrees of land-use and climate.

We used the 'dismo' package for species distribution modeling in R version 4.3.2. Three modeling algorithms, including additive models (GAMs), and two machine learning methods (random forest [RF] and maximum entropy [MaxEnt]), were selected because they have been reported to exhibit high performance in species distribution assessments(Razgour et al., 2019; Hu et al., 2022). Then, we used true skill statistics and the values of the area under a receiver operating characteristic curve (AUC) to calibrate and validate the robustness of the evaluation using the three models (Mi et al., 2023). The values ranged from 0.5 to 1, with over 0.8 implying high levels of model prediction accuracy (Zhang et al., 2018). In the habitat identification Reeves's s Pheasant, this study randomly 75% of the records from the observed dataset as the training set 25% as the test set. We calculated the weights for the predictions from each model based on its AUC score by subtracting 0.5 (the random expectation) and then squaring the result. This approach provided additional weight to the models with higher AUC values (Tian et al., 2022).

2.4 Quantifying changes in habitat connectivity

Habitat connectivity is a major concern for the survival of wildlife populations and the risk of extinction (Kramer-Schadt et al., 2004). The integral index of connectivity (IIC) and probability of connectivity (PC) were calculated based on the estimated dispersal distance (Eqs. (1) and (2) are used to evaluate the habitat connectivity between two randomly selected patches from the entire fragmented landscape (Pascual-Hortal & Saura, 2006; Saura & Pascual-Hortal, 2007).

$$IIC = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} a_i a_j/(1+nl_{ij})}{A_L^2}\ , 0 < IIC < 1 \quad (1)$$

$$PC = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} a_i \times a_j \times P_{ij}/(1+nl_{ij})}{A_L^2}, 0 < PC < 1 \quad (2)$$

where n is the total number of ecological patches; ai represents the area of patch i; nl_{ij} denotes the number of links in the shortest path (topological distance) between patches i and j; p_{ij} is the maximum product probability of all paths between patches i and j; and A_L is the total landscape area. In this study, two dispersal distances (500, 1000 m) were selected, as they covered a wide range of species of Reeves's Pheasant (Tian et al., 2022). All of these indices were calculated for the two selected dispersal distances.

2.5 Ecological corridor identification

2.5.1 ecological source identification

In this study, we used the Morphological Spatial Pattern Analysis (MSPA) segmentation method, which is integrated into the Guidos Tool Box (Vogt & Riitters, 2017) developed by the European Commission Joint Research Centre (JRC), to identify core areas in the habitat raster. The MSPA classification routine begins by identifying core areas, using user-defined rules to determine connectivity and edge width. We used habitat as the foreground and non-habitat as the background, setting the landscape width at the edge of one image element and using 8 neighborhood connectivity to identify core areas (Li et al., 2024). Studies have shown that a green space area threshold of 35 km^2 is important in supporting the survival of Reeves's Pheasant population (Tian et al., 2022). The index was used to exclude core area patches smaller than 35 km^2 and to identify the remaining core areas as potential habitat patches.

2.5.2 Ecological resistance surface construction

The resistance surface reflects the level of resistance and landscape heterogeneity that impact species movement. For this study, an ensemble modeling approach based on multiple models was used to calculate the spatial distribution of habitat quality. Then we invert the habitat quality in ArcGis 10.7 to obtain the resistance surface. This approach also prevents the resistance surface from being in binary states and avoids simplification of resistance surfaces due to consideration of land-use types only (Gao et al., 2023).

2.5.3 Construction of corridor systems under different scenarios

After identifying the source sites and resistance values using the species distribution model, we established ecological corridors between the core patches based on the minimum cumulative resistance (MCR) model (McRae et al., 2012) and circuit theory (McRae et al., 2008). We used Linkage Mapper and Circuitscape to jointly model these as corridors.

Linkage Mapper is designed to support regional analyses of wildlife habitat connectivity. It is used to identify the source site vector patches and resistance surface raster in order to map the least costly linkage paths between the source sites. We set a default cost-weighted distance limit threshold of 200,00 to avoid calculations between patches that are overly distant (Colyn et al., 2020).

