Potential spatial distributions of Tibetan antelope and protected areas on the Qinghai-Tibetan Plateau, China

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Abstract

Climate change has been regarded as a major factor affecting the geographic distribution of many endemic rare species on the Qinghai-Tibetan Plateau. Tibetan antelope, an endemic rare wildlife, is identified as a national first-class protected wild animal in China. To explore the impacts of human activities and climate change on the spatial distribution pattern of Tibetan antelope, the MaxEnt model was used to simulate the potential distribution of Tibetan antelope under four Shared Socio-economic Pathways in 2050s and 2070s and combined the modelling results of the main forage plants considering the food chains. The results showed that the environment indicators, e.g., elevation, mean temperature of wettest quarter, slope, mean temperature of warmest quarter, landcover, max temperature of warmest month, precipitation of driest month, *Stipa capillata*, *Oxytropis ochrocephala*, human influence index, were the main factors controlling the distribution of Tibetan antelope. The potential distributions of Tibetan antelope and their 10 forage plants were significantly different under future climate scenarios such as expanding, contracting and shifting. The mean elevation of suitable habitats for Tibetan antelope all increased under the four future scenarios compared with current value. There were protection gaps for Tibetan antelope. Considering the long-distance migration, the integrity of the ecosystem including Qiangtang National Nature Reserve, Altun National Nature Reserve, and Kekexili National Nature Reserve would be established for Tibetan antelope. Our findings will provide important references for the protection and investigation of Tibetan antelope.

Introduction

From 1880 to 2012, the global annual average temperature rose by 0.85 ° C, and it is predicted that it will continue to rise in the future (IPCC 2018). Continuous climate change has a significant influence on species distribution (Davis and Shaw 2001). Many species with narrow niches may face increasing risk of habitat loses under climate changes and intensified human activities (Svenning and Skov 2005; Pearson et al. 2014). The QTP is one of the most sensitive regions in the world. Due to the drastically changes in terrain and climate, it has a high degree of diversity (Liu et al. 2018). In recent decades, compared with other low altitude regions in the world, the QTP is experiencing an unprecedented warming period (Dong et al. 2012). The threatens to the habitats of endemic species on the QTP may increase with climate changes.

Tibetan antelope (*Pantolops hodgsonii*), known as the “elves of the plateau” (Feng et al. 2008), is endemic to the QTP (Buho et al. 2011). Tibetan antelope is identified as a national first-class protected wild animal in China (World Heritage Encyclopedia 2016), listed as an Appendix 1 species (CITES) (CITES 2017), and classified as Near Threatened (NT) by The International Union for the Conservation of Nature (IUCN) Red List in 2016 (IUCN 2016). Tibetan antelopes are mainly distributed in the alpine desert ecosystem about 3700–5000 m in Qinghai, Tibet and Xinjiang province of China. Its habitats are mostly desert steppe, alpine vegetation, and some alpine meadows and swamps with simple vegetation community structure, sparse plants and low coverage. *Poaceae*, *Cyperaceae* and *Leguminosae* plants make up the main recipes for Tibetan antelope (Cao 2007).

The spatial patterns distribution of vegetation forages determines the distributions and numbers of wildlife based on the food networks. On the other hand, human activities are the main factor affecting the habitat selection of Tibetan antelopes (Xia et al. 2007). Tibetan antelopes will obviously avoid human activity area when choosing habitats as their natural alertness. Many studies have demonstrated that the vegetation types can largely determine the habitat chooses of wildlife. For example, Vina et al. (2008) reported that the classification of vegetation through MODIS data can successfully predict the distribution of giant pandas in Wolong reserve Situation. Ito et al. (2006) pointed out that the NDVI can be used as an effective indicator of animal habitat. However, in previous studies, when predicting the future habitat of wild animals, little consideration was given to changes in the food habitat required by animals.

Species distribution models (SDMs), also known as ecological niche models (ENMs) (Brown et al. 2017), are employed to simulate the potential habitats of species (Conolly et al. 2012). In recent decades, SDMs have played a significant role in simulating the potential suitable habitats of species under climate change, and have been widely selected in the fields of ecology, biology, biogeography, species conservation, and evolutionary biology (Araujo and Guisan 2006). Among various SDM methods, the MaxEnt model has performed a better simulation ability, and has been one of the most widely used models currently (Zeng et al. 2016; Phillips et al. 2017).

In this study, the impacts of climate change and human activities were combined to simulate the potential distribution of Tibetan antelope using the MaxEnt model in current, 2050s and 2070s. The objectives of this study are: (1) to assess the most important environmental factors affecting the distribution of Tibetan antelope and determine the area of suitable habitats; (2) to reveal the changes of the suitable habitat will vary with climate scenarios; and (3) to propose recommendations for the protection areas of Tibetan antelope based on the results of our analysis.

Materials And Methods

Study area

The Qinghai-Tibetan Plateau, well known as the “Roof of the World” and the “third pole”, is located in western China (Liu et al. 2018). It lies between 20°N to 39°N and 73°E to 104°E and covers Tibet, Qinghai, Gansu, Sichuan, Yunnan and Xinjiang of China with an average elevation of more than 4000 m and a total area of about 2.5 million square kilometers. From the northeast to the southwest of QTP, there are forest, shrub, alpine grassland, alpine meadow and alpine desert ecosystem (Xia et al. 2021). The annual average temperature of the QTP will increase 1.6-2.0 ℃ by 2050 and rise 1.2-3.0 ℃ by2070 caused by greenhouse gas emissions under global warming (Wei et al. 2021). Rapid climate change, human activities and landcover change are becoming the greatest drivers threatening biodiversity (Leach et al. 2013). Many species on the QTP will face extinction due to the continuous temperature rise (Wang et al. 2021). The QTP is an natural laboratory for studying the adaptation of species to climate change.

