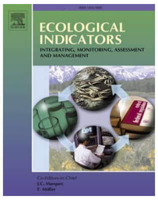
Ecological Indicators 123 (2021) 107337

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind



# The four antelope species on the Qinghai-Tibet plateau face habitat loss and redistribution to higher latitudes under climate change

Jingjie Zhang [a,b,c,1], Feng Jiang [a,b,c,1], Guangying Li [d], Wen Qin [a,b], Tong Wu [a,b], Feng Xu [e], Yuansheng Hou [f], Pengfei Song [a,b], Zhenyuan Cai [a,b], Tongzuo Zhang [a,c,*]

[a] *Key Laboratory of Adaptation and Evolution of Plateau Biota, Northwest Institute of Plateau Biology, Chinese Academy of Sciences, Xining, 810001 Qinghai, China*
[b] *University of Chinese Academy of Sciences, Beijing 100049, China*
[c] *Qinghai Provincial Key Laboratory of Animal Ecological Genomics, Xining, 810001 Qinghai, China*
[d] *Qinghai Provincial Environmental Protection Department, Xining, 810007 Qinghai, China*
[e] *Cas Key Laboratory of Biogeography and Bioresource in Arid Land, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi, 830011*
[f] *Qinghai Lake National Nature Reserve Bureau, Xining, 810001 Qinghai, China*

---

## ARTICLE INFO

*Keywords:*
Climate change
Qinghai-Tibet plateau
MaxEnt model
Range shift
MCR model
Corridor construction

## ABSTRACT

Climate change is predicted to directly or indirectly affect species distribution and abundance, especially the species that live on the Qinghai-Tibet plateau that is highly sensitive to climate change. The Przewalski's gazelle (*Procapra przewalskii*), the Goitered gazelle (*Gazella subgutturosa*), the Tibetan gazelle (*Procapra picticaudata*) and the Tibetan antelope (*Pantholops hodgsonii*) are the only four existing antelopes living on the plateau. They play indispensable roles in regulating the structure and function of the plateau ecosystem. To understand how climate change affects the spatial distribution and migration direction of these ungulates, we applied the maximum entropy (MaxEnt) model and used 82, 57, 397 and 324 GPS points of Przewalski's gazelle, Goitered gazelle, Tibetan gazelle and Tibetan antelope, respectively. These points were mainly obtained through the survey of the line transect method and a small part from the database, and then we combined with the related environmental variables, and afterwards evaluated to predict the habitat change and shift of species geographic range under three climate scenarios in the 2050s and 2070s. Additionally, the potential migration paths in the future were simulated by the Minimal Cumulative Resistance (MCR) model. The results showed that climate change would cause habitat loss for all four species. The Tibetan antelope was predicted to lose over 50% of its current inhabited area under the most severe climate scenario. Also, the suitable habitat of all species would shift to higher latitudes. In particular, the Przewalski's gazelle as an endangered species that occupies narrow habitat area would face more severe challenges in the future. Therefore, all suitable habitats should be considered as important protection areas, and our results also provide a reference for designing the optimal migration corridors for the investigated species.

## 1. Introduction

The distribution of organisms and their ecosystems are affected by climate change (Parmesan and Yohe, 2003; Root et al., 2003). In fact, climate change has influenced the distribution patterns of a large number of species and even led to the extinction of certain species (Walther et al., 2002; Sinervo et al., 2010). At present, climate change induced degradation or loss of habitats resulted in range shift of species, which seem to be the response to a generally warming trend (Parmesan, 2006; Bateman et al., 2016). For example, a series of exceptionally warm weathers in the 20th century has driven tree lines to move higher and northward in Sweden and Russia (Meshinev et al., 2000; Kullman, 2001; Moiseev and Shiyatov, 2003). In a sample of 35 non-migratory European butterflies, 63% of butterflies ranges have shifted from 35 to 240 km to the north during the last century (Parmesan et al., 1999). In a *meta*-analysis of terrestrial species distributions in response to climate change, it was estimated that the species moved to higher elevations at a rate of 11 m per decade, and to higher latitudes at a rate of 16.9 km per decade

---

* Corresponding author: Northwest Institute of Plateau Biology, Chinese Academy of Sciences, 23 Xinning Rd, Chengxi District, Xining, 810001 Qinghai Province, China.

*E-mail address:* zhangtz@nwipb.cas.cn (T. Zhang).

[1] These authors contributed equally.

https://doi.org/10.1016/j.ecolind.2021.107337
Received 31 May 2020; Received in revised form 4 November 2020; Accepted 3 January 2021

(Chen et al., 2011).

In general, species in the polar regions and in high-altitude ecosystems would be more vulnerable to global warming due to limited space or geographical barriers for an effective migration (Harris and Pimm, 2008). This is especially true for species with limited distribution range or with high sensitivity to changing conditions. According to the Intergovernmental Panel on Climate Change (IPCC) AR5 report, it was estimated that global temperature will continue to rise from 0.3 °C to 4 °C (Stocker, 2014). Furthermore, it was predicted that this situation will increase the risk of species extinction (Davis and Shaw, 2001).

A large number of studies showed that land use changes due to land conversion represent another important threat to species survival (Wilcove et al., 1998; Pimm and Raven, 2000). Land use changes around the world are driven by numerous human or natural factors (Verstegen et al., 2019) such as overexploitation of natural resources that represent a threat to species (Di Marco et al., 2018). In addition, climate change and global warming could directly influence the permafrost and vegetation cover, which in turn would affect the biomass and phenology of the sensitive plateau ecosystems (Harte and Shaw, 1995; Klein et al., 2004). Therefore, it is necessary to consider climate change and land use change when assessing and predicting future species distributions.

The Qinghai-Tibet Plateau, known as the “Third Pole” of the world, is an important part of the global terrestrial ecosystem. The climate fluctuations in this region are more extensive than in other regions of the Northern hemisphere, thus demonstrating its high sensitivity to climate change (Lin and Zhao, 1996; Yao et al., 2000; Piao et al., 2006). Studies provided increasing evidence that show how the Qinghai-Tibet Plateau is already experiencing climate change effects (Thompson et al., 1993; Wang and French, 1994). It is also expected that its land use dynamics will change due to changing climate (Walker et al., 2001). Because of the geographical and ecological characteristics of the Qinghai-Tibet Plateau, the species living in this region are adapted to low temperature, low oxygen level, high UV radiation and limited production (Xu et al., 2005; Wang et al., 2016). The Przewalski’s gazelle (*Procapra przewalskii*), the Goitered gazelle (*Gazella subgutturosa*), the Tibetan antelope (*Pantholops hodgsonii*) and the Tibetan gazelle (*Procapra picticaudata*) are the only four existing antelopes in the Qinghai-Tibet Plateau. The Przewalski’s gazelle is among the most endangered wildlife in the world. It is only found in the surrounding area of the Qinghai lake in China and has a population of less than 3000 (Lei et al., 2001; Yu et al., 2017). The Goitered gazelle represents a typical specie of desert ecosystem (Kingswood and Blank, 1996), and its population stability is important for the balance and stability of the ecosystem. In addition, the Tibetan antelope and the Tibetan gazelle are the ungulates that are endemic to the Qinghai-Tibet plateau. The Tibetan antelope represents a key sensitive species in the alpine and desert ecosystem of the plateau, while the Tibetan gazelle is widely distributed and abundant in the region (Leslie and Schaller, 2008; Leslie, 2010). Both species have important roles in maintaining the stability of the ecosystem and preserving the species diversity in the region. By considering the climate sensitivity of this unique habitat and the adaptation possibilities of these four species, it can be assumed that any changes in the environment would likely affect species survival.

We assume that climate change will affect the distribution of the four antelopes on the Qinghai-Tibet plateau, and accordingly it is important to find the solutions on how to better protect these species from the expected strong impacts of climate change. In this regard, improving landscape connectivity or building corridors for species migration are the most popular suggestions for climate change adaptation (Heller and Zavaleta, 2009). Landscape connectivity is critical for the viability of species and for the conservation of biodiversity (Beier and Noss, 1998; Crooks and Sanjayan, 2006). By maintaining the landscape connectivity, it is possible to help species to better and more quickly adapt to changes in environmental conditions, thus alleviating the pressures caused by climate change (Opdam and Wascher, 2004). Therefore, we applied the MaxEnt model and MCR model to construct the path and corridor from the distribution space (under the current climate scenario) to the survival space (under the climate change scenario).

