

# Integrating habitat suitability modelling and assessment of the conservation gaps of nature reserves for the threatened Reeves's Pheasant

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## Summary

As threats to biodiversity proliferate, establishment and expansion of protected areas have increasingly been advocated in recent decades. In establishing a network of protected areas, recurrent assessments of the biodiversity conservation actually afforded by these areas is required. Gap analysis has been useful to evaluate the sufficiency and performance of protected areas. We surveyed Reeves's Pheasant *Syrnaticus reevesii* populations in 2018–2019 across its distribution range in central China to quantify the distribution of habitat suitable for this species. Our goal was to ascertain the current distribution of Reeves's Pheasant and then identify the gaps in protecting Reeves's Pheasant of the existing national nature reserve (NNR) network to provide suggestions for improving the conservation of this important species. The existing NNR network encompassed only 17.0% of the habitat suitable for Reeves's Pheasant. Based on the current distributions of both suitable habitat and NNRs for Reeves's Pheasant, we suggest most currently unprotected areas comprised moderately suitable habitat for species and should be prioritized in the future. A multiple species approach using Reeves's Pheasant as a flagship species should be considered to understand the extent of mismatch between the distributions of protected areas and suitable habitat to improve the management effectiveness of NNRs. This case study provides an example of how the development of a conservation reserve network may be based on species distribution and habitat assessments and is useful to conservation efforts in other regions and for other species.

**Keywords:** Gap analysis, *Syrnaticus reevesii*, National nature reserves, Suitable habitat

## Introduction

A common metric of conservation effort is the size and number of protected areas (Pack *et al.* 2016), which are critical to sustaining natural ecosystems in the context of expanding human impact (Ahmadi *et al.* 2020), and provide important benefits by conserving biodiversity and maintaining ecosystem services (Andam *et al.* 2008, Ma *et al.* 2009, Schreckenberg *et al.* 2016, Ma *et al.* 2019). Although covering only 15% of Earth's terrestrial area (Visconti *et al.* 2019), the global protection network has expanded rapidly over the past decade (Ahmadi *et al.* 2020). Among nations, China has some of the highest climatic and ecological diversity (Ren *et al.* 2015). To protect this diversity, China has established a network of strictly managed nature reserves (Wu *et al.* 2011, Ma *et al.* 2019). By the end of 2019, China contained 2,750 nature reserves covering a total area of 1.47 million km<sup>2</sup> (Xu *et al.* 2019), which is equivalent to 66% of the overall forest cover in China (NFGA 2020). However, there are still gaps in the coverage of protected areas for biodiversity, as the mismatches between habitat needs of species and availability often occur, and many species are not assured of long-term persistence within the existing 'man-made boundary' of a protected area (Newmark 1996, Jenkins *et al.* 2013).

One method commonly used in conservation biology for identifying gaps in conservation lands (e.g. nature reserves) where target species and their habitat or important ecological features occur is known as gap analysis (Jennings 2000). Gap analysis is often based on assessments of species' habitat needs, determinations of their potential range and subsequent analysis of the adequacy of existing protection networks (Ahmadi *et al.* 2020). Gap analysis can be used to identify habitats not well represented in existing protected areas for a species (Yip *et al.* 2004), and it has been used to assess conservation status in light of landscape changes, habitat loss, and climate change (Sharafi *et al.* 2012), thus informing decision makers about land management priorities. Studies have also employed it to evaluate the representation of species (De Klerk *et al.* 2004), habitats or vegetation cover (Maiorano *et al.* 2006, Cano *et al.* 2014), and biomes and ecoregions (Franco *et al.* 2007, Sharafi *et al.* 2012) in protected areas.