Occurrence data

From 2020 to 2021, a survey of Tibetan antelope was carried out using the transect method, and a total of 41 spatial distribution data of Tibetan antelopes were recorded. The data of 97 Tibetan antelope distribution data were obtained from the network. Finally, we obtained 138 distribution points for Tibetan antelope. 10 forge plants of Tibetan antelope were as follows: *Stipa capillata*, *Stipa purpurea*, *Poa annua, Poa crymophila*, *Kobresia humilis*, *Kobresia pygmaea*, *Saussurea arenaria*, *Saussurea superba*, *Oxytropis ochrocephala*, *Androsace integra* (Table 1). The 21 occurrence data of Tibetan antelope and all the distribution points of 10 forage plants were obtained from the following sources: Global Biodiversity Information Facility (https://www.gbif.org), China Digital Herbarium (https://www.cvh.ac.cn) and CNKI database (https://www.cnki.net). Duplicate records were removed and the records wihout precise geographic locations were examined by Google Earth (http://ditu.google.cn). The longitude and latitude of the sample were imported in Excel and changed to CSV format for model.

Table 1
The list of the 10 forage plants for the Tibetan antelope

Plant name	Family	Genus	Occurrence records
Stipa capillata	Poaceae	Stipa	26
Stipa purpurea	Poaceae	Stipa	228
Poa annua	Poaceae	Bluegrass	203
Poa crymophila	Poaceae	Bluegrass	68
Kobresia humilis	Cyperaceae	Sorrel	48
Kobresia pygmaea	Cyperaceae	Sorrel	233
Saussurea arenaria	Compositae	Pseudomonas	46
Saussurea superba	Compositae	Pseudomonas	54
Oxytropis ochrocephala	Leguminosae	Acanthobean	89
Androsace integra	Primrose	Plumeria	47

Environment variables

Climate data

The Current (average for the period 1970–2000) and future (2050s and 2070s) bioclimatic variables were downloaded from the WorldClim Global Climate Database (version 2.1) at 30" spatial resolution (approximately 1 km^2) (Fick and Hijmans 2017), which reflected temperature and precipitation. The future climate model adopted the second-generation National (Beijing) Climate Center moderate resolution climate system model (BCC-CSM2-MR) provided by the sixth phase of the Coupled Model Intercomparison Projects, which was more skilled in reproducing the climate average state and standard deviation of soil moisture with enhanced model correlation and significantly reduced deviation (Sang et al. 2020). Considering the influences of climate change scenarios on the model development accuracy (Santos-Hernandez et al. 2021), the four Shared Socioeconomic Pathways (SSPs: SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5) were selected for future simulation (Riahi et al. 2017). SSP1-2.6 is the updated scenario of RCP2.6, which reflects a sustainable development path with a low level of greenhouse-gas emissions; SSP2-4.5 is the updated circumstance of RCP4.5, which is a moderate development path with a intermediate level of greenhouse-gas emissions; SSP3-7.0 is the updated circumstance of RCP7.0, which represents a mediate-high development path with a moderate high level of greenhouse-gas emissions; and SSP5-8.5 is the updated circumstance of RCP8.5, which uses the development path dominated by fossil fuels with a high level of greenhouse-gas emissions (Riahi et al. 2017; Li et al. 2020).

Terrain data

The Digital Elevation Model (DEM) was obtained from NASA's WIST Earth Databasethe (http://srtm.csi.cgiar.org/). Terrain data including elevation, slope and aspect were extracted from DEM using spatial analyst tools in ArcGis 10.7.

Soil data

Soil variables are the key factors affecting plant species distribution (Song and Liu 2019). The topsoil data used for simulating the plant food of Tibetan antelope were extracted from Harmonized World Soil Database (HWSD, http://www.fao.org/soils-portal).

Human influence index and land cover

The data of Human Influence Index (HII) was downloaded from the NASA Socioeconomic Data and Application Center. The human impact index is a global dataset of 1 km grid cell, which is created by 9 global data layers, including human population pressure (population density), human land use and infrastructure (built-up area, night lighting, land use/land cover) and human channels (coastline, roads, railways, navigable rivers). The data of land cover was obtained from Geographical National Condition Monitoring Cloud Platform (http;//www.resdc.cn/).

Treatment and selection of environment factors

All the environment grid data were resampled to the same spatial resolution with approximately 1 km^2 and were converted to the asc format for model. The autocorrelation and multiple linear repetition among the environmental factors have an effect on the simulation results (Carlos et al. 2015), so the correlation coefficient was used to choose the environmental factors for model and the environmental variables with high correlation were eliminated (Dupin et al. 2011). Environmental factors with correlation coefficient less than 0.8 and high contribution rate were adopted for simulation to enhance the model accuracy (Table 2) (Johnson et al. 2016).

Table 2
Environmental variables selected for Tibetan antelope and 10 plants modelling in this study

Variable name for Tibetan antelope	Variable name for 10 plants
Elevation	Elevation
Aspect	Aspect
Slope	Slope
Max temperature of warmest month (Bio5)	Max temperature of warmest month (Bio5)
Temperature annual range (Bio7)	Mean temperature of wettest quarter (Bio8)
Mean temperature of wettest quarter (Bio8)	Mean temperature of driest quarter (Bio9)
Mean temperature of driest quarter (Bio9)	Mean temperature of warmest quarter (Bio10)
Mean temperature of warmest quarter (Bio10)	Mean temperature of coldest quarter (Bio11)
Annual precipitation (Bio12)	Annual precipitation (Bio12)
Precipitation of wettest month (Bio13)	Precipitation of wettest month (Bio13)
Precipitation of driest month (Bio14)	T_BULK_DEN
Landcover	T_CEC_CLAY
Human influence index	T_CEC_SOIL
MaxEnt results of 10 plants	

MaxEnt model processing

We supposed that climate change could also affect the distribution of food trains of wildlife. When simulating the future habitats of Tibetan antelope, we considered the impacts of climate change on food resources and the influences of human activities in this study. The MaxEnt software was selected to predict the potential distribution of Tibetan antelope and its plant food based on the species geographic locations and the environmental variables. Among the distribution point data, 70% were set for training, and the remaining 30% were set for testing (Sjv and

Pona). The model can create the probability graph of species distribution in three output forms (logical, cumulative and primitive). The logical output format was selected to obtain the probability of species existence and the value of the suitability ranged from 0 (not applicable) to 1 (best applicable) (Urbani et al. 2015). The number of repeated operations was set to 10. Other parameter settings were set with maximum iterations of 500, maximum number of background points of 10,000 and a convergence threshold of 0.00001 (Elith et al. 2011). The area under receiver-operating characteristic curve (AUC) was adopted to evaluate the model operation accuracy. The AUC values ranged from 0.5 to 1. When the value was 0.5–0.6, the model was regarded as fail, 0.6–0.7 was poor, 0.7–0.8 was fair, 0.8–0.9 was good and 0.9–1 was excellent (Fourcade et al. 2014). The higher the value, the closer the spatial distribution of the simulated species is to the actual distribution (Soucy et al. 2018). The importance of each environmental variable in the model was evaluated by the Jackknife method (Pearson et al. 2007).