2.6 Extraction of important ecological source and important corridor

One of the study's objectives was to identify priority areas of history and current for potential habitat restoration and to connect individual populations of Reeve's Pheasants population increase through construction ecological corridors. In this study, we identify critical ecological sources that significantly impact the transfer of material and energy within a network, with betweenness centrality increasing in a pairwise manner. The importance of individual patches (dPC) (Eqs.3) is significant. The dPC to maintain overall connectivity was evaluated according to Saura and Pascual-Hortal (2007), using the following formula:

$$dPC = \frac{PC - PC'}{PC} \times 100\%, \qquad 0 < dPC < 1 \;\; (3)$$

Where PC and PC' represent the values of the 'Probability of Connectivity' index when an individual patch is present (PC) and when it is removed (PC') from the studied landscape. The connectivity and important source of the Reeves's Pheasant were determined using Conefor Sensinode 2.2 (Saura & Torné, 2009).

The significant corridors identified by the Linkage Pathways Tool in the LM function as edges in the topological network structure. The ecological corridor is weighted by the standardized cost-weighted distance, indicating the varying strength of interactions between nodes and revealing the differing transmission capacities of ecological corridors within ecological networks (Gao et al., 2023). Finally, priority corridor construction areas were identified based on the distribution of critical ecological resources and important corridors.

3. Results

3.1 Habitat patches connectivity and proportion within and outside PAs

After conducting the Jackknife test on the Species Distribution Model (SDM) results for Reeve's Pheasant, we kept the results with high prediction model accuracy (AUC > 0.85). The AUC values of each SDM were greater than 0.85, indicating strong predictive capability. We found that the current habitat distribution of Reeves's Pheasant in China is affected by land-use (contribution of 31.9 %), while the habitat distribution in 1995 and 2050 is affected by bio 12 (contribution of 33.7 % ± 1.1 %) (Fig. 1). Considering the synergistic effect of climate and land-use change, area of suitable habitat decreased by 89.58 % from 1995 to 2050. It reached a peak of 91,571 km^2 in 1995 and then dropped to 15, 436 km^2 in 2020, and further decreased to 10, 002 km^2 in 2050 (Fig. 2).

Both the probability of connectivity (PC) and the index of connectivity (IIC) decreased as dispersal distance increased from 500 to 1000 m (Table 2). This indicates an overall decrease in landscape connectivity under conditions of land-use and climate change from 1995 to 2050.

3.2 Results of corridor construction

According to the MSPA classification results of ecological sources in 1995, there were a total of 121 Reeve's Pheasant ecological sources in China, covering a total area of about 72,831 km^2. The 332 ecological corridors formed a complex network connecting the southwestern, northwestern, and central parts of the Reeve's Pheasant habitat in China. The ecological corridors have an average length of 5467 m (ranging from 9.82 m to 61289 m) (Fig. 3 a). The average current density of ecological corridors was low.

In 2020, there were a total of 21 ecological sources for the Reeve's Pheasant in China, covering a combined area of approximately 13,239.80 km^2, and 55 ecological corridors identified. The ecological corridors have an average length of 41,615 m (ranging from 35 m to 272,884 m). The 2020 ecological corridor is essentially divided into three isolated regions located mainly in central China, a small portion locate in southwestern and the northwestern region (Fig. 3b).

There was a total of 16 ecological source for Reeve's Pheasant in China in 2050, covering a combined area of approximately 8325.80 km^2. To 2050, there will be only 38 ecological corridors in China. There are ecological corridors with an average length of 5263 m (ranging from 65 m to 27057 m) (Fig. 3c). The ecological source and corridor are only located in the central part of China.

3.3 Extraction of critical ecological sources and important ecological corridor

Based on the dPC of individual patches and corridor cost-weight distance, this study reclassified the data into four ranks of corridor and patches (0–25%, 25–50%, 50–75%, >75%) (Fig. 3 d, e, f). Five, four and three habitat patches contributed significantly to Reeve's Pheasants habitat connectivity in 1995, 2020 and 2050, respectively (Fig. 3 d, e, f). Based on the cost distance of each corridor, 24, 18 and 8 of important corridors made significant contributions in 1995 and 2020, 2050 respectively (Fig. 3 d, e, f).