Reeves's Pheasant *Syrnaticus reevesii*, a forest-dwelling Galliformes species (Zheng 2017), is listed as 'Vulnerable' on the IUCN Red List (IUCN 2018). As a nationally protected species in China, it is a flagship species for conservation initiatives in some of the mountain ranges in Central China where it was once widely distributed (Cheng *et al.* 1978). Reeves's Pheasants are sensitive to environmental changes, and their survival depends on specific topographical factors, such as altitude and slope (Xu *et al.* 2007, Zhou *et al.* 2017). The species is also strongly affected by land cover and other broad-scale climatic factors (such as temperature and rainfall). Human disturbance is one of the most important factors causing the population decline of Reeves's Pheasant (Zheng 2015, Zhou *et al.* 2017, Tian *et al.* 2020). In the 1990s, illegal hunting was a factor that caused the direct decline in the population of Reeves's Pheasant (Zheng 2015). Also, eggs are harvested, and chicks, sometimes even adults, are captured to meet the demand for recruits for some zoos or breeding centres, which could directly cause a population decline and decrease in reproductive rate (CITES 2019). In addition, poison baits used by farmers to protect their crops cause additional mortalities of this pheasant (Zhou *et al.* 2015).

Owing to illegal hunting, habitat loss and fragmentation (MacKinnon *et al.* 1996, Zheng and Wang 1998), Reeves's Pheasant populations have decreased dramatically, and its distribution has been divided into two geographical parts (Zhou *et al.* 2015). The effective population size of Reeves's Pheasant has decreased about 99% over the last thousand years (Chang *et al.* 2011, CITES 2019). An investigation in Taibai County in Qinling Mountains in Shaanxi showed that the population density in the breeding season has a tendency to decrease: 6.1 birds / km<sup>2</sup> in 1983, 3.5 birds / km<sup>2</sup> in 1985, and 2.6 birds / km<sup>2</sup> in 2001–2002 (CITES 2019). According to the report of the *First National Terrestrial Wildlife Resource Survey* published in 2009, there were about 23,000 Reeves's Pheasants remaining in the wild in China. However, the surveys in 89 historical distribution sites from 2011 to 2012 found that the pheasant has disappeared from 46% of the surveyed sites and populations decline in 46 sites, and the population densities in protected areas in 2011

were significantly lower compared to those in 2003–2005 (Zhou *et al.* 2015). Moreover, the estimation made by the IUCN was only 3,500–15,000 in 2018 (IUCN 2018). Due to the decrease in abundance, Reeves's Pheasant was recently listed in Appendix II of CITES (CITES 2019) and upgraded as a first class national protected animal (NFGA 2021b).

The central and provincial governments have assigned great importance to the conservation of this species and established more than 60 national nature reserves (NNRs) specifically for its conservation, as the species is endemic to China and it is closely related to some traditional cultures of the country. However, the Reeves's Pheasant population continues to decline at a rate of about 20% per decade, and its range is also shrinking dramatically even within nature reserves (Zhou *et al.* 2015, 2017). In reality, the distribution, population size, and survival of this species likely reflect the quality of the forests they inhabit (Zhang *et al.* 2003), and it is critical to assess the nature reserves, especially the NNRs that may be important for the conservation of this species. Therefore, this study aimed to: 1) characterize the current distribution of Reeves's Pheasant; 2) identify gaps in protecting Reeves's Pheasant in the NNR network as the representation of existing protected areas; and 3) provide suggestions for the management of nature reserves for Reeves's Pheasant and species or locations with similar conservation needs.

## Methods

### *Study area and data collection*

Using data on the historical distribution of Reeves's Pheasant, current reports, and interviews with the personnel of provincial forestry departments responsible for wildlife conservation and management, we established a rough outline of the species' distribution in China. After 1980, Reeves's Pheasants have been documented in Anhui, Chongqing, Gansu, Guizhou, Henan, Hubei, Hunan, Shaanxi, Sichuan and Yunnan provinces or municipalities (Wu *et al.* 1994, Zheng 2015). We excluded Yunnan and Gansu province from our study as there were no reports of Reeves's Pheasant from these two provinces in the last 30 years (Zhou *et al.* 2015). Therefore, eight provinces or municipalities were included in this study, covering an area of 741,104 km<sup>2</sup> and encompassing a total of 233 counties and cities (Figure 1).