Analysis of model prediction

The "ASCII" format results of MaxEnt's simulation of the habitat suitability of Tibetan antelope and 10 plants eaten by Tibetan antelope were converted into raster format by ArcGIS. Using the reclassification tool of ArcGIS, the suitable habitat is divided into 4 grades: the existence probability more than 0.6 is the high suitable area; the existence probability 0.4 ~ 0.6 is the medium suitable area; the existence probability 0.2–0.4 is the low suitable area; the existence probability lower than 0.2 is the unsuitable area (Padalia et al. 2015; Li et al. 2020). Different colors were selected to represent the overlapping parts of the suitable distribution areas of Tibetan antelope and 10 plants, and ArcGIS zonation tool was used to analyze and calculate the area and elevation of the 4 grade areas on the QTP (Brown 2014). The raster calculator on ArcGIS platform was used to binarize and overlay to obtain the richness of 10 plants eaten by Tibetan antelope (Figure. 2). The selection threshold was 0.05, and the continuous habitat suitability of each plant was transformed into a binary habitat. In terms of the abundance value, four grades (0, 1, 2–3, 4–8) were divided to reflect the distribution trend of plants. The tool of "Distribution changes between binary SDMs" was used to calculate the area changes between different time periods (Hu et al. 2019).

Results

Accuracy of the Maxent model and importance of environmental factors

The testing and training AUCs of the models for 10 plants eaten by Tibetan antelope were more than 0.8, demonstrating that the model performance was good. The testing and training AUCs of the models for Tibetan antelope were higher than 0.9, showing that the model performance was excellent. In a word, the model accuracy indicated that all the model performances were acceptable.

The main environmental variables influencing the Tibetan antelope and 10 forage plants distribution and their contribution rates were obtained from the jackknife analysis. The important variables affecting the distribution of Tibetan antelope as follows: elevation, mean temperature of wettest quarter (Bio8), slope, mean temperature of warmest quarter (Bio10), landcover, max temperature of warmest month (Bio5), precipitation of driest month (Bio14), *Stipa capillata*, *Oxytropis ochrocephala* and human influence index (HII) (Table 3). All the contribution of these variables was 97.6%, indicating that the Tibetan antelope distribution was strongly affected by these factors. The contribution rate of the three terrain variables was 40.6%. All the contribution rate of bioclimatic variables was 39.8%. The contribution rate of the landcover and human influence index were 10.3%. The total contribution rate of plant variables was 7.9%. It indicated that the influence of the topography and bioclimatic variables on the Tibetan antelope distribution was much greater than that of plants, landcover and human influence index. The important variables affecting the distribution of 10 plants eaten by Tibetan antelope as follows: elevation, annual precipitation (Bio12), mean temperature of coldest quarter (Bio11), slope, precipitation of wettest month (Bio13), mean temperature of driest quarter (Bio9), aspect, T_BULK_DEN and max temperature of warmest month (Bio5). The contribution rate of the three terrain variables was 63.53%. All the contribution rate of the bioclimatic variables was 33.8%. The results indicated that the distribution of the 10 plants eaten by the Tibetan antelope was strongly influenced by climatic and terrain variables.

Current potential distribution of 10 plants eaten by the Tibetan antelope

The potential distribution area for 10 plants with the richness of 4–8 under current climate scenario was 181,626 km^2, and mainly scattered in the southern of QTP (Fig. 3). The mean elevation for 10 plants with the richness of 4–8 under current climate scenario was 3879 m. The potential distribution area for 10 plants with the richness of 2–3 under current climate scenario was 539,638 km^2. The mean elevation for 10 plants with the richness of 2–3 under current climate scenario was 4358 m. The average altitude of all the potential distribution of 10 plants under current climate circumstance was between 3879 m and 4262 m.

Table 3
The contribution percentage of environmental variables.

Tibetan antelope		**10 forage plants**	
Variables	Contribution (%)	Variables	Mean contribution (%)
Elevation	25.1	Elevation	55.05
Bio8	16.6	Bio12	18.08
Slope	15.5	Bio11	6.69
Bio10	12.1	Slope	5.86
Landcover	8.5	Bio13	3.09
Bio5	5.9	Bio9	2.64
Bio14	5.2	Aspect	2.62
Stipa capillata	5	T_BULK_DEN	1.89
Oxytropis ochrocephala	1.9	Bio5	1.72
Human influence index	1.8	Bio10	0.75
Poa crymophila	0.9	T_CEC_CLAY	0.72
Bio7	0.5	Bio8	0.41
Stipa purpurea	0.1	T_CEC_SOIL	0.25
Androsace integra	0.1		
Aspect	0.1		

Current potential distribution of the Tibetan antelope

The current potential suitable habitat of Tibetan antelope covered a total area of 502,906 km^2 (about accounting for 20% of QTP), and were mostly concentrated in Shenza County, Nima county and Zhongba County of Tibet Automonous Region, Zhiduo County and Qumalai County of Qinghai province and Ruoqiang County of Xinjiang Uygur Autonomous (Fig. 4). The areas of high, moderately and low potential suitable habitat were 65,119 km^2, 130,426 km^2 and 307,361 km^2, respectively. Qiangtang National Nature Reserve, Kekexili National Nature Reserve and Altun National Nature Reserve were the main suitable habitats for Tibetan antelope.