As existing and potential habitat restoration areas, this study analyzed critical habitat restoration areas and corridor construction areas for Reeve's Pheasant in 1995 and 2020 (Fig. 3). According to the important habitat and ecological corridor distribution status of the Reeve's Pheasant in 2020, it can be planned as four areas in Guizhou and Shaanxi Provinces, the synergistic management area in Henan and Anhui Provinces, and Hubei Province (Fig. 4 a, b, c, d). In addition to this, the northern part of Guizhou Province, the northwestern part of Hunan Province, and the northern part of Chongqing City, which are historically important habitat distribution areas, can be used as potential restoration areas for the Reeve's Pheasant habitat (Fig. 4 a, b, c, d).

4. Discussion

4.1 Impacts of land-use and climate change

It is widely known that the main direct drivers of biodiversity loss are habitat transformation (i.e., conversion to agriculture), climate change, and overexploitation (e.g., hunting) (Banks-Leite et al., 2020). More than 70% of the surviving forest is currently located less than one kilometer from the edge of a non-forest ecosystem, according to earlier research that suggested both global warming and cooling could result in animal range shifts and local extinction (Li et al., 2018; Banks-Leite et al., 2020). Reeves's Pheasant, a forest-dwelling Galliformes species (Zheng, 2017). This study indicated that both land-use and climate change were associated with increased local extinction of the Reeve's Pheasant during 1995 to 2050. The habitat of Reeve's Pheasants declined significantly between 1995 and 2020, losing around half of it, and declining even more by 89.58 % by 2050, according to this study.

During the past three decades, China has experienced a rapid increase in population, as well as industrialization and urbanization, and other land-use changes at the local scale, thus imposing great pressure on animal (Wan et al., 2019). High land-use change not only destroyed habitats of animals via increasing cropland coverage and deforestation but also poached. It is important to stress that unlawful hunting and habitat destruction have caused the Reeves's Pheasant's effective population size to decline by roughly 20% annually over the past few decades (Zhou et al., 2017; Han et al., 2022). This study provides quantitative evidence of land-use change due to human interference driving local extinction of Reeve's Pheasant. In recent decades, anthropogenic interference was larger positively associated with local extinction of Reeve's Pheasant compared to climate and environmental change (Fig. 1).

The local extinction sensitivity of Reeve's Pheasant to change in land-use was significant in 1995 to 2020, while the local extinction sensitivity to climate change was much significant in prior to 1995 and 2020 to 2050. This maybe mean that Reeve's Pheasant survival depends on specific topographical factors, such as altitude and slope and other broad-scale climatic factors (such as temperature and rainfall) in the past (Xu et al., 2007; Zhou et al., 2017). Following significant human disturbance, Reeve's Pheasants are primarily found in fragmented landscapes with little landscape connectedness, providing little chance for gene flow between subpopulations (Tian et al., 2020; Lu et al., 2023). Even with efforts to minimize land-use change and climate change, the research indicates that in response to extreme weather events and rising temperatures, habitat fragmentation and area and connectivity may increase further due to climate change. Therefore, the Reeve's Pheasant in severely fragmented landscapes continues to be at high risk of extinction in the absence of improving habitat connectivity.

4.2 Implication for conservation

Current human disturbances have consistently and global climate change was associated with increased local extinction of Galliformes (Liu et al., 2023). In this study, we assessed the change of ecological corridor and ecological source of Reeve's Pheasant and estimated their importance to landscape connective. The results derived from the study should have important implications for the conservation of Reeve's Pheasant and elsewhere. Our study revealed that solutions to the Reeve's Pheasant extinction crisis in China require a dedicated national effort designed to restore native habitat and the immediate construction of natural and human made corridors to connect isolated species subpopulations (Fig. 4).

Ecological corridors composed of sources and corridors are considered a sustainable landscape pattern that serves as an effective spatial pathway to maintain regional ecological security and promote sustainable development (Tang et al., 2023). The ability to maintain a viable population of native forest species, promote the long-distance movement of those species as stepping stones, thus reducing their potential isolation, is a reflection of the importance of ecological sources (Han et al., 2022). To protect important sources could reduce movement risks across the landscape (Almeida-Gomes & Lindenmayer 2018; Le Roux et al., 2018), increases ecological connectivity, and allows species to colonize new suitable areas (Herrera et al., 2017; Saura et al., 2014). Prioritizing habitat restoration for species involves constructing ecological corridors within their existing or historical importance source areas (Banks-Leite et al., 2020). This study analyzed importance habitat for Reeve's Pheasant habitat in 1995, 2020 and 2050, revealed that the habitats in Guizhou and Shanxi Province are critical and endangered ecological sources. The ecological sources in Henan and Anhui Province are critical and stable, providing a refuge for Reeve's Pheasant habitat and ecological security under changing climate and land-use conditions (Fig. 4).