We divided the study area into grid cells of 100 km × 100 km, which ensured complete coverage of study area and the feasibility of completing field surveys within the limits of time and available funds (Figure 1). We contacted staff of county or municipal forestry bureaus to obtain detailed information of Reeves's Pheasant for each county on monitoring and annual wildlife surveys. Based on records and surveys we excluded counties or municipalities where there was convincing evidence that the species had not been recorded for more than 25 years. As a result, we identified 49 counties or municipalities for field surveys and to reduce spatial autocorrelation, the distance between sites was kept to at least 20 km (Dormann *et al.* 2007, Zhou *et al.* 2015).

To further ensure that our field work covered possible occurrence areas, we first interviewed 4–5 local village elders who were mostly hunters previously and had extensive knowledge of local pheasant species at each site. We verified their ability to identify Reeves's Pheasant by showing them photographs of male Reeves's Pheasants along with similar species such as Ring-necked Pheasant *Phasianus colchicus*, Golden Pheasant *Chrysolophus pictus*, Koklass Pheasant *Pucrasia macrolopha* and Temminck's Tragopan *Tragopan temminckii*. We included information only from interviewees who identified Reeves's Pheasant correctly for the field surveys. Additional informal interviews with similar procedures were conducted to reaffirm findings from the interviews. For sites where there was no evidence of Reeves's Pheasant for more than 10 years, we considered the species locally extinct (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 length were randomly distributed within the survey area (Zhou *et al.* 2015, Tian *et al.* 2020); a fixed width

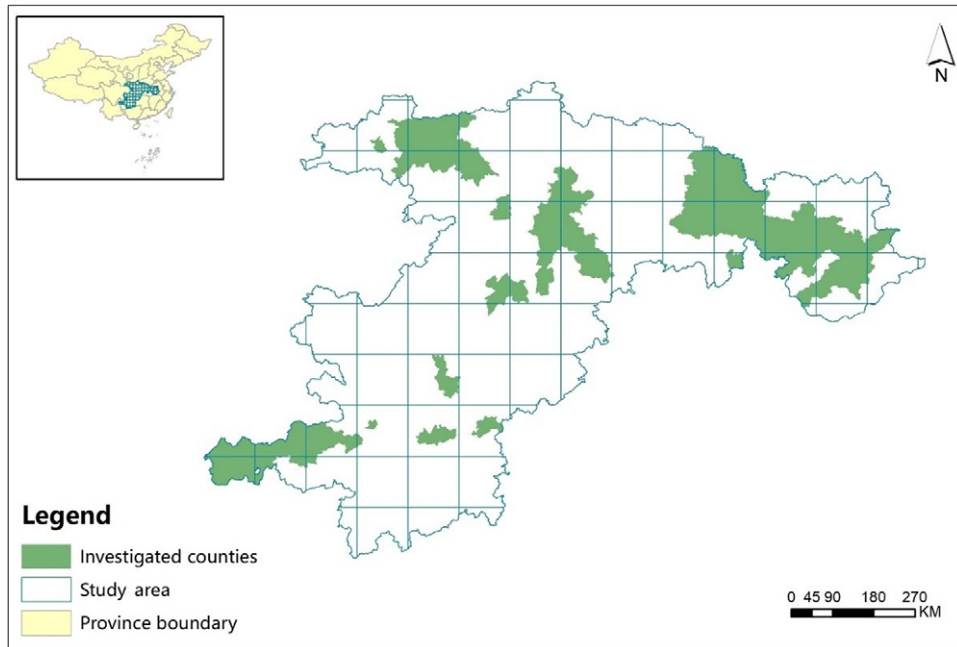


Figure 1. Location of the study area surveyed to determine the distribution of Reeves's Pheasants in 2018–2019.

of 50 m 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. We focused surveys on forest and shrublands and excluded grasslands, wetlands, impervious surfaces, and barren lands because Reeves's Pheasant does not use these habitats (Tian *et al.* 2020).