Future potential distribution of Tibetan antelope

Under the four climate scenarios, the distribution changes in potential suitable habitats for Tibetan antelope during the two future periods were different. Yet there were some similarities in the trends. Under the four future climate scenarios in 2050s, the area of high, moderately and low suitable habitats all increased compared with current value. Under the four future climate scenarios in 2070s, the area of low suitable habitats all decreased compared with current value. In 2050s, the tatal area of high, moderately and low suitable habitats increased from SSP1-2.6 to SSP2-4.5, decreased from SSP2-4.5 to SSP3-7.0, and increased from SSP3-7.0 to SSP5-8.5. However, the total area of high, moderately and low suitable habitats decreased from SSP1-2.6 to SSP2-4.5, increased from SSP2-4.5 to SSP3-7.0, and decreased from SSP3-7.0 to SSP5-8.5 in 2070s (Table 4, Fig. 5).

The mean elevation of the high, moderately and low suitable habitats all increased compared with current value under the four future scenarios in 2050s and 2070s. The mean elevation of the high suitable habitats climbed from SSP1-2.6 (4767 m) to SSP5-8.5 (4838 m) in 2050s. The mean elevation of the high suitable habitats declined from SSP1-2.6 (4771 m) to SSP3-7.0 (4736 m), and increased from SSP3-7.0 to SSP5-8.5 (4778 m) in 2070s. The mean elevation of the moderately suitable habitats increased from SSP2-4.5 to SSP5-8.5 in 2050s and 2070s. The mean elevation of the low suitable habitats also increased from SSP2-4.5 to SSP5-8.5 in 2050s. The minimum mean elevation (4698 m) was at the high suitable habitat under current climate circumstance. The maximum mean elevation (4838 m) was at the high suitable habitat under the SSP5-8.5 circumstance in 2050s (Table 5).

Table 4. The area of the potential suitable habitats under different climate scenarios.

Habitat Suitability	The area of suitable habitats under different climate scenario (km2)								
	2050s				2070s				Current
	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5	
High suitable habitat	71,825	73,151	72,743	80,694	86,939	68,312	59,639	81,756	65,119
Moderately suitable habitat	151,919	154,935	155,246	158,990	161,197	124,947	154,821	147,399	130,426
low suitable habitat	320,213	318,869	294,409	351,395	303,661	279,579	302,231	271,786	307,361
Total suitable habitat	543,957	546,955	522,398	591,079	551,797	472,838	516,691	500,941	502,906

Table 5
The mean elevation of the potential suitable habitats under different climate scenarios.

Habitat Suitability	The mean elevaton of suitable habitats under different climate scenario								The mean elevation of suitable habitats under current climate
	2050s				2070s				
	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5	
High suitable habitat	4767	4771	4780	4838	4771	4739	4736	4788	4698
Moderately suitable habitat	4775	4760	4776	4834	4781	4767	4783	4826	4749
low suitable habitat	4794	4786	4791	4826	4795	4801	4789	4807	4770

Area changes of suitable habitats under different climate scenarios

We used the tool of “Distribution Changes Between Binary SDMs” by ArcGis to obtain the area changes of suitable habitats under different climate scenarios from current to 2050s and from current to 2070s, The results demonstrated that the area of suitable habitats under SSP2-4.5 from current to 2070s would shrink largest than other climate scenarios (Fig. 6). The SSP2-4.5 in 2070s was regarded as the worst scenario for Tibetan antelope. The area of suitable habitats under SSP1-2.6 from current to 2070s would expand largest than other climate scenarios. The SSP1-2.6 in 2070 was regarded as the best suitable habitats for Tibetan antelope. The results showed that the expanded habitat areas were basically larger than the predicted shrinking areas. This potential expanded habitats would be regarded as a new refuge for Tibetan antelope.

The Intersection Distribution Changes With The Forage Plants And Tibetan Antelope

We analyzed the intersection distribution changes of the 10 plants and Tibetan antelope under future climate scenarios. The results demonstrated that the area of the intersection distribution expanded most under the SSP5-8.5 scenario which were suitable for Tibetan antelope and main forge plants. The area of the intersection distribution shrank from SSP1-2.6 (72,081 km^2) to SSP2-4.5 (44,900 km^2) and gone on expanding to SSP5-8.5 (78,436 km^2) in 2050s. The area of the intersection distribution expanded from SSP1-2.6 (32,979 km^2) to SSP2-4.5 (70,712 km^2), shrank from SSP2-4.5 to SSP3-7.0 (58,986 km^2) and expanded to SSP5-8.5 (88,568 km^2) in 2070s. The smallest area of the intersection distribution was 44,900 km^2 under SSP2-4.5 in 2050s. The largest area of the intersection distribution was 88,568 km^2 under SSP5-8.5 in 2070s. If there was grass, there would not be sheep, and where there were sheep, there would not be grass (Fig. 7).

Discussion

Analysis of main influencing factors

Environmental factors affect the distribution, survival and reproduction of species. Therefore, the species are intend to change their habitats to adapt to the changing environment. There are two important environmental variables for the species on the QTP, namely the elevation and the changeable climate.

Elevation can limit the distribution of the species living on the high-altitude regions because it decides the food resources related to the temperature and precipitation. The results indicated that elevation was the most key factor limiting the distribution of the Tibetan antelope. The mean elevation of the suitable habitats for the Tibetan antelope was between 4446 m and 4699 m (Table 4). where the temperatures is lower and the Tibetan antelopes are tolerant to low temperature (Zhang et al. 2021).

In previous studies, climate has often been considered as the important factor affecting the distribution of the species (Pearson and Dawson 2003; Virkkala et al. 2005). The temperature and the precipitation can directly affect the behavior and the physiology tolerance of the species and also indirectly affect the growth of vegetation supplied for the species (Fuller et al. 2016). The results showed that mean temperature of wettest quarter (Bio8), mean temperature of warmest quarter (Bio10), max temperature of warmest month (Bio5) and precipitation of driest month (Bio14) were the main climate variables affecting the distribution of the Tibetan antelope. It has been found that the seasonal climate change can seriously affect the seasonal reproduction of mammals and can result in a significant decline in the reproduction and the abundance of food resource (Parmesan 2007; Bronson 2009).