This study aims to: 1) predict the distribution of four existing antelopes on the Tibetan plateau under current and future climate change; 2) compare habitat changes in different periods and understand the impact of climate change on the antelopes; and 3) provide a scientific basis for the dispersal paths of antelopes.

## 2. Materials and methods

### 2.1. Occurrence data and processing

The distribution data of the four antelopes in the Qinghai-Tibet Plateau were mainly obtained from the large-scale terrestrial wildlife surveys done in the Qinghai Province from 2014 to 2018 and Global Biodiversity Information Facility (GBIF) (https://www.gbif.org/). To avoid spatial autocorrelation due to close points of species, we removed the points that are less than 1 km apart and used the remaining points in the study. Finally, we obtained 82 distribution points for the Przewalski’s gazelle, 57 points for the Goitered gazelle, 397 points for the Tibetan gazelle, and 324 points for the Tibetan antelope (Fig. 1).

### 2.2. Environment variables

We have initially selected 21 environmental variables that might affect the distribution of four species. The data used for climate assessment was obtained from the WorldClim database (http://www.worldclim.org). Other 19 bioclimatic variables (at 1 km resolution) that reflect temperature and precipitation under the current climatic conditions (average for the period 1970–2000) were used as current climate data. For future climate variables, we used the climate data from 2050s and 2070s.

BCC-CSM1-1 was used as the climate model, as it represents one of the most common models for simulating climate change in China (Zhang et al., 2018). Three representative concentration pathway scenarios (RCP 2.6, RCP 4.5 and RCP 8.5) developed by the IPCC (Pachauri et al., 2014) were used in the study. The RCP 2.6 was used as the minimum emission scenario, RCP 4.5 as the medium emission scenario, and RCP 8.5 as the maximum emission scenario.

Elevation and land use were also considered in the study. Elevation data was derived from the ASTER DEM V2 digital elevation model at 30 m resolution (http://www.gscloud.cn/) and this variable remained unchanged for the present and the future scenarios. The current and future land use data were obtained from the global land use dataset (2010–2100) at 1 km resolution (http://data.ess.tsinghua.edu.cn/data/Simulation/), which provides the most current and finest-scale future LULC dynamics from 2010 to 2100 (Li et al., 2016). We used the land use data in 2010 to assess the current species distribution and also selected the land use data under the same RCP scenarios (i.e. RCP 2.6, RCP 4.5, and RCP 8.5) to predict future distributions.

All layers of environmental variables were resampled to 1 km resolution by ArcGIS 10.2. To avoid the strong correlation among multiple variables that can cause multicollinearity, we screened the correlation of 21 environmental variables and eliminated the variables in each pair that had a Pearson correlation value $\geq 0.8$ (Désamoré et al., 2012; Harrington et al., 2018), while the remaining variables were incorporated into the model (Table S1, Table S2).

### 2.3. Habitat distribution modeling

MaxEnt model was used to predict the habitat distribution of the four species, as it is superior in predicting performance and stability when compared to other similar niche models (Elith et al., 2006; Wisz et al., 2008). MaxEnt model can produce output of higher quality if the model parameters are optimized or adjusted, instead of using the default setting (Anderson and Gonzalez, 2011; Warren and Seifert, 2011). The

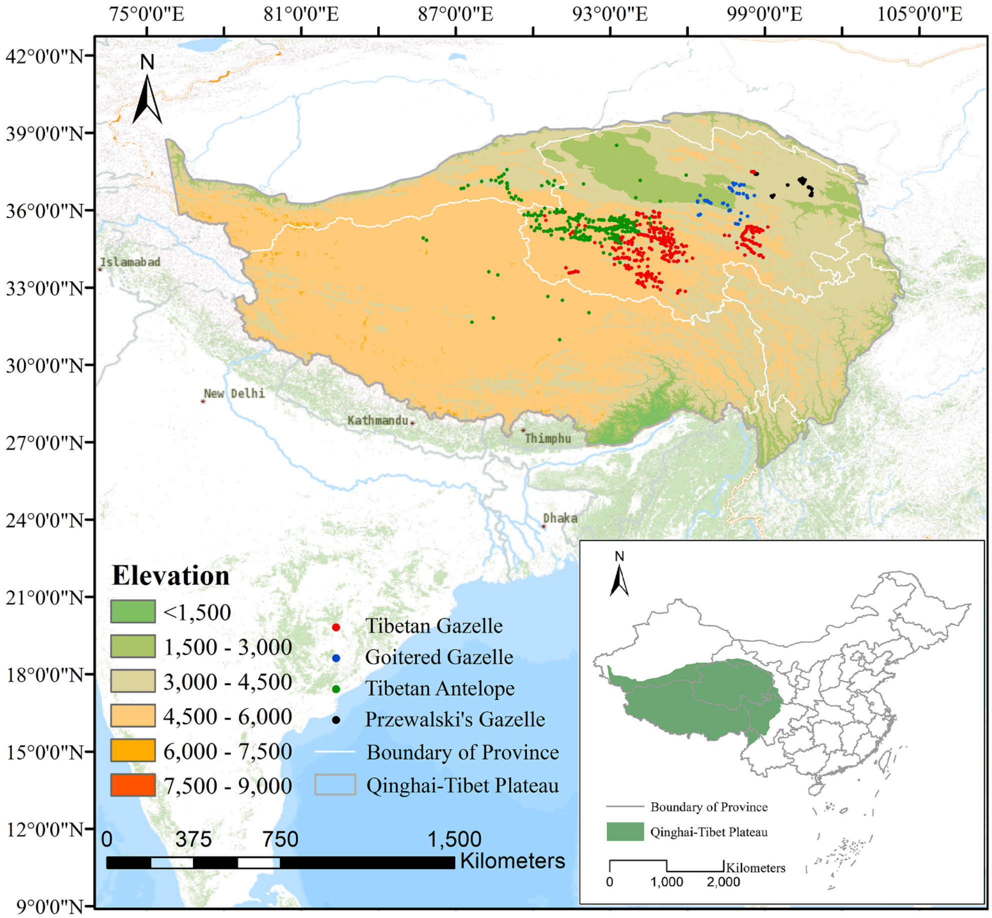


**Fig. 1.** Distribution points of four antelopes in the Qinghai-Tibet Plateau.

response curve was adjusted by combining the different parameters and by assessing the accuracy of the model with the corrected Akaike information criterion (AICc) values calculated under different parameters in ENMTools1.4.3. Because the sample size can be ignored, we used AICc instead of AIC generally (Burnham and Anderson, 2004; Song et al., 2017). Priority was given to the parameters with smooth response curve that is characterized by small AICc values (Muscarella et al., 2014; Moreno-Amat et al., 2015). Finally, 75% of the species distribution points were selected as training values, while the remaining 25% were used as test values.

The area under the receiver operating characteristic curve (ROC) was used to evaluate model performance (Phillips et al., 2006). The area under the curve (AUC) values ranged from 0 to 1, and the model accuracy can be judged as excellent if the AUC value is between 0.9 and 1, good if between 0.8 and 0.9, fair if it is between 0.7 and 0.8, poor if it is between 0.6 and 0.7, and failed if the AUC values are between 0.5 and 0.6 (Swets, 1988; Liao et al., 2017). The suitability maps were generated by applying the logistic output of MaxEnt, and the obtained logical habitat suitability index was the lowest at “0” and the highest at “1”. The logistic threshold applied to cut-off the models and for converting the continuous probability model in a binary model (0 = unsuitable, 1 = suitable) assumed the maximum test sensitivity plus specificity (Bean et al., 2012; Jorge et al., 2013).