A total of 219 line transects were surveyed. We excluded detections within 1 km to avoid pseudo-replication and spatial autocorrelation by using ArcMap 10.4 (Esri Inc., 2017) as the average maximum home range of Reeves's Pheasant measures 1.05 km across (Zheng 2015, Zhou *et al.* 2017, Tian *et al.* 2020). A total of 171 occurrence locations were retained for modelling habitat suitability. The GPS coordinates of all field survey locations were recorded with an accuracy within 10 m (GPSMAP 60CSX, Garmin Inc.).

### Environmental variables

The presence of Reeves's Pheasant is affected by environmental factors, including topography, climate, land cover, and human disturbance (see Xu *et al.* 2007, Zheng 2015, Zhou *et al.* 2017). We used these four groups of environmental variables to model the occurrence and suitable habitat of Reeves's Pheasant. Topographic variables (altitude, slope, and aspect) were derived from a digital elevation model (DEM) (<http://srtm.csi.cgiar.org/>, retrieved 9 May 2019). The slope orientation was reclassified to eight aspect classes: north, north-east, east, south-east, south, south-west, west, and north-west. We used 19 bioclimatic variables downloaded from the database of WorldClim (<http://worldclim.org/>). These bioclimatic variables are derived from the monthly temperature and rainfall values, representing annual trends (e.g. mean annual temperature, annual precipitation) seasonality (e.g. annual range in temperature and precipitation) and extreme or limiting environmental factors (e.g. temperature of the coldest and warmest month, and precipitation of the

wet and dry quarters), and are often used in species distribution and ecological modelling (Fick and Hijmans 2017). Land cover data were obtained from Finer Resolution Observation and Monitoring of Global Land Cover (FROM-GLC) (<http://data.ess.tsinghua.edu.cn/>, retrieved 15 April 2019); these 10 m resolution land cover maps included 10 land cover types, including Cultivated land, Forest, Grassland, Shrubland, Wetland, Water bodies, Tundra, Impervious surface, Bareland, Permanent snow and ice. Land-cover data were resampled to a resolution of 1 km for consistency with the bioclimatic data. The human influence index (HII, Version 2, 2005) data were downloaded from the Wildlife Conservation Society (WCS) and the Columbia University Center for International Earth Science Information Network (CIESIN) (<https://sedac.ciesin.columbia.edu/data/set/wildareas-v2-human-influence-index-geographic>). It is a global dataset of 1 km grid cells, created from nine global data layers covering human population pressure (population density), human land use and infrastructure (built-up areas, night time lights, land use / land cover), and human access (coastlines, roads, railroads, navigable rivers) (WCS and CIESIN 2005).

To reduce multicollinearity between model variables, we used the ‘band collection statistics’ in the ‘spatial analyst’ extension of ArcMap to calculate correlations among variables (Lu *et al.* 2012). If two variables were found to be highly correlated ( $R^2 > 0.75$ ), we removed one from modelling based on the variable that was deemed to be less relevant in to Reeves’s Pheasant and habitat management (Razgour *et al.* 2011). In consequence, a total of 10 variables were retained to model the occurrence and suitable habitat for Reeves’s Pheasant (Table 1). Environmental layers were treated as either continuous or categorical, depending on the variable properties. For example, land cover type and slope orientation were coded categorically, while altitude was continuous. All predictor layers had the same spatial extent, resolution, origin, and projection.

### Habitat distribution prediction

To reduce the uncertainty associated with the predictions based a single model and increase the efficacy of conservation effort, we adopted the ensemble modelling approach based on multi-model predictions (Jones-Farrand *et al.* 2011) for the occurrence and suitable habitat. We used ‘dismo’ package for species distribution modelling of R 4.0.3 (Hijmans *et al.* 2014). Six modelling algorithms, including two profile methods (bioclimatic envelope algorithm [Bioclim] and domain algorithm [Domain]), two classical regression models (generalized linear models [GLMs] and generalized additive models [GAMs]) and two machine learning methods (random forest [RF] and maximum entropy [MaxEnt]), were chosen as they were reported to have high performance in species distribution assessments (Martinez-Freiria *et al.* 2013, Naimi and Araújo 2016). Profile methods only consider presence data, while regression and machine learning methods use

Table 1. Selected environmental variables for modelling the habitat suitability distribution for Reeves’s Pheasant.