The number of ecological corridors for Reeve's Pheasants decreased with habitat loss, while the increase in length of ecological corridors has increased since 1995. This would result in the loss of core breeding and/or foraging habitats, while additionally impacting on genetic diversity and population integrity through habitat fragmentation (Jones-Farrand et al., 2011). However, the unweighted complex networks assume that all corridors are equally accessible, which does not reflect the true topological relationships (Gao et al., 2023). In this study, we assigned weights to edges based on the cost-weight distances derived from resistance surfaces on corridors. This was done to demonstrate the significant impact of weight on the network and to reflect the difference between weighted and unweighted networks (Fig. 4). Screening one and two important ecological corridors based on the distribution of critical ecological sources and ecological corridor cost-weight in Guizhou and Shaanxi province, respectively. To prevent fragmentation and manage the area under a standardized regime, it is suggested that the concentration of critical sources and important corridors in Henan and Anhui should be integrated. Therefore, the protection of Reeve's Pheasant habitat and the construction of ecological corridors also depend on the coordination and cooperation among provincial governments.

4.3 Limitation of this study

Our study provides insights into the reason of historical extinctions of Reeve's Pheasants and should have important conservation implications. However, due to the precision limitation of our historical data and various environmental elements (e.g., uncertainty of historical records, biased recording efforts in space and time, and land-use or climate resolutions) conclusions should be cautiously interpreted. In addition, this study proposes a model for constructing ecological corridors for Reeve's Pheasants, which can be adapted to assess individual Galliformes birds. This approach allows for the differentiated modeling of each ecological corridor and the identification of important habitat conservation and construction areas. Unfortunately, we are unable to include information on dispersal abilities and preferences among different habitats in the assessments due to the unavailability of information on dispersal abilities for Reeve's Pheasant. Understanding the ecological habits of species will enhance the accuracy of ecological networks (Xu et al., 2023). Second, as many scholars have pointed out, the construction of ecological corridors depends on various factors such as environmental conditions, habitat heterogeneity, population density, economic development, and resource availability (Dai et al., 2021; Abrahms et al., 2021). Therefore, interdisciplinary research that combines geography, ecology, economics, and movement ecology is needed.

AUTHOR CONTRIBUTION

Jiliang Xu conceived the ideas and designed methodology; *Junqin Hua* and *Tin Jin* collected the data; *Zhengxiao Liu* and *Yating Liu* analysed the data; *Qingqing He* and *Shan Tian* led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflict of interest to declare.

DATA AVAILABILITY STATEMENT

Data are available in supplementary material.

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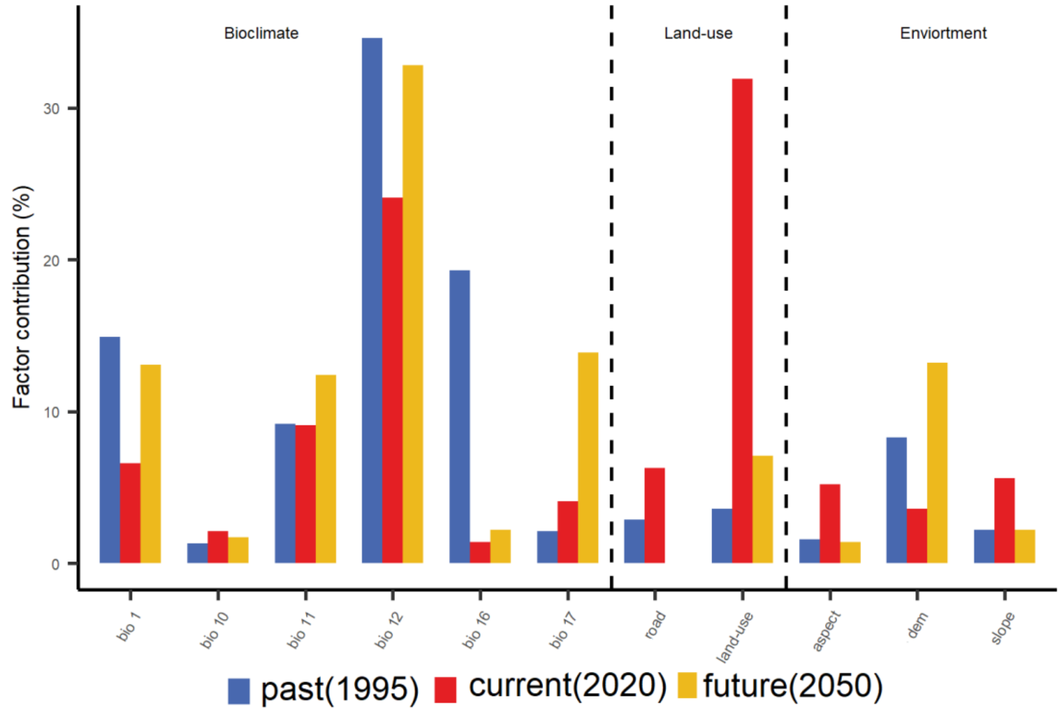
Table 1 Probability of connectivity index PC and IIC normalized for the two dispersal distances (500 and 10 000 m) selected in this study.