### 2.4. Assessment of distribution change and migration path

We also assessed the current and future species distribution areas and calculated the suitable habitat change rates. Stable, vulnerable and expansion area, as well as proportions of the four species were determined by applying the method of layer superposition in ArcGIS. ArcGIS was also utilized to find the central point of the suitable habitat of four species in each period, and we also used the MCR to describe their range shifts and migration paths. MCR is widely used in the planning of ecological corridor (Ersoy et al., 2019; Ma et al., 2020) with the formula as follows:

$$MCR = fmin\sum_{j=n}^{i=m} D_{ij} \times R_i$$

MCR represents the minimum cumulative resistance; $f$ is a monotonic increasing function that indicates the positive correlation between the minimum cumulative resistance and the ecological process; $D_{ij}$ represents the distance from source $j$ to landscape unit $i$; and $R_i$ represents the resistance coefficient of landscape unit $i$ to species movement. This model requires data of source (origin) and sink (destination). Our research used the current habitat center as the source and the future habitat center as the sink under various climate scenarios. Another part of the data represents the construction of resistance surface that reflects the difficulty of species migration in the landscape. The resistance surface was obtained by transforming the habitat suitability index into a negative exponential transformation function (Keeley et al., 2016; Dai et al., 2019) by following:

$$HSI \geqslant threshold, \quad resistance = 1 \tag{1}$$

$$HSI < \text{threshold}, \quad \text{resistance} = e^{\frac{\ln(0.001)}{threshold} \times HSI} \times 1000 \tag{2}$$

Finally, we combined data for resistance surface, source, and sink, and constructed the migration path of species through the cost path tool of ArcGIS.

## 3. Results

### 3.1. Model performance and important environmental variables

Compared with the AICc values and the smoothness of response curves under different combined parameters, the optimal feature combination (FC) was selected for the Przewalski's gazelle, the Goitered gazelle and the Tibetan antelope with all combinations of linear, quadratic and product equations. The regularization multiplier (RM) of the Przewalski's gazelle and the Goitered gazelle was 1, while it was 2 for the Tibetan antelope. The optimal FC of the Tibetan gazelle was a combination of linear and quadratic trends with an optimal RM of 1. Results of model prediction showed that the average AUC values of the four antelopes were 0.995 ± 0.001, 0.983 ± 0.01, 0.965 ± 0.004, and 0.969 ± 0.005, respectively (Table S4, Fig.S1). The predicted model results for each species were highly informative and could be used for further research since the AUC value of each species exceeded 0.9.

Elevation was determined as a common and important factor affecting species distribution according to the corresponding curves of the four species. In addition, the extreme or limiting environmental factors (i.e. bio6, bio8 and bio11), and biological variables representing seasonal precipitation (bio18) and seasonal changes in temperature (bio4) were determined as important factors for the future distribution of species (Fig.S2).

### 3.2. Current distribution of antelopes

Our results showed that the suitable habitat of the Przewalski's gazelle was extremely small in the Qinghai-Tibet Plateau (3.6% of the total area), and was mainly concentrated in the northeastern part of the plateau only. In contrast, the Goitered gazelle was mainly distributed in the northern part of the Qinghai-Tibet Plateau and accounted for 12.7% of the total area. The Tibetan gazelle had the widest distribution and occupied 37.1% of the Plateau. The Tibetan antelope was mainly distributed in the central and northern regions having 22.2% suitable habitat in the Qinghai Tibet Plateau (Fig. 2, Table S3).

### 3.3. Prediction of future distribution of antelopes under various climate scenarios

We calculated the habitat change rates of the four species, and compared the area of habitat increase (gain), decrease (loss) and stability (unchanged) under different concentrations and years. The results showed that suitable habitats for the four antelope species had a decreasing trend with the predicted warming of the climate in the future. Among them, predicted loss of suitable habitats for the Przewalski's gazelle ranged from 16.3% to 24.9%, while predicted loss of suitable habitats for the Goitered gazelle ranged from 0.3% to 35.2%. The loss of suitable habitat for the Tibetan gazelle ranged from 2.2% to 36.3%, while the loss of suitable habitat for the Tibetan antelope ranged from 24.5% to 53.2% (Table S5). The suitable habitats of the four species would be especially reduced under RCP 8.5 (worst case scenario). The potential expanded habitats can be regarded as a new refuge for the species, yet our results showed that these newly expanded habitat areas were small when compared to the predicted loss. (Fig. 3, Fig.S3).

### 3.4. Species range shift under climate change

We calculated range of high latitude migration of the suitable habitats. The migration ranges of the Przewalski's gazelle, the Goitered

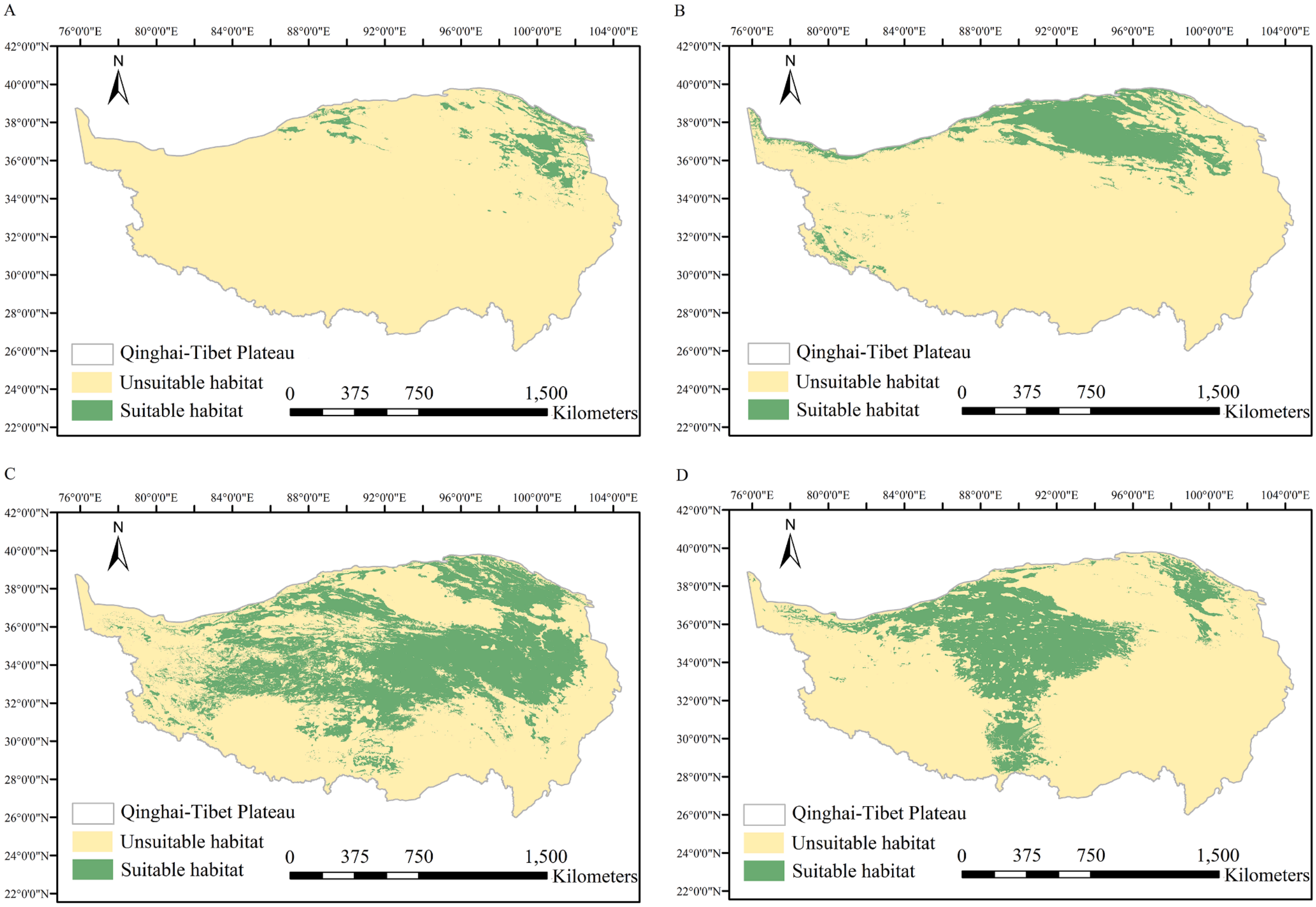


**Fig. 2.** Current distribution maps of the Przewalski's gazelle (A), the Goitered gazelle (B), the Tibetan gazelle (C) and the Tibetan antelope (D).