Category	Variables	Abbreviation	Units	Type
Topographic	Altitude	DEM	M	continuous
	Slope	Slope	Degree	continuous
	Slope orientation	Aspect	Class	categorical
Bioclimatic	Annual mean temperature	Bio 1	°C	continuous
	Isothermality (BIO2/BIO7) (*100)	Bio 3	–	continuous
	Temperature seasonality (standard deviation * 100)	Bio 4	°C	continuous
	Annual precipitation	Bio 12	mm	continuous
	Precipitation seasonality (Coefficient of variation)	Bio 15	Fraction	continuous
Land cover	Land cover	LC	–	categorical
Human disturbance	Human influence index	HII	–	continuous

both presence and absence. As confirmed absences are difficult to obtain, especially for mobile and/or secretive species, pseudo-absences are usually derived from the background data (Phillips *et al.* 2006, Martinez-Freiria *et al.* 2013). We generated absence data using the predictor raster data and random points function in the software package to create a raster 'mask' such that the background random points were from the same geographic area for places where there were background values.

For Bioclim modelling, predicted values larger than 0.5 are subtracted from 1, the minimum percentile score across all the environmental variables was computed, and the final value subtracted from 1 and multiplied with two so that the results were between 0 and 1. For Domain modelling, the minimum distance between a site and any of the training points of each variable was taken; to integrate environmental variables, the maximum distance to any of the variables was generated, subtracted from one, and values below zero were truncated so that the scores were between 0 (low) and 1 (high). We used 'logit' as the link functions and 'binomial' distribution for GLMs. Our GAMs included multiple smoothing functions to model the complex patterns. We fitted MaxEnt as the profile methods (e.g. Bioclim) and provided presence points and a RasterStack of predictors. RF relies on a diverse set of classifiers with randomness in the classifier construction. We used all default settings of the software for RF modelling for predicting presence and absence.

We used 80% of occurrence points for training the models, and the remaining 20% were used to test their performance. The area under the curve (AUC) of the receiver operating characteristic (ROC) plot was used to assess the prediction accuracy of models (Phillips *et al.* 2006, Phillips and Dudik 2008). We excluded the 'Bioclim' and 'Domain' models from final ensemble predictions because their AUC values were below 0.7 (an threshold that is commonly used to identify 'poor' models) and averaged the predictions from remaining models (Hijmans 2012, Kindt 2018). We created the weights for the predictions from each model based on its AUC score by subtracting 0.5 (the random expectation) and squaring the result, which gave further weight to the models with higher AUC values. The average of the weighted predictions from different models was used as the ensemble prediction. We then converted ensemble predictions to a binary suitable (presence) and unsuitable (absence) map with the classification threshold based on the "maximum of the sum of the sensitivity (true positive rate) and specificity (true negative rate)" (Liu *et al.* 2005, Pearson *et al.* 2007).

### Gap analysis

Nature reserves in China are managed nationally or locally. Among these protected areas, NNRs are considered the best designed and managed because of the highest conservation priority with rich biodiversity, concentrated distribution of rare and endangered species, and less developed ecosystems. Aiming to protect species and the environment, a strict environmental protection institution system has been established based on strict prevention of sources, strict control of processes and severe punishment of consequences (The State Council of PRC 2005, Zhang *et al.* 2017, Ma *et al.* 2019).

The NNRs play a more important role in biodiversity conservation, national and international significance for conservation, science and scientific research compared to local (i.e. provincial and county) nature reserves (LNRs) (The State Council of PRC 2017), as LNRs (provincial and county-level reserves) are often not as well managed and generally have lower conservation value (MEE PRC 2018, Ma *et al.* 2019). Moreover, we currently do not have data to estimate how much suitable habitat is available outside the NNR network because of the lack of clear boundaries of these protected areas (The State Council of PRC 2005, Xu *et al.* 2016). A gap analysis was performed by overlapping the habitat suitability map based on the ensemble models with the NNR network map. By the end of 2019, there were 66 NNRs in the study area, and we excluded three wetland NNRs as Reeves's Pheasant does not use wetland and retained 63 NNRs for further analysis. The map of NNR boundaries was digitized using data from the Ministry of Ecology and Environment (<http://www.mee.gov.cn/> accessed November 2019). All mapping steps were performed in ArcMap 10.4.