Dispersal distance (m)	PC			IIC		
	1990	2020	2050	1990	2020	2050
500	91	21	23	90	27	31
1000	92	43	48	92	49	51

543 

544 Fig.1 Percentage contribution of different type factors to suitable habitat for Reeve's Pheasants in

545 the past (1995), present (2020) and future (2050).

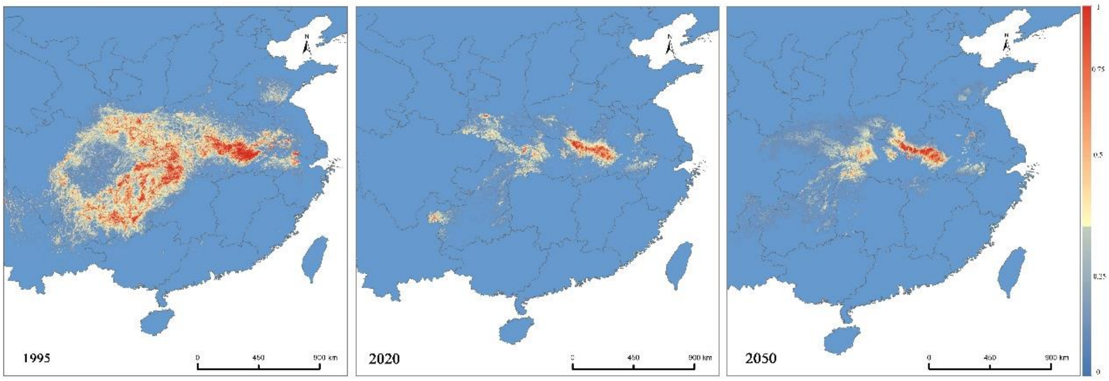


Fig. 2. Spatial distribution of the Reeve's Pheasants habitat

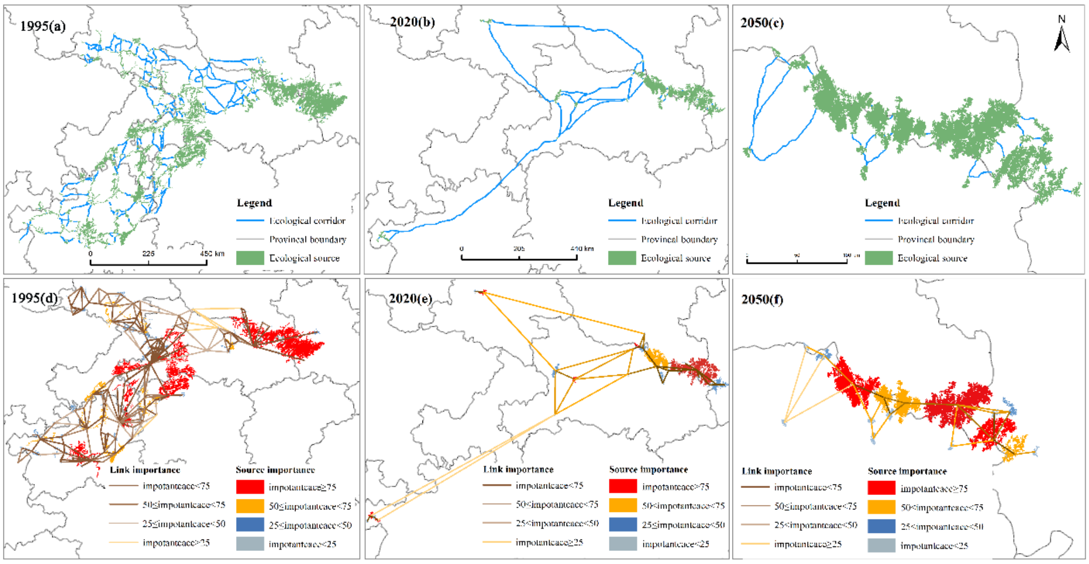


Fig. 3. a, b , c : Spatial distribution of the 1995, 2020, 2050 Reeve's Pheasants ecological corridor; d, e, f: Complex