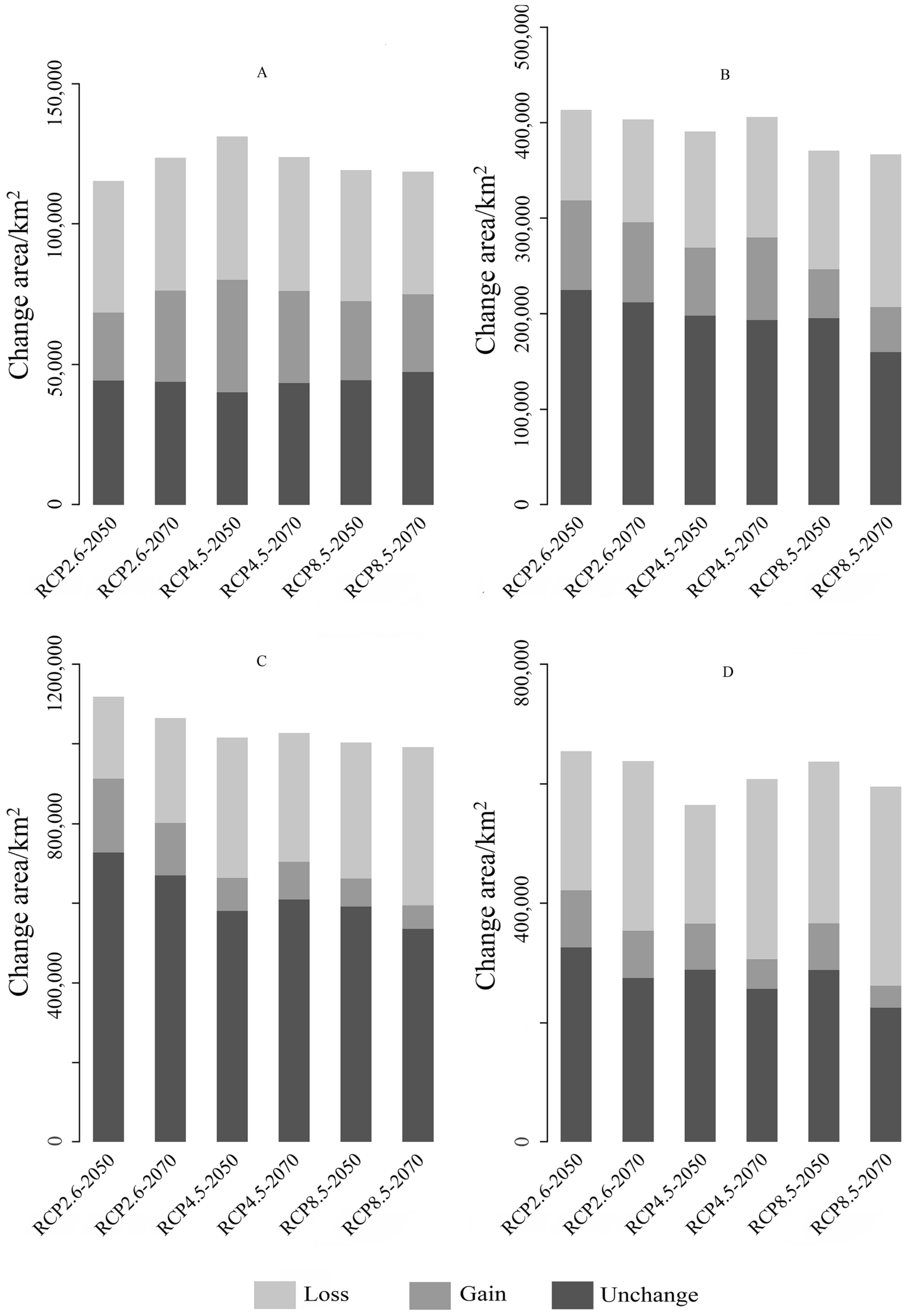


**Fig. 3.** The area of unchanged, lost and acquired habitats under different future climate scenarios for the Przewalski's gazelle (A), the Goitered gazelle (B), the Tibetan gazelle (C) and the Tibetan antelope (D).

gazelle, the Tibetan gazelle and the Tibetan antelope were 24–118 km, 297–356 km, 22–112 km and 85–257 km, respectively. Furthermore, the average distance was 61 km, 332 km, 55 km and 184 km, respectively. According to the analysis of the MCR model results, it can be noticed that the minimum migration path of the Przewalski's gazelle, the Goitered gazelle, the Tibetan gazelle and the Tibetan antelope ranged from 54 to 1057 km, from 1142 to 1355 km, from 127 to 451 km, and from 360 to 538 km, respectively. In addition, the average minimum distance was 318 km, 1235 km, 295 km and 456 km, respectively (Fig. 4, Table S6).

According to the above-mentioned results, the Goitered gazelle would be the furthest migrating species under climate change, while the Tibetan gazelle would be the closest migrating species under climate

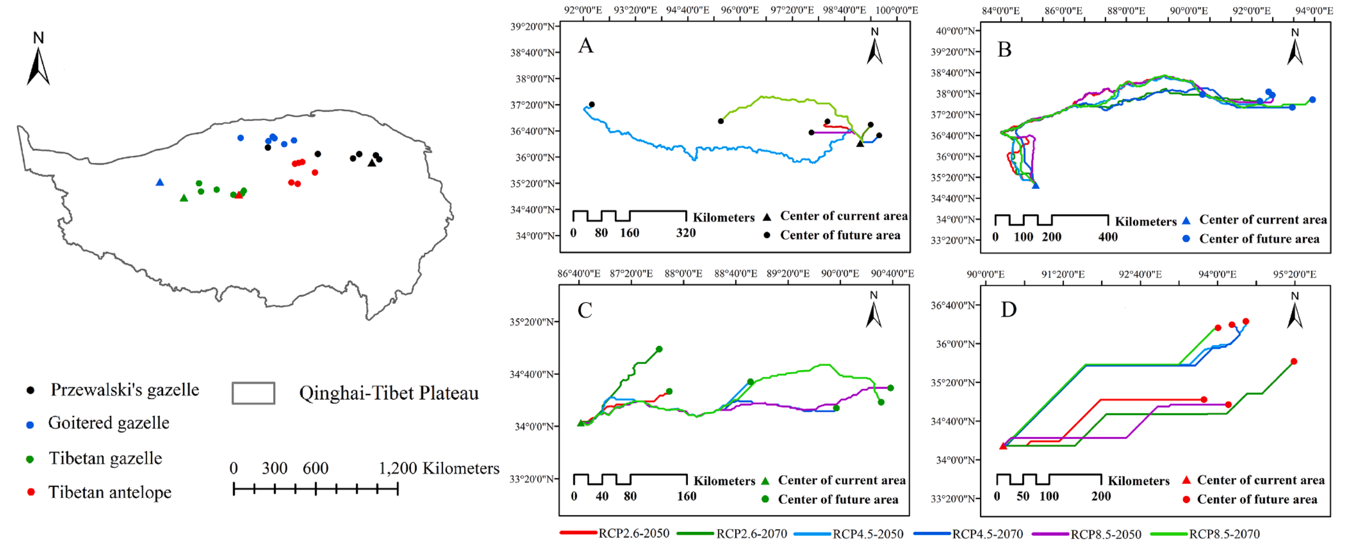


**Fig. 4.** The migration path of the Przewalski's gazelle (A), the Goitered gazelle (B), the Tibetan gazelle (C) and the Tibetan antelope (D) from the current climate scenario to the future. Different colors represent different species, triangle sign represents the center point of suitable habitats for each species in the current climate scenario, and the dots sign represent the center point of suitable habitats in future climate scenarios.

change. In addition, the suitable habitats of the Goitered gazelle, the Tibetan gazelle and the Tibetan antelope were predicted to migrate to the northeast. For the Przewalski's gazelle was predicted to migrate northwest and northeast. In general, predicted distribution of suitable habitats for all species will be in higher latitudes in the future.