### Effectiveness of functional zoning

Nature reserves in China are designed to include three functional zones, core, buffer, and experimental zones (The State Council of PRC 2005, Ma et al. 2019). According to the *Regulations of Nature Reserves* (2017), the core zone is for protecting the important natural ecosystems and suitable habitat for threatened species, the experimental zone allows for sustainable development, while between these two zones, the buffer zone serves to reduce the impact of human activities on the core zone (The State Council of PRC 2017). Trespass is not allowed in the core and buffer zones without special approval, and ecotourism and other business operations are only allowed in the experimental zone (The State Council of PRC, 2005, 2017). To understand the effectiveness of the functional zones of the existing NNRs for habitat protection of Reeves's Pheasant, we overlaid a map of the NNR network with the distribution map of suitable habitat for Reeves's Pheasant. We digitized the functional zones of the 63 NNRs using data from the Ministry of Ecology and Environment (<http://www.mee.gov.cn/>, accessed November 2019). After overlaying the maps, we calculated the area and percentage of suitable habitat in the functional zones of each NNR.

## Results

### Species distribution model

The ensemble model from four predictive algorithms with good discriminatory power. The weighted average area under the curve (AUC) across the four models was 0.87, comprising RF (AUC = 0.99), MaxEnt (0.89), GAMs (0.80) and GLMs (0.78) (Figure S1 in the online supplementary material).

The suitable habitat covered an area of 36,189 km<sup>2</sup> (4.9%) (Figure 2) in the study area. The distribution of suitable habitat was largely divided into two regions, eastern (Dabie Mountains) and western (Qinling, Daba Mountains and Dalou Mountains).

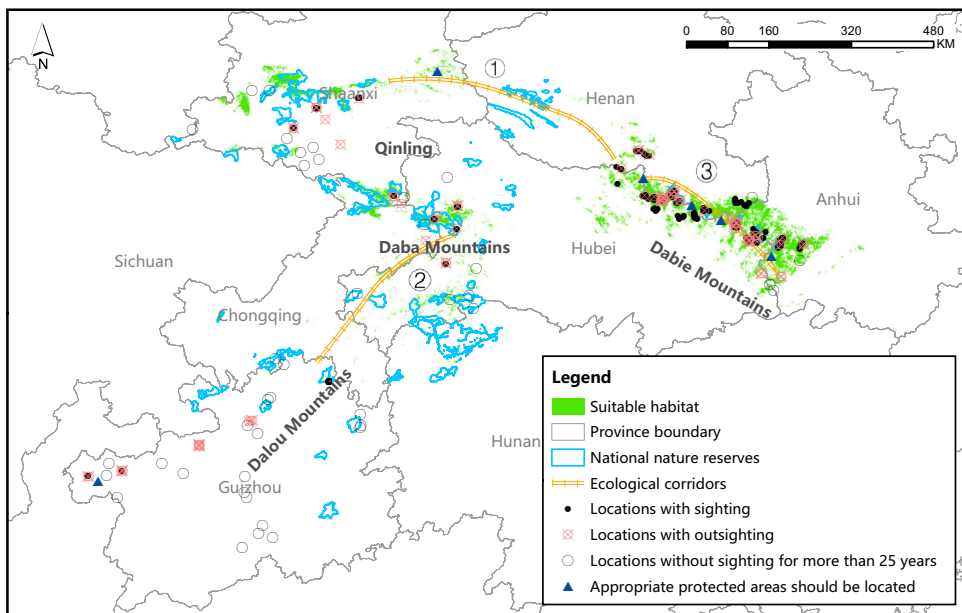


Figure 2. The NNRs, survey locations, suitable habitat, and potential ecological corridors of Reeves's Pheasant based on the gap analysis.