networks of 1995、2020 and 2050 (The color of the ecological source is determined by their importance, The color depth of the corridor is determined by the cost-weight of ecological corridor).

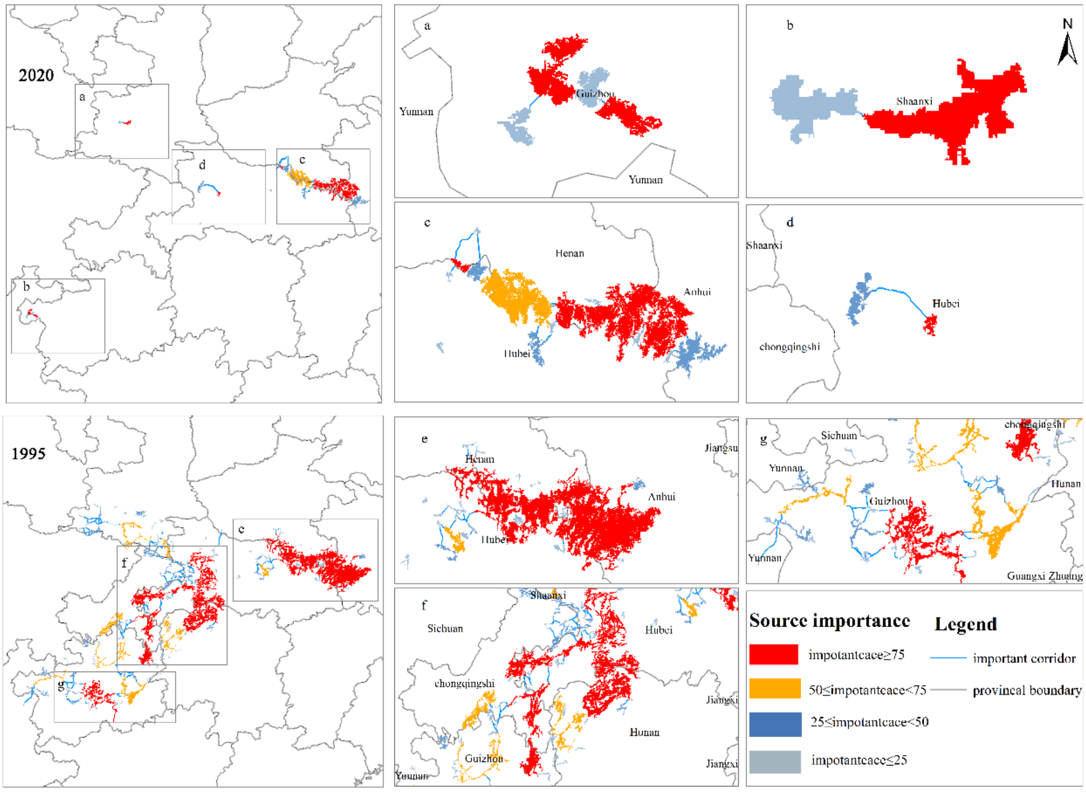


Fig. 4. Importance ecological sources and ecological corridors. a, b, c, d: Current (2020) areas of important habitat restoration and ecological corridor construction for Reeve's Pheasants; e, f, g: Historic (1995) Reeve's Pheasants potential habitat restoration and ecological corridor construction area.