## 4. Discussion

Environmental factors determine the survival, reproduction and distribution of organisms, and accordingly organisms are trying to adapt to the environment in which they live. For species living on the Qinghai-Tibet Plateau, two important environmental variables are changeable climate and high altitude. In previous studies, climate has often been regarded as important factor in determining the range of species (Pearson and Dawson, 2003; Virkkala et al., 2005). This is due to the climate factors (e.g. precipitation and temperature) that directly affect the physiology tolerance and behavior of organisms, and also indirectly affect the resource supply that influences the growth of vegetation (Fuller et al., 2016). Elevation represents another significant factor that can constrain the distribution of high-altitude species as it determines food resources that are related to factors such as temperature, precipitation, and radiation. Furthermore, land use can restrict the distribution of species due to their occupation patterns on the landscape scale (Cord et al., 2014). Therefore, the environmental variables of bioclimate, topography and land use were selected to simulate the species distribution range and pattern in current climate and in the changed climate of the future.

Analyses of environmental variables showed that elevation was one of the most important factors that limited the distribution of all investigated species. The four antelope species live on different elevations and their habitats have different ecological characteristics. Among them, the Przewalski's gazelle and the Goitered gazelle live on relatively lower elevation. The Przewalski's gazelle is mainly distributed in the range of 3000–3500 m. The Goitered gazelle lives on the elevations between 2700 m and 3500 m. The Tibetan antelope and the Tibetan gazelle live on elevations between 4000 m and 5000 m, where ambient temperature is lower and these species are more tolerant to low temperatures. In addition, the vegetation types change on different elevations. The habitat of the Przewalski's gazelle is mainly covered with alpine steppes (temperate grassland), while the Goitered gazelle is distributed in the alpine desert of Chai Damu. The Tibetan antelopes and the Tibetan gazelle are distributed in alpine steppes and meadows at higher altitude (Han et al., 2016), which indicates that the adaptive diets and food preferences of these species are quite different.

In addition to elevation, the results showed that climatic factors are another major factor that influences species distribution. The minimum temperature of coldest month, mean temperature of wettest quarter and mean temperature of coldest quarter (bio6, bio8 and bio11) are three extreme or limiting environmental factors, which are recognized as the main climate variables affecting the Przewalski's gazelle, the Tibetan gazelle and the Tibetan antelope. In general, the wettest season coincides with the breeding season of antelope on the plateau. Therefore, the temperature changes in this season would influence the reproduction of herbivores by affecting the plant phenology, vegetation yield, and by changing the distribution of vegetation on the Plateau. Evidence showed that the primary productivity of the Tibetan Plateau increases with a slight increase in temperature and precipitation (Melillo et al., 1993), which would stimulate production of food resources for the antelopes. Furthermore, the seasonal reproduction of mammals has been found to be seriously affected by climate change, and this is reflected by the significant periodic mismatch between their reproductive peaks and the abundance of food resource, which can result in a sharp decline in the production of newborn babies (Parmesan, 2007; Bronson, 2009). Both the minimum temperature of the coldest month and the mean temperature of the coldest quarter represent two extreme or restrictive climatic variables that can reflect the low temperature boundaries that species can withstand. Furthermore, these temperatures can limit the species distribution. The decrease of temperature seasonality (bio4) in the future is also a reflection of the temperature rise. The projected increase in temperature affects vegetation resources, and the physiology and behavior of wildlife. For example, significant temperature increase will likely induce heat stress and affect vital rates of species that are adapted to the alpine region (Hansen, 2009). Also, rising temperatures may limit the distribution of species by limiting the available time for vital activities such as foraging or by limiting the time necessary to find mating partner (Conley and Porter, 1986; Sinervo et al., 2010). Compared with other three species, the distribution of Goitered gazelle was strongly affected by precipitation in the warmest quarter. For the species that mainly inhabits extremely arid desert regions, the precipitation increase may have a positive impact on the local vegetation yield (Qin et al., 2020). Nevertheless, the combined changes in temperature and precipitation have a wide and long-term continuous effect on the environment (Mann et al., 1998), and accordingly the distribution range of local species would inevitably shift due to environmental changes. Considered together, changes in temperature and precipitation affect the distribution of species by changing their food abundance, physiological water tolerance, reproduction and behavior.

We used land use data that is synchronized with the future climate in order to assess the current and future distribution ranges of species. The results showed that the contribution rate of land use in assessing the current and future species distribution was relatively low, thus indicating that climate and topographic factors are more important than land use in determining species distribution. Although the impact of land use was not significant in our study, increased human activities and overgrazing could represent threats that should be considered as they could result in grassland degradation and reduction of available resources in the future (Zhang et al., 2015).

Although the suitable habitat of the Tibetan gazelle in the plateau was larger than other three antelopes, the fragmentation degree of its suitable habitat seemed to be much higher than others. This is especially evident in the western part of the plateau. Species with high degree of habitat fragmentation are likely to face the risk of reduced gene flow (Keller and Largiadèr, 2003; Dixo et al., 2009), which may aggravate the negative impact on species in addition to the effects of global climate change (Didham et al., 2007; Krosby et al., 2010). The high sensitivity and vulnerability of the Qinghai-Tibet plateau to climate change have determined that the wildlife in the region will face greater threats of climate change.

Driven by climate change, species often acquire new habitats by changing their range of distribution (migration) (Visser et al., 2009; Chen et al., 2011; Fordham et al., 2012). By comparing the shifts of central points in the range of suitable habitats under current and future climate change, it was noticed that the distribution of the four species have changed significantly. The basic trend of habitat migration of the four antelopes northward was recognized. The habitat distance of the Goitered gazelle was more than 350 km in the latitude direction. The migration to the higher latitudes is likely to be the response of species to future high temperatures and land use changes (Davis and Shaw, 2001; VanDerWal et al., 2013). Additionally, competition between species could be additional factor affecting shifts in species habitat range. Although the four antelopes are capable of rapid migration, climate change may lead to changes in the habitat of a large number of other herbivores on the Qinghai-Tibet Plateau. Due to that, species with similar ecological habits are likely to compete for resources such as habitat or food. Evidence showed that warming of climate will likely change the composition of vegetation communities and cause a decline in plant diversity in high-altitude ecosystems (Zhang et al., 2017). Stronger vegetation reduction due to further warming (Klein et al., 2004) will inevitably increase competition among species. Therefore, both climate and species interactions may influence the changes in suitable habitats of four antelopes or influence them to retreat to smaller areas.

Our results showed that the suitable habitat of four antelopes had decreased and that the distribution range would shift due to climate change. This situation is more dangerous to species that have low migration potential to move to high altitudes or high latitudes. Therefore, we believe that establishing low-cost corridors between the current and future habitats could have multiple benefits, such as the reduction of migration barriers, provision of the best route for successful migration, and smaller the pressures of habitat losses due to climate change (Fall et al., 2007; Hodgson et al., 2009; Koen et al., 2014).

The results from this study suggest that suitable habitats under climate change should be regarded as key protected areas and prevent the increase in human disturbances in these areas in the future. Additionally, a number of studies should be carried out that are related to population survey, population monitoring, early warning and risk assessment. Since the monitoring of population can grasp the true migration and distribution of species, this would provide effective information for real-time understanding of the dynamics of the four antelopes. Furthermore, research should be carried out on the utilization and carrying capacity of grassland by large wild herbivorous and co-distributed livestock in order to provide the support for the protection of wildlife resources and for the stability of the ecosystem on the Qinghai-Tibet plateau. Moreover, our research can provide a reference for the migration of species between current and future habitats. Nevertheless, we need to increase the barrier effect of the fence to comprehensively consider the construction of migration corridors in future research.