The contribution rate of the land cover and human influence index were 8.5% and 1.8% respectively. Land cover can constrict the species distribution with their various occupation types on the landscape (Cord et al. 2014). Although the impact of land cover and human influence index were not significant, they could induce grassland degradation and decrease of available food resources for Tibetan antelope in the future (Zhang et al. 2015). Other human factors such as tourism, mining and herb collection would also have the influence on the distribution of habitats (Edmonds 2009). If they were considered, the accuracy of the analyses would increase.

Potential distribution for Tibetan antelope and their forage plants

As far as we know, the research is the first quantitative study on the suitable habitat and distribution of Tibetan antelope and forage plants on the QTP. The previous study mainly concentrated on the study of the Tibetan antelope at some certain region of the QTP. Feng et al (2016) identified and ranked the distribution of the Tibetan antelope in the Chang Tang district of the QTP. The result demonstrated that the suitable habitat of the Tibetan antelope was spread primarily in the central (Nyingma county and Shuanghu county) and western (Geze county) regions of the Chang Tang. Bleisch et al (2009) studied the migration of the Tibetan antelope at the Arjinshan Nature Reserve and Xia et al (2007) studied the influences of the Qinghai-Tibet railway on the migration of Tibetan antelope in Kekexli National Nature Reserve. Our results showed that the suitable habitats of the Tibetan antelope mainly concentrated in the Altun, Qiangtang and Kekexili National Nature Reserve. The Tibetan antelope, the flagship species of the QTP, has achieved recovery growth in the past five years with the establishment and protection of Qiangtang and Kekexili National Reserves. The wild population has increased from about 60,000 in 1995 to about 200,000 at present. The threat level has been reduced from Endangered (EN) to Near Threatened (NT) (Fu et al. 2021). The Tibetan antelope showed an increasing trend, which was consistent with our findings that the area of high, moderately and low suitable habitats increased compared with its current value except under SSP3-7.0 in 2050s. We found there were significant differences in the impacts of climate change on the potential habitats of Tibetan antelope and 10 plants with food chain relationships (Fig. 8). The changes of the potential distributions of Tibetan antelope and forage plants with climate change need the flexible actions in future protection planning

In addition, the prohibition of grazing may alter the local vegetation in some cases, but in other cases, wild herbivores will replace cattle and sheep to eat grass, helping to maintain balance. The number of Tibetan antelope has increased in this way. Many animals on QTP are actually very adaptable to low-grade roads. We usually find high biodiversity along the road. Tibetan antelope activities and human transportation can be guaranteed along the Qinghai Tibet Highway (Zhao 2022).

Suggested Protected Area of the Tibetan antelope based on this research

In this study, the current and future species distribution probability maps (TIF format) generated by Maxent simulation were selected as input data to carry out systematic conservation planning in Zonation v4 software. The weight of the current potential habitat was set to 2. The weight of the future prediction result was set to 1 (Moilanen 2007). Other parameters in the model were set as default values. The output of the zonation model was reclassified to obtain three priority protection level (Yang et al, 2019). The top 10% of the conservation value was mandatory reserve (257,403 km^2), 10%-20% of the conservation value was negotiable reserve (257.417 km^2), and 20%-30% of the conservation value was partial reserve (257.412 km^2) (Fig. 8). Based on the overlay analysis of the priority conservation areas and established protected areas, we found that there were protection gaps for the Tibetan antelope. Considering the long-distance migration, we should protect a large area including Qiangtang National Nature Reserve in Tibet Autonomous, the Altun National Nature Reserve in Xinjiang Uygur Autonomous Region, and Kekexili National Nature Reserve in Qinghai Province, which may be a reasonable region for the integrity of the ecosystem.

Based on a large number of basic investigations and researches, the research used the MaxEnt model to establish a systematic, comprehensive, accurate and reliable database of species distribution, evaluated the habitat suitability of Tibetan antelopes with important ecological roles, preliminarily discussed the spatial distribution patterns of the Tibetan antelopes and 10 plants with food chain relationships, and analyzed the correlation between suitable habitats and the main environmental variables. The follow-up research will form the spatial distribution map of Tibetan antelope conservation gaps on the QTP through the assessment of the Tibetan antelope habitat and the spatial overlay analysis of the data layers of various nature reserves. Areas that have not been designated as fragile ecosystems or important ecological functions can be used as implementation areas for the optimized layout of the nature reserve network and the construction of ecological corridors. Our study will provide data support for the selection and protection of potential suitable habitats for the Tibetan antelope on the QTP.

Conclusions

In this study, we used the MaxEnt model to simulate the potential distribution of Tibetan antelope and 10 forage plants with the food chains under different climate scenarios in 2050s and 2070s. The important variables affecting the distribution were evaluated, and the areas and the mean elevation changes of the suitable habitats were calculated. The conclusions were as follows:

1. Elevation, mean temperature of wettest quarter (Bio8), slope, mean temperature of warmest quarter (Bio10), land cover, max temperature of warmest month (Bio5), precipitation of driest month (Bio14), *Stipa capillata*, *Oxytropis ochrocephala* and human influence index (HII) were the main factors which could limit the distribution of the Tibetan antelope. The important variables affecting the distribution of 10 plants eaten by Tibetan antelope as follows: elevation, annual precipitation (Bio12), mean temperature of coldest quarter (Bio11), slope, precipitation of wettest month (Bio13), mean temperature of driest quarter (Bio9), aspect, T_BULK_DEN and max temperature of warmest month (Bio5).
2. The potential distributions of Tibetan antelopes and their 10 forage plants were significantly different under different climate scenarios in 2050s and 2070s such as expanding, contracting and shifting. The expanded habitat areas were basically larger than the predicted shrinking areas. The mean elevation of the high, moderately and low suitable habitats for Tibetan antelope all increased compared with current value under the four future scenarios in 2050s and 2070s.

3. There were protection gaps for Tibetan antelope. Considering the long-distance migration, we should protect a large area including Qiangtang National Nature Reserve in Tibet Autonomous, the Altun National Nature Reserve in Xinjiang Uygur Autonomous Region, and Kekexili National Nature Reserve in Qinghai Province, which may be a reasonable area for the integrity of the ecosystem.
4. The following conservation measures for Tibetan antelope in the future on the QTP would be taken, such as considering the suitable habitats in national park planning, constructing migration corridors, constructing and restoring water points and strengthening the monitor of Tibetan antelope.
5. Our findings will provide important references for the protection and investigation of Tibetan antelope on the QTP and provide the data support for the protection and selection of potential habitats for wildlife in national nature reserves.