Table 2. The suitable habitat of Reeves's Pheasant within the national natural reserves (NNRs) network by provinces or municipalities.

Provinces / Municipalities	Area (km <sup>2</sup> )	Percentage (%)	Number of NNRs
Shaanxi	2,068	33.6	14
Hubei	1,223	19.9	16
Chongqing	1,201	19.5	5
Henan	928	15.1	8
Anhui	627	10.2	3
Hunan	78	1.3	7
Sichuan	17	0.3	2
Guizhou	11	0.2	8
<b>Total</b>	<b>6,153</b>	<b>100</b>	<b>63</b>

Table 3. The total and suitable habitat area of Reeves's Pheasant within the national natural reserves (NNRs) by functional zone.

Functional zone	NNR area (km <sup>2</sup> )	Suitable habitat (km <sup>2</sup> )	Percentage (%)
Core zone	6,692	2,958	44.2
Buffer zone	4,279	1,041	24.3
Experimental zone	7,669	2,154	28.1
<b>Total</b>	<b>18,640</b>	<b>6,153</b>	<b>33.0</b>

### Gap analysis

There were major conservation gaps in the suitable habitat of Reeves's Pheasant. Only 17.0% (6,153 km<sup>2</sup>) of the suitable habitat was within the NNR network (45 NNRs), and only five provinces or municipalities (Shaanxi, Hubei, Chongqing, Henan and Anhui) of 29 NNRs had more than 10% of the suitable habitat within the NNR network (Table 2). Within the network, 45.1% the suitable habitat occurred in Dabie Mountains (including parts of Henan, Anhui and Hubei provinces) (Table 2), and only nine (14.3%) NNRs were located in the Dabie Mountains (Figure 2).

### Effectiveness of the functional zoning in the suitable habitat conservation

The suitable habitat for Reeves's Pheasant accounted for less than 33.0% of the total area encompassed by the NNRs in our study area (Table 3). Of the suitable habitat of this species, the core zone accounted for the highest proportion (44.2%), followed by experimental and buffer zones, 28.1% and 24.3%, respectively (Table 3).

## Discussion

### Distribution of suitable habitat and conservation gaps

Nature reserves are the most important and effective refuges for wild species in China (Ma *et al.* 2019). However, more than 80% of the suitable habitat for Reeves's Pheasant falls outside the NNR network. The existing NNRs also do not put in as much effort as they should be to protect Reeves's Pheasant based on our observations and existing data. Suitable habitat within the network occurred at only 45 NNRs in the study area, and was concentrated at 29 NNRs of the five provinces or municipalities (>98%). There are similar observations on other species with extensive suitable



habitat occurring outside the NNR network and unprotected, such as Giant Panda *Ailuropoda melanoleuca* (Yang et al. 2020), Brown-eared Pheasant *Crossoptilon mantchuricum* (Li et al. 2016, Song et al. 2020), and the most concerned endangered species in China (Wen et al. 2015).

Our gap analysis suggested that current conservation effort for Reeves's Pheasant at the study area is not sufficient and not effective. A great mismatch existed between the locations of suitable habitat and the placement of NNRs for Reeves's Pheasant. Less than 15% of the area of NNRs was located in the eastern part of the Reeves's Pheasant distribution, while nearly half of the suitable habitat was situated in the eastern part of the distribution. Compared to western part of the range, the habitat in the eastern part is more suitable for many forest birds, but the NNRs in the east are smaller and more dispersed (Wen et al. 2015). The small size and poor connectivity among the NNRs provide poor habitat conditions and ineffective protection, particularly for those species with larger home ranges.