## 5. Conclusions

Simulating the effects of climate change and land use on the spatial distribution of antelopes on the Tibetan plateau was performed. The results of this study showed that four antelopes are highly sensitive to climate change, with their habitat loss likely increasing the survival pressure. Furthermore, habitat transfer was considered as the response of species to climate change as species are predicted to migrate to higher latitudes in the future. Therefore, we propose to build migration corridors in order to connect the suitable habitats in current climate scenario with suitable habitats in future climate scenario. In addition, we recommend additional important measures such as: establishing key protected areas, implementing long-term monitoring to obtain effective information on species transfer and distribution trends, and strengthening research on the balance of livestock and forage reserves. The above-mentioned measures would alleviate the climate change pressures on the Plateau species and provide scientific support and evidences for the protection of wildlife in this region.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### *Acknowledgement*

Our thanks and appreciation go to Professor Tamas Szekely at University of Bath for his valuable comments on earlier versions of the manuscript. This work was supported by the Strategic Priority Research Program of the Chinese Academy of Sciences (Grant numbers XDA23060602, XDA2002030302), National Key R&D Program of China (Grant number 2017YFC0506405, 2018YFC0507201), the Second Tibetan Plateau Scientific Expedition and Research Program (STEP) (grant number 2019QZKK0501), Qinghai Key R&D and Transformation Program (grant number 2019-SF-150), and Science and Technology Department of Qinghai Province Major Project "Sanjiangyaun National Park Animal Genome Program".

### *Data accessibility*

We used open- access data from WorldClim (http://www.worldclim.org/), GBIF (https://www.gbif.org/), ASTER DEM V2 (http://www.gscloud.cn/) and land use data (http://data.ess.tsinghua.edu.cn/data/Simulation/).

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolind.2021.107337.

## References

Anderson, R.P., Gonzalez Jr., I., 2011. Species-specific tuning increases robustness to sampling bias in models of species distributions: an implementation with Maxent.

Ecol. Model. 222 (15), 2796–2811. https://doi.org/10.1016/j.ecolmodel.2011.04.011.

Bateman, B.L., Pidgeon, A.M., Radeloff, V.C., VanDerWal, J., Thogmartin, W.E., Vavrus, S.J., Heglund, P.J., 2016. The pace of past climate change vs. potential bird distributions and land use in the United States. Glob. Change Biol. 22 (3), 1130–1144. https://doi.org/10.1111/gcb.13154.

Bean, W.T., Stafford, R., Brashares, J.S., 2012. The effects of small sample size and sample bias on threshold selection and accuracy assessment of species distribution models. Ecography 35 (3), 250–258. https://doi.org/10.1111/j.1600-0587.2011.06545.x.

Beier, P., Noss, R.F., 1998. Do habitat corridors provide connectivity? Conserv. Biol. 12, 1241–1252. https://doi.org/10.1111/j.1523-1739.1998.98036.x.

Bronson, F.H., 2009. Climate change and seasonal reproduction in mammals. Phil. Trans. R. Soc. B 364 (1534), 3331–3340.

Burnham, K.P., Anderson, D.R., 2004. Multimodel inference: understanding AIC and BIC in model selection. Sociol. Methods Res. 33 (2), 261–304.

Chen, I.C., Hill, J.K., Ohlemüller, R., Roy, D.B., Thomas, C.D., 2011. Rapid range shifts of species associated with high levels of climate warming. Science 333, 1024–1026. https://doi.org/10.1095/biolreprod32.1.1.

Conley, K.E., Porter, W.P., 1986. Heat loss from deer mice (Peromyscus): evaluation of seasonal limits to thermoregulation. J. Exp. Biol. 126, 249–269.

Cord, A.F., Klein, D., Mora, F., Dech, S., 2014. Comparing the suitability of classified land cover data and remote sensing variables for modeling distribution patterns of plants. Ecol. Model. 272, 129–140. https://doi.org/10.1016/j.ecolmodel.2013.09.011.

Crooks, K.R., Sanjayan, M., 2006. In: Connectivity Conservation. Cambridge University Press. https://doi.org/10.1098/rstb.2011.0120.

Dai, Y., Hacker, C.E., Zhang, Y., Li, W., Zhang, Y., Liu, H., Zhang, J., Ji, Y., Xue, Y., Li, D., 2019. Identifying climate refugia and its potential impact on Tibetan brown bear (Ursus arctos pruinosus) in Sanjiangyuan National Park, China. Ecol. Evol. https://doi.org/10.1016/j.gecco.2019.e00664.

Davis, M.B., Shaw, R.G., 2001. Range shifts and adaptive responses to Quaternary climate change. Science 292, 673–679. https://doi.org/10.1126/science.292.5517.673.

Désamoré, A., Laenen, B., Stech, M., Papp, B., Hedenäs, L., Mateo, R.G., Vanderpoorten, A., 2012. How do temperate bryophytes face the challenge of a changing environment? Lessons from the past and predictions for the future. Glob. Change Biol. 18 (9), 2915–2924. https://doi.org/10.1111/j.1365-2486.2012.02752.x.

Di Marco, M., Venter, O., Possingham, H.P., Watson, J.E.M., 2018. Changes in human footprint drive changes in species extinction risk. Nat. Commun. 9 https://doi.org/10.1038/s41467-018-07049-5.

Didham, R.K., Tylianakis, J.M., Gemmell, N.J., Rand, T.A., Ewers, R.M., 2007. Interactive effects of habitat modification and species invasion on native species decline. Trends Ecol. Evol. 22 (9), 489–496. https://doi.org/10.1016/j.tree.2007.07.001.

Dixo, M., Metzger, J.P., Morgante, J.S., Zamudio, K.R., 2009. Habitat fragmentation reduces genetic diversity and connectivity among toad populations in the Brazilian Atlantic Coastal Forest. Biol. Conserv. 142, 1560–1569. https://doi.org/10.1016/j.biocon.2008.11.016.

Elith, J., Graham, C.H., Anderson, R.P., Dudík, M.F., Simon, Guisan, A., Hijmans, R.J., Huettmann, F., Leathwick, J.R., Lehmann, A., 2006. Novel methods improve prediction of species' distributions from occurrence data. Ecography 29, 129–151. https://doi.org/10.1111/j.2006.0906-7590.04596.x.

Ersoy, E., Jorgensen, A., Warren, P.H., 2019. Identifying multispecies connectivity corridors and the spatial pattern of the landscape. Urban For. Urban Green. 40, 308–322. https://doi.org/10.1016/j.ufug.2018.08.001.

Fall, A., Fortin, M.-J., Manseau, M., O'Brien, D., 2007. Spatial graphs: principles and applications for habitat connectivity. Ecosystems 10, 448–461. https://doi.org/10.1007/s10021-007-9038-7.

Fordham, D.A., Watts, M.J., Delean, S., Brook, B.W., Heard, L.M.B., Bull, C.M., 2012. Managed relocation as an adaptation strategy for mitigating climate change threats to the persistence of an endangered lizard. Glob. Change Biol. 18, 2743–2755. https://doi.org/10.1111/j.1365-2486.2012.02742.x.

Fuller, A., Mitchell, D., Maloney, S.K., Hetem, R.S., 2016. Towards a mechanistic understanding of the responses of large terrestrial mammals to heat and aridity associated with climate change. Clim. Chang. Responses 3. https://doi.org/10.1186/s40665-016-0024-1.

Han, M., Brierley, G.J., Cullum, C., Li, X., 2016. Climate, vegetation and human land-use interactions on the Qinghai-Tibet plateau through the Holocene. In: Landscape and Ecosystem Diversity, Dynamics and Management in the Yellow River Source Zone. Springer, Cham, pp. 253–274. https://doi.org/10.1007/978-3-319-30475-5_12.

Hansen, P.J., 2009. Effects of heat stress on mammalian reproduction. Philos. Trans. Roy. Soc. B Biol. Sci. 364, 3341–3350. https://doi.org/10.1098/rstb.2009.0131.

Harrington, S.M., Hollingsworth, B.D., Higham, T.E., Reeder, T.W., 2018. Pleistocene climatic fluctuations drive isolation and secondary contact in the red diamond rattlesnake (Crotalus ruber) in Baja California. J. Biogeogr. 45, 64–75. https://doi.org/10.1111/jbi.13114.

Harris, G., Pimm, S.L., 2008. Range size and extinction risk in forest birds. Conserv. Biol. 22, 163–171. https://doi.org/10.1111/j.1523-1739.2007.00798.x.