Declarations

Author contributions

HH: the main data search, processing, and paper writing work; YW and WW: proposed the paper ideas and carried out the paper revision work; ZC: helped to collect and check the data. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

All environmental variables used in the manuscript are already publicly accessible, and we have provided the download address in the manuscript; relevant sampling site information can be found in the online version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

1. Araujo, M. B.and Guisan, A (2006) Five (or so) challenges for species distribution modelling. Journal of Biogeography 33:1677-1688. https://doi.org/ 10.1111/j.1365-2699.2006.01584.x
2. Bleisch, W. V., Buzzard, P. J., Zhang, H., Xue, D., Liu, Z., Li, W., et al (2009) Surveys at a Tibetan antelope Pantholops hodgsonii calving ground adjacent to the Arjinshan Nature Reserve, Xinjiang, China: decline and recovery of a population. Oryx 43:191-196. https://doi. org/10.1017/s0030605308001506
3. Bronson, F. H (2009) Climate change and seasonal reproduction in mammals. Philosophical Transactions of the Royal Society B-Biological Sciences 364:3331-3340. https://doi.org/10.1098/rstb.2009.0140

4. Brown, J. L (2014) SDMtoolbox: a python-based GIS toolkit for landscape genetic, biogeographic and species distribution model analyses. Methods in Ecology and Evolution
5. Brown, J. L., Bennett, J. R.and French, C. M (2017) SDMtoolbox 2.0: the next generation Python-based GIS toolkit for landscape genetic, biogeographic and species distribution model analyses. PeerJ 5:e4095
6. Buho, H., Jiang, Z., Liu, C., Yoshida, T., Mahamut, H., Kaneko, M., et al (2011) Preliminary study on migration pattern of the Tibetan antelope (Pantholops hodgsonii) based on satellite tracking. Advances in Space Research 48:43-48. https://doi.org/10.1016/j.asr.2011.02.015
7. Carlos, L. A., Neves, D. M., Barbosa, N. P. U., Moulton, T. P.and Creed, J. C (2015) Occurrence of an invasive coral in the southwest Atlantic and comparison with a congener suggest potential niche expansion. Ecology and Evolution 5:2162-2171. https://doi.org/10.1002/ece3.1506
8. Cao, Y. F., Su, J. P., lian, X. M., Zhang, T. Z., Cui, Q. H (2007) Dietary Analysis of Tibetan Antelopes in Hoh Xil Nature Reserve. Acta Theriologica Sinica. (01):14-19. https://doi.org/10.16829/j.slxb.2008.01.003
9. CITES, 2017. Convention on International Trade in Endangered Species of Wild Fauna and Flora. AppendicesI,IIandIII.Https://cites.org/sites/default/files/eng/app/2017/E-Appendices-2017-10-04
10. Conolly, J., Manning, K., Colledge, S., et al (2012) Species distribution modelling of ancient cattle from early Neolithic sites in SW Asia and Europe. HOLOCENE -SEVENOAKS-
11. Cord, A. F., Klein, D., Mora, F.and Dech, S (2014) Comparing the suitability of classified land cover data and remote sensing variables for modeling distribution patterns of plants. Ecological Modelling 272:129-140. https://doi.org/10.1016/j.ecolmodel.2013.09.011
12. Davis, M. B.and 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
13. Dong, M. Y., Jiang, Y., Zheng, C. T.and Zhang, D. Y (2012) Trends in the thermal growing season throughout the Tibetan Plateau during 1960-2009. Agricultural and Forest Meteorology 166:201-206. https://doi.org/10.1016/j.agrformet.2012.07.013
14. Dupin, M., Reynaud, P., Jarosik, V., Baker, R., Brunel, S., Eyre, D., et al. (2011) Effects of the Training Dataset Characteristics on the Performance of Nine Species Distribution Models: Application to Diabrotica virgifera virgifera. Plos One 6. doi: 10.1371/journal.pone.0020957
15. Edmonds, R. L (2009) Wildlife Conservation in China: Preserving the Habitat of China's Wild West. China Quarterly:804-805
16. Elith, J., Phillips, S. J., Hastie, T., Dudik, M., Chee, Y. E.and Yates, C. J (2011) A statistical explanation of MaxEnt for ecologists. Diversity and Distributions 17:43-57. https://doi: 10.1111/j.1472-4642.2010.00725.x
17. Feng, F., Yang, Z., Owens, J. R., Hou, R., Zhang, Z.and Qi, D (2016) An assessment of endangered species habitat at large scale: chiru distribution across the Tibetan region of Chang Tang. Folia Zoologica 65:65-71. https://doi.org/10.25225/fozo.v65.i1.a10.2016
18. Feng, Z., Fan, B., Li, K., Zhang, Q. D., Yang, Q. S.and Liu, B (2008) Molecular characteristics of Tibetan antelope (Pantholops hodgsonii) mitochondrial DNA control region and phylogenetic inferences with related species. Small Ruminant Research 75:236-242. https://doi.org/10.1016/j.smallrumres.2007.06.011
19. Fick, S. E.and Hijmans, R. J (2017) WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. International Journal of Climatology 37:4302-4315. https://doi.org/10.1002/joc.5086
20. Fourcade, Y., Engler, J. O., Rodder, D.and Secondi, J (2014) Mapping Species Distributions with MAXENT Using a Geographically Biased Sample of Presence Data: A Performance Assessment of Methods for Correcting Sampling Bias. Plos One 9. https://doi.org/ 10.1371/journal.pone.0097122