### *Effectiveness of the NNR functional zones*

The percentage of suitable habitat for Reeves's Pheasant within NNRs on average was the lowest in the buffer zone in this study, which is against our expectation that the experimental zone with the greatest human disturbance should have the lowest available suitable habitat. This conclusion is consistent with findings by other researchers (e.g. in Hubei Dabieshan NNR), where the abundance of Reeves's Pheasant was higher in the experimental zone than that in the buffer zone (Xu et al. 2005, Zheng 2015). This might suggest that the Reeves's Pheasant survives relatively well in habitats with some degree of human intervention, similar to Brown-eared Pheasant (Xu et al. 2005, Zhou et al. 2017, Song et al. 2020). On the other hand, habitat in the buffer zone may not be as pristine as the core zone (Xu et al. 2007). The core zone is characterized by well-preserved natural ecosystems that constitute suitable habitats for rare and endangered species. However, during the establishment of the functional zoning, many NRs in China lacked scientific baseline data, such as the type and available habitat, distribution and abundance of target species, and the level and type of human disturbance (Xu et al. 2016). The arbitrary division based on experience has led to a mismatch in the conservation effort and the needs of the target species such as Reeves's Pheasant in some NNRs. The areas that constitute suitable or important habitat for endangered species might be excluded from the core zones and classified as experimental and buffer zones, with potentially negative effects on species conservation, and thus on the overall conservation effectiveness of nature reserves (Xu et al. 2014).

### *Management implications*

Our research assessed the relationship between the distribution of suitable habitat and nature reserve networks and showed gaps for effective conservation of Reeves's Pheasant. In addition to the effort to protect more suitable habitat, connectivity has been highlighted as a biodiversity conservation priority to improve habitat integrity and reduce target species vulnerability (Li et al. 2016, Xu et al. 2017). The government of China has adopted a policy to enhance the connectivity of existing NNRs by using national parks as the main structure to break the 'man-made boundary' of individual NNRs (Duan and Yang 2020). The approach also includes expanding protected natural area system with new NNRs (Quan et al. 2011, Xu et al. 2019), integrating surrounding protected areas (Xu et al. 2017, 2019), restoring habitats, and establishing ecological corridors (Doko et al. 2011).

Establishing ecological corridors have been successful in protecting the threatened giant panda (Lu et al. 2019) and Marco Polo sheep *Ovis ammon polii* (Chen et al. 2019), and a similar approach could be applied to other endangered species such as the Reeves's Pheasant. We recommend establishing three ecological corridors (Figure 2). Ecological corridor 1 can be established between Henan and Shaanxi provinces for the two disjointed populations in the west and east by creating new NNRs in the gaps to improve the conservation effectiveness for Reeves's Pheasant and

associated species. The establishment of ecological corridor 1 is at a large scale to strengthen the connectivity and integrity of the eastern region dominated by forest cover and the western region dominated by karst landforms, and to improve the regional ecosystem service function as a whole. Ecological corridor 2 may be established in the western region. Fragmentation in this area is widespread, but the vegetation suitable for Reeves's Pheasant is slowly recovering through the conservation efforts (NFGA 2021a). Ecological corridor 3 may be established in the eastern region. This area has a concentrated distribution area of Reeves's Pheasant, but there is a trend towards fragmentation (Tian *et al.* 2020). The area is dominated by forest, and the establishment of ecological corridors can increase concealment and habitat suitability. Ecological corridors 2 and 3 are on a small scale, away from areas with intensive human activities and the corridor distance is short so that species can cross in a short time (Xiao and Wang 2015). In 2019, the Chinese government enacted a series of measures to better protect species and habitats, including the establishment of ecological corridors (NFGA 2019). It is believed that by establishing ecological corridor, the habitat of Reeves's Pheasant will be greatly improved in the future.

Given the increasing impact of human activities and climate change, well managed and protected NRs will become increasingly important for the maintenance of biodiversity and healthy ecosystems, upon which human well-being depends (Ma *et al.* 2019). Although further studies of distributions and gap analysis based on multiple species are warranted, we believe that the gap analysis approach adopted by our study can be applied to other species and areas for identifying conservation needs and increasing the effectiveness of protection for the species concerned.

## Supplementary Materials

To view supplementary material for this article, please visit <http://doi.org/10.1017/S095927092100023X>.

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