Harte, J., Shaw, R., 1995. Shifting dominance within a Montane vegetation community: results of a climate-warming experiment. Science 267, 876–880. https://doi.org/10.1126/science.267.5199.876.

Heller, N.E., Zavaleta, E.S., 2009. Biodiversity management in the face of climate change: a review of 22 years of recommendations. Biol. Conserv. 142, 14–32. https://doi.org/10.1016/j.biocon.2008.10.006.

Hodgson, J.A., Thomas, C.D., Wintle, B.A., Moilanen, A., 2009. Climate change, connectivity and conservation decision making: back to basics. J. Appl. Ecol. 46, 964–969. https://doi.org/10.1111/j.1365-2664.2009.01695.x.

Jorge, M.L.S.P., Galetti, M., Ribeiro, M.C., Ferraz, K.M.P.M.B., 2013. Mammal defaunation as surrogate of trophic cascades in a biodiversity hotspot. Biol. Conserv. 163, 49–57. https://doi.org/10.1016/j.biocon.2013.04.018.

Keeley, A.T.H., Beier, P., Gagnon, J.W., 2016. Estimating landscape resistance from habitat suitability: effects of data source and nonlinearities. Landscape Ecol. 31 (9), 2151–2162. https://doi.org/10.1007/s10980-016-0387-5.

Keller, I., Largiadèr, C.R., 2003. Recent habitat fragmentation caused by major roads leads to reduction of gene flow and loss of genetic variability in ground beetles. Proc. R. Soc. Lond. B 270, 417–423. https://doi.org/10.1098/rspb.2002.2247.

Kingswood, S.C., Blank, D.A., 1996. Gazella subgutturosa. Mammalian species 490, 1–10. https://doi.org/10.2307/0.490.1.

Klein, J.A., Harte, J., Zhao, X.-Q., 2004. Experimental warming causes large and rapid species loss, dampened by simulated grazing, on the Tibetan Plateau. Ecol. Lett. 7, 1170–1179. https://doi.org/10.1111/j.1461-0248.2004.00677.x.

Koen, E.L., Bowman, J., Sadowski, C., Walpole, A.A., Tatem, A., 2014. Landscape connectivity for wildlife: development and validation of multispecies linkage maps. Methods Ecol. Evol. 5, 626–633. https://doi.org/10.1111/2041-210X.12197.

Krosby, M., Tewksbury, J., Haddad, N.M., Hoekstra, J., 2010. Ecological connectivity for a changing climate. Conserv. Biol. 24, 1686–1689. https://doi.org/10.1111/j.1523-1739.2010.01585.x.

Kullman, L., 2001. 20th Century climate warming and tree-limit rise in the Southern Scandes of Sweden. AMBIO J. Human Environ. 30, 72–80. https://doi.org/10.1579/0044-7447-30.2.72.

Lei, R., Jiang, Z., Liu, B., 2001. Group pattern and social segregation in Przewalski's gazelle (Procapra przewalskii) around Qinghai Lake, China. J. Zool. 255, 175–180. https://doi.org/10.1017/S0952836901001248.

Leslie, D.M., Schaller, G.B., 2008. Pantholops hodgsonii (Artiodactyla: Bovidae). Mammalian Species 42, 1–13. https://doi.org/10.1644/861.1.

Leslie Jr., D.M., 2010. Procapra picticaudata (Artiodactyla: Bovidae). Mamm Species 42 (861), 138–148.

Li, X., Yu, L.e., Sohl, T., Clinton, N., Li, W., Zhu, Z., Liu, X., Gong, P., 2016. A cellular automata downscaling based 1 km global land use datasets (2010–2100). Sci. Bull. 61, 1651–1661. https://doi.org/10.1007/s11434-016-1148-1.

Liao, Y., Lei, Y., Ren, Z., Chen, H., Li, D., 2017. Predicting the potential risk area of illegal vaccine trade in China. Sci. Rep. 7 https://doi.org/10.1038/s41598-017-03512-3.

Lin, Z., Zhao, X., 1996. Spatial characteristics of changes in temperature and precipitation of the Qinghai-Xizang (Tibet) Plateau. Sci. China Ser. D Earth Sci. 39, 442–448. https://doi.org/10.1360/yd1996-39-4-442.

Ma, B., Xie, Y., Zhang, T., Zeng, W., Hu, G., 2020. Identification of conflict between wildlife living spaces and human activity spaces and adjustments in/around protected areas under climate change: a case study in the Three-River Source Region. J. Environ. Manage. 262, 110322. https://doi.org/10.1016/j.jenvman.2020.110322.

Mann, M.E., Bradley, R.S., Hughes, M.K., 1998. Global-scale temperature patterns and climate forcing over the past six centuries. Nature 392, 779–787. https://doi.org/10.1038/33859.

Melillo, J.M., McGuire, A.D., Kicklighter, D.W., Moore, B., Vorosmarty, C.J., Schloss, A. L., 1993. Global climate change and terrestrial net primary production. Nature 363, 234–240. https://doi.org/10.1038/363234a0.

Meshinev, T., Apostolova, I., Koleva, E., 2000. Influence of warming on timberline rising: a case study on Pinus peuce Griseb. in BulgariaInfluence of warming on timberline rising: a case study on Pinus peuce Griseb. in Bulgaria. phyto 30, 431–438. https://doi.org/10.1127/phyto/30/2000/431.

Moiseev, P.A., Shiyatov, S.G., 2003. Vegetation dynamics at the treeline ecotone in the Ural highlands, Russia. In: G. G., Nagy L., Körner C., Thompson D.B.A. (Eds.), Alpine Biodiversity in Europe. Ecological Studies (Analysis and Synthesis). Berlin, pp. 423–435. https://doi.org/10.1007/978-3-642-18967-8_26.

Moreno-Amat, E., Mateo, R.G., Nieto-Lugilde, D., Morueta-Holme, N., Svenning, J.-C., García-Amorena, I., 2015. Impact of model complexity on cross-temporal transferability in Maxent species distribution models: an assessment using paleobotanical data. Ecol. Model. 312, 308–317. https://doi.org/10.1016/j.ecolmodel.2015.05.035.

Muscarella, R., Galante, P.J., Soley-Guardia, M., Boria, R.A., Kass, J.M., Uriarte, M., Anderson, R.P., 2014. ENM eval: an R package for conducting spatially independent evaluations and estimating optimal model complexity for Maxent ecological niche models. Methods Ecol. Evol. 5, 1198–1205. https://doi.org/10.1111/2041-210X.12261.

Opdam, P., Wascher, D., 2004. Climate change meets habitat fragmentation: linking landscape and biogeographical scale levels in research and conservation. Biol. Conserv. 117, 285–297. https://doi.org/10.1016/j.biocon.2003.12.008.

Pachauri, R.K., Allen, M.R., Barros, V.R., Broome, J., Cramer, W., Christ, R., Church, J.A., Clarke, L., Dahe, Q., Dasgupta, P., 2014. Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Ipcc, Switzerland.

Parmesan, C., 2006. Ecological and evolutionary responses to recent climate change. Annu. Rev. Ecol. Evol. Syst. 37, 637–669. https://doi.org/10.1146/annurev.ecolsys.37.091305.110100.

Parmesan, C., 2007. Influences of species, latitudes and methodologies on estimates of phenological response to global warming. Global Change Biol. 13, 1860–1872. https://doi.org/10.1111/j.1365-2486.2007.01404.x.

Parmesan, C., Ryrholm, N., Stefanescu, C., Hill, J.K., Thomas, C.D., Descimon, H., Huntley, B., Kaila, L., Kullberg, J., Tammaru, T., Tennent, W.J., Thomas, J.A., Warren, M., 1999. Poleward shifts in geographical ranges of butterfly species associated with regional warming. Nature 399, 579–583. https://doi.org/10.1038/21181.

Parmesan, C., Yohe, G., 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature 421 (6918), 37–42. https://doi.org/10.1038/nature01286.

Pearson, R.G., Dawson, T.P., 2003. Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful? Global Ecol. Biogeogr. 12, 361–371. https://doi.org/10.1046/j.1466-822X.2003.00042.x.