21. Fuller, A., Mitchell, D.and Maloney..., S. K (2016) Towards a mechanistic understanding of the responses of large terrestrial mammals to heat and aridity associated with climate change. Climate Change Responses 3
22. Fu, B. J., Ouyang. Z., Shi, P., Fan, J., Wang, X. D., Zheng. H., et al (2021) Current Condition and Protection Strategies of Qinghai-Tibet Plateau Ecological Security Barrier. Policy & Management Research.
23. Hu, Z. J., Guo, K., Jin, S. L.and Pan, H. H (2019) The influence of climatic changes on distribution pattern of six typical Kobresia species in Tibetan Plateau based on MaxEnt model and geographic information system. Theoretical and Applied Climatology 135:375-390. https://doi.org/ 10.1007/s00704-018-2373-0
24. IPCC (2018) An IPCC special report on the impacts of global warming of 1.5 C above pre-i ndustrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. http://www.ipcc.ch/report/sr15/.
25. Ito, T. Y., Miura, N., Lhagvasuren, B., Enkhbileg, D., Takatsuki, S., Tsunekawa, A., et al (2006) Satellite tracking of Mongolian gazelles (Procapra gutturosa) and habitat shifts in their seasonal ranges. Journal of Zoology 269:291-298. https://doi.org/ 10.1111/j.1469-7998.2006.00077.x
26. UCN SSC ANTELOPE SPECIALIST GROUP (2016) Pantholops hodgsonii. In The IUCN Red List of Threatened Species 2016
27. Johnson, T. L., Bjork, J. K., Neitzel, D. F., Dorr, F. M., Schiffman, E. K.and Eisen, R. J (2016) Habitat Suitability Model for the Distribution of Ixodes scapularis (Acari: Ixodidae) in Minnesota. J Med Entomol 53:598-606. https://doi.org/ 10.1093/jme/tjw008
28. Leach, K., Zalat, S.and Gilbert, F (2013) Egypt's Protected Area network under future climate change. Biological Conservation 159:490-500. https://doi.org/ 10.1016/j.biocon.2012.11.025
29. Li, J. J., Fan, G.and He, Y (2020) Predicting the current and future distribution of three Coptis herbs in China under climate change conditions, using the MaxEnt model and chemical analysis. Science of the Total Environment 698. https://doi.org/ 10.1016/j.scitotenv.2019.134141
30. Li, S.-Y., Miao, L.-J., Jiang, Z.-H., Wang, G.-J., Gnyawali, K. R., Zhang, J., et al (2020) Projected drought conditions in Northwest China with CMIP6 models under combined SSPs and RCPs for 2015–2099. Advances in Climate Change Research 11:210-217. https://doi.org/10.1016/j.accre.2020.09.003
31. Liu, J., Milne, R. I., Cadotte, M. W., Wu, Z. Y., Provan, J., Zhu, G. F., et al (2018) Protect Third Pole's fragile ecosystem. Science 362:1368-1368. https://doi.org/ 10.1126/science.aaw0443
32. Moilanen, A (2007) Landscape Zonation, benefit functions and target-based planning: Unifying reserve selection strategies. Biological Conservation 134:571-579. https://doi.org/10.1016/j.biocon.2006.09.008
33. Padalia, H., Srivastava, V.and Kushwaha, S. P (2015) How climate change might influence the potential distribution of weed, bushmint (Hyptis suaveolens)? Environ Monit Assess 187:210. https://doi.org/ 10.1007/s10661-015-4415-8
34. Parmesan, C (2007) Influences of species, latitudes and methodologies on estimates of phenological response to global warming. Global Change Biology 13:1860-1872. https://doi.org/ 10.1111/j.1365-2486.2007.01404.x
35. Pearson, R. G.and Dawson, T. P (2003) Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful? Global Ecology and Biogeography 12:361-371. https://doi.org/ 10.1046/j.1466-822X.2003.00042.x
36. Pearson, R. G., Raxworthy, C. J., Nakamura, M.and Peterson, A. T (2007) ORIGINAL ARTICLE: Predicting species distributions from small numbers of occurrence records: a test case using cryptic geckos in Madagascar. Journal of Biogeography 34

37. Pearson, R.G., Stanton, J.C., Shoemaker, K.T., Aiello-Lammens, M.E., Ersts, P.J., Horning, N., Fordham, D.A., Raxworthy, C.J., Ryu, H.Y., McNees, J., Akçakaya, H.R (2014) Life history and spatial traits predict extinction risk due to climate change. Nat. Clim. Chang. 4, 217–221.

38. Phillips, S. J., Anderson, R. P., Dudik, M., Schapire, R. E.and Blair, M. E (2017) Opening the black box: an open-source release of Maxent. Ecography 40:887-893. https://doi.org/ 10.1111/ecog.03049

39. Riahi, K., van Vuuren, D. P., Kriegler, E., Edmonds, J., O'Neill, B. C., Fujimori, S., et al (2017) The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. Global Environmental Change 42:153-168. https://doi.org/ 10.1016/j.gloenvcha.2016.05.009

40. Sang, Y., Ren, H.-L., Shi, X., Xu, X.and Chen, H (2020) Improvement of Soil Moisture Simulation in Eurasia by the Beijing Climate Center Climate System Model from CMIP5 to CMIP6. Advances in Atmospheric Sciences 38:237-252. https://doi.org/10.1007/s00376-020-0167-7

41. Santos-Hernandez, A. F., Monterroso-Rivas, A. I., Granados-Sanchez, D., Villanueva-Morales, A.and Santacruz-Carrillo, M (2021) Projections for Mexico's Tropical Rainforests Considering Ecological Niche and Climate Change. Forests 12. https://doi.org/10.3390/f12020119

42. Sjv, A.and Pona, B. The expanding distribution of the Indian Peafowl (Pavo cristatus) as an indicator of changing climate in Kerala, southern India: A modelling study using MaxEnt. Ecological Indicators 110

43. Song, C.and Liu, H (2019) Habitat differentiation and conservation gap of Magnolia biondii, M. denudata, and M. sprengeri in China. PeerJ 6:e6126

44. Soucy, Jean-Paul, R., Slatculescu, Andreea, M., et al (2018) High-Resolution Ecological Niche Modeling of Ixodes scapularis Ticks Based on Passive Surveillance Data at the Northern Frontier of Lyme Disease Emergence in North America. Vector Borne & Zoonotic Diseases