Phillips, S.J., Anderson, R.P., Schapire, R.E., 2006. Maximum entropy modeling of species geographic distributions. Ecol. Model. 190, 231–259. https://doi.org/10.1016/j.ecolmodel.2005.03.026.

Piao, S., Fang, J., He, J., 2006. Variations in vegetation net primary production in the Qinghai-Xizang Plateau, China, from 1982 to 1999. Clim. Change 74, 253–267. https://doi.org/10.1007/s10584-005-6339-8.

Pimm, S.L., Raven, P., 2000. Extinction by numbers. Nature 403, 843–845. https://doi.org/10.1038/35002708.

Qin, A., Jin, K., Batsaikhan, M.-E., Nyamjav, J., Li, G., Li, J., Xue, Y., Sun, G.e., Wu, L., Indree, T., Shi, Z., Xiao, W., 2020. Predicting the current and future suitable habitats of the main dietary plants of the Gobi Bear using MaxEnt modeling. Global Ecol. Conserv. 22, e01032. https://doi.org/10.1016/j.gecco.2020.e01032.

Root, T.L., Price, J.T., Hall, K.R., Schneider, S.H., Rosenzweig, C., Pounds, J.A., 2003. Fingerprints of global warming on wild animals and plants. Nature 421, 57–60. https://doi.org/10.1038/nature01333.

Sinervo, B., Mendez-de-la-Cruz, F., Miles, D.B., Heulin, B., Bastiaans, E., Villagran-Santa Cruz, M., Lara-Resendiz, R., Martinez-Mendez, N., Calderon-Espinosa, M.L., Meza-Lazaro, R.N., Gadsden, H., Avila, L.J., Morando, M., De la Riva, I.J., Sepulveda, P.V., Rocha, C.F.D., Ibarguengoytia, N., Puntriano, C.A., Massot, M., Lepetz, V., Oksanen, T.A., Chapple, D.G., Bauer, A.M., Branch, W.R., Clobert, J., Sites, J.W., 2010. Erosion of lizard diversity by climate change and altered thermal niches. Science 328, 894–899. https://doi.org/10.1126/science.1184695.

Song, G., Dong, X., Wu, J., Wang, Y.-G., 2017. Blockwise AICc for model selection in generalized linear models. Environ. Model. Assess. 22, 523–533. https://doi.org/10.1007/s10666-017-9552-8.

Stocker, T., 2014. Climate change 2013: the physical science basis. In: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, United Kingdom and New York. https://doi.org/10.1016/S0925-7721(01)00003-7.

Swets, J., 1988. Measuring the accuracy of diagnostic systems. Science 240, 1285–1293. https://doi.org/10.1126/science.3287615.

Thompson, L.G., Mosley-Thompson, E., Davis, M., Lin, P.N., Yao, T., Dyurgerov, M., Dai, J., 1993. "Recent warming": ice core evidence from tropical ice cores with emphasis on Central Asia. Global Planet. Change 7, 145–156. https://doi.org/10.1016/0921-8181(93)90046-Q.

VanDerWal, J., Murphy, H.T., Kutt, A.S., Perkins, G.C., Bateman, B.L., Perry, J.J., Reside, A.E., 2013. Focus on poleward shifts in species' distribution underestimates the fingerprint of climate change. Nat. Clim. Change 3, 239–243. https://doi.org/10.1038/nclimate1688.

Verstegen, J.A., van der Laan, C., Dekker, S.C., Faaij, A.P.C., Santos, M.J., 2019. Recent and projected impacts of land use and land cover changes on carbon stocks and biodiversity in East Kalimantan, Indonesia. Ecol. Ind. 103, 563–575. https://doi.org/10.1016/j.ecolind.2019.04.053.

Virkkala, R., Luoto, M., Heikkinen, R.K., Leikola, N., 2005. Distribution patterns of boreal marshland birds: modelling the relationships to land cover and climate. J. Biogeogr. 32, 1957–1970.

Visser, M.E., Perdeck, A.C., van Balen, J.H., Both, C., 2009. Climate change leads to decreasing bird migration distances. Global Change Biol. 15, 1859–1865. https://doi.org/10.1111/j.1365-2486.2009.01865.x.

Walker, M.D., Gould, W.A., Chapin, F.S., 2001. Scenarios of biodiversity changes in arctic and alpine tundra. In: S. O. E. Chapin F.S., Huber-Sannwald, E., (Eds.), Global Biodiversity in a Changing Environment. Ecological Studies (Analysis and Synthesis). Springer, New York, pp. 83–100. https://doi.org/10.1007/978-1-4613-0157-8_5.

Walther, G.-R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T.J.C., Fromentin, J.-M., Hoegh-Guldberg, O., Bairlein, F., 2002. Ecological responses to recent climate change. Nature 416, 389–395. https://doi.org/10.1038/416389a.

Wang, B., French, H.M., 1994. Climate controls and high-altitude permafrost, qinghai-xizang (tibet) Plateau, China. Permafrost Periglac. Process. 5 (2), 87–100. https://doi.org/10.1002/ppp.3430050203.

Wang, Y., Shen, Y., Feng, C., Zhao, K., Song, Z., Zhang, Y., Yang, L., He, S., 2016. Mitogenomic perspectives on the origin of Tibetan loaches and their adaptation to high altitude. Sci. Rep. 6 https://doi.org/10.1038/srep29690.

Warren, D.L., Seifert, S.N., 2011. Ecological niche modeling in Maxent: the importance of model complexity and the performance of model selection criteria. Ecol. Appl. 21 (2), 335–342.

Wilcove, D.S., Rothstein, D., Dubow, J., Phillips, A., Losos, E., 1998. quantifying threats to imperiled species in the United States. BioScience 48, 607–615. https://doi.org/10.2307/1313420.

Wisz, M.S., Hijmans, R.J., Li, J., Peterson, A.T., Graham, C., Guisan, A., N.P.S.D.W. Group, 2008. Effects of sample size on the performance of species distribution models. Divers. Distrib. 14, 763–773. https://doi.org/10.1111/j.1472-4642.2008.00482.x.

Xu, S.-Q., Yang, Y.-Z., Zhou, J., Jin, G.-E., Chen, Y.-T., Wang, J., Yang, H.-M., Wang, J., Yu, J., Zheng, X.-G., Ge, R.-L., 2005. A Mitochondrial genome sequence of the Tibetan Antelope (Pantholops hodgsonii). Genom., Proteom. Bioinf. 3, 5–17. https://doi.org/10.1016/S1672-0229(05)03003-2.

Yao, T., Liu, X., Wang, N., Shi, Y., 2000. Amplitude of climatic changes in Qinghai-Tibetan Plateau. Chin. Sci. Bull. 45, 1236–1243. https://doi.org/10.1007/BF02886087.

Yu, H., Song, S., Liu, J., Li, S., Zhang, L., Wang, D., Luo, S.-J., 2017. Effects of the Qinghai-Tibet railway on the landscape genetics of the endangered Przewalski's gazelle (Procapra przewalskii). Sci. Rep. 7, 1–13. https://doi.org/10.1038/s41598-017-18163-7.

Zhang, C., Willis, C.G., Klein, J.A., Ma, Z., Li, J., Zhou, H., Zhao, X., 2017. Recovery of plant species diversity during long-term experimental warming of a species-rich alpine meadow community on the Qinghai-Tibet plateau. Biol. Conserv. 213, 218–224. https://doi.org/10.1016/j.biocon.2017.07.019.

Zhang, K., Yao, L., Meng, J., Tao, J., 2018. Maxent modeling for predicting the potential geographical distribution of two peony species under climate change. Sci. Total Environ. 634, 1326–1334. https://doi.org/10.1016/j.scitotenv.2018.04.112.

Zhang, Y., Gao, Q., Dong, S., Liu, S., Wang, X., Su, X., Li, Y., Tang, L., Wu, X., Zhao, H., 2015. Effects of grazing and climate warming on plant diversity, productivity and living state in the alpine rangelands and cultivated grasslands of the Qinghai-Tibetan Plateau. Rangeland J. 37, 57–65. https://doi.org/10.1007/s40333-014-0010-z.