45. Svenning, J. C.and Skov, F (2005) Limited filling of the potential range in European tree species (vol 7, pg 565, 2004). Ecology Letters 8:240-240

46. Urbani, F., D'Alessandro, P., Frasca, R.and Biondi, M (2015) Maximum entropy modeling of geographic distributions of the flea beetle species endemic in Italy (Coleoptera: Chrysomelidae: Galerucinae: Alticini). Zoologischer Anzeiger 258:99-109. https://doi.org/ 10.1016/j.jcz.2015.08.002

47. Vina, A., Bearer, S., Zhang, H. M., Ouyang, Z. Y.and Liu, J. G (2008) Evaluating MODIS data for mapping wildlife habitat distribution. Remote Sensing of Environment 112:2160-2169. https://doi.org/ 10.1016/j.rse.2007.09.012

48. Virkkala, R., Luoto, M., Heikkinen, R. K.and Leikola, N (2005) Distribution patterns of boreal marshland birds: modelling the relationships to land cover and climate. Journal of Biogeography 32:1957-1970. https://doi.org/10.1111/j.1365-2699.2005.01326.x

49. Wang, W. T., Guo, W. Y., Jarvie, S.and Svenning, J. C (2021) The fate of Meconopsis species in the Tibeto-Himalayan region under future climate change. Ecology and Evolution 11:887-899. https://doi.org/ 10.1002/ece3.7096

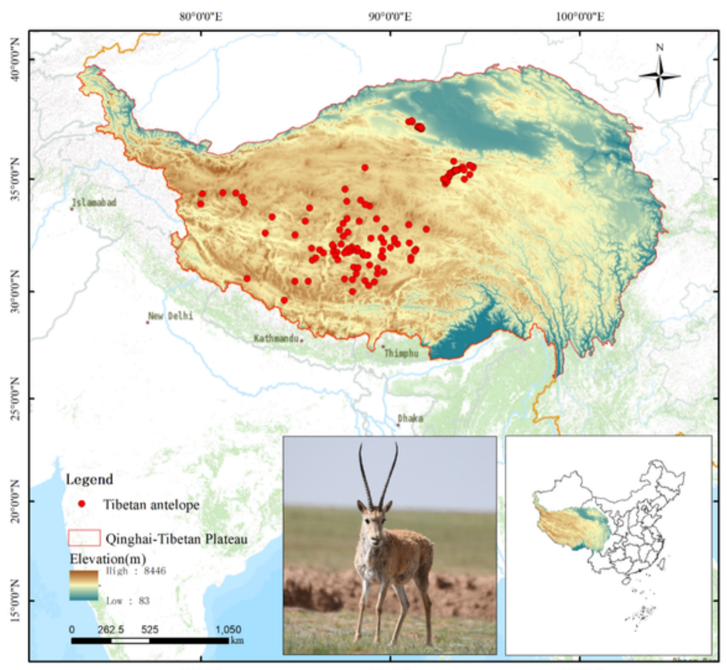
50. Wei, Y. Q., Zhang, L., Wang, J. N., Wang, W. W., Niyati, N., Guo, Y. L., et al (2021) Chinese caterpillar fungus (Ophiocordyceps sinensis) in China: Current distribution, trading, and futures under climate change and overexploitation. Science of the Total Environment 755. https://doi.org/ 10.1016/j.scitotenv.2020.142548

51. WORLD HERITAGE ENCYCLOPEDIA (2016) list of endangered and protected species of Chian. In World Heritage Encyclopedia.

52. Xia, L., Yang, Q., Li, Z., Wu, Y.and Feng, Z (2007) The effect of the Qinghai-Tibet railway on the migration of Tibetan antelope Pantholops hodgsonii in Hoh-xil National Nature Reserve, China. Oryx 41:352-357. https://doi.org/ 10.1017/s0030605307000116

53. Xia, M., Jia, K., Zhao, W. W., Liu, S. L., Wei, X. Q.and Wang, B (2021) Spatio-temporal changes of ecological vulnerability across the Qinghai-Tibetan Plateau. Ecological Indicators 123. https://doi.org/10.1016/j.ecolind.2020.107274
54. Yang L Yang L Li J X Zhang C Huo Z M Luan X F (2019) Potential distribution and conservation priority areas of five species in Northeast China Acta Ecologica Sinica 39(3) : 1082-1094 https://doi.org/ 10 5846 /stxb201804130847
55. Zeng, Y. W., Wei, L. B.and Yeo, D. C. J (2016) Novel methods to select environmental variables in MaxEnt: A case study using invasive crayfish. Ecological Modelling 341:5-13. https://doi.org/10.1016/j.ecolmodel.2016.09.019
56. Zhang, J. J., Jiang, F., Li, G. Y., Qin, W., Wu, T., Xu, F., et al (2021) The four antelope species on the Qinghai-Tibet plateau face habitat loss and redistribution to higher latitudes under climate change. Ecological Indicators 123. https://doi.org/ 10.1016/j.ecolind.2021.107337
57. Zhang, Y., Gao, Q. Z., Dong, S. K., Liu, S. L., Wang, X. X., Su, X. K., et al (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 Journal 37:57-65. https://doi.org/ 10.1071/rj14080
58. Zhao, W (2022) Beginning: China's national parks system. National Science Review. https://doi.org/10.1093/nsr/nwac150

Figures



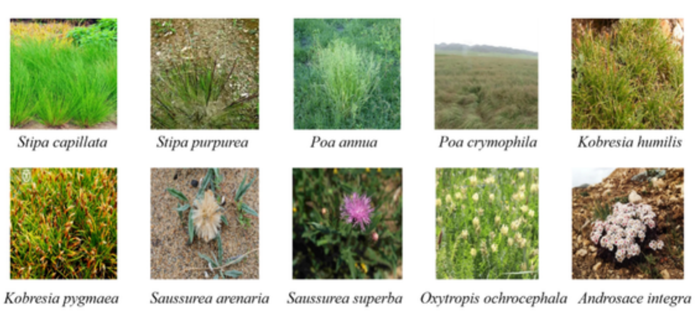


Figure 1

Geographical locations of Tibetan antelope on the QTP and photos of Tibetan antelope and its main forage plants in this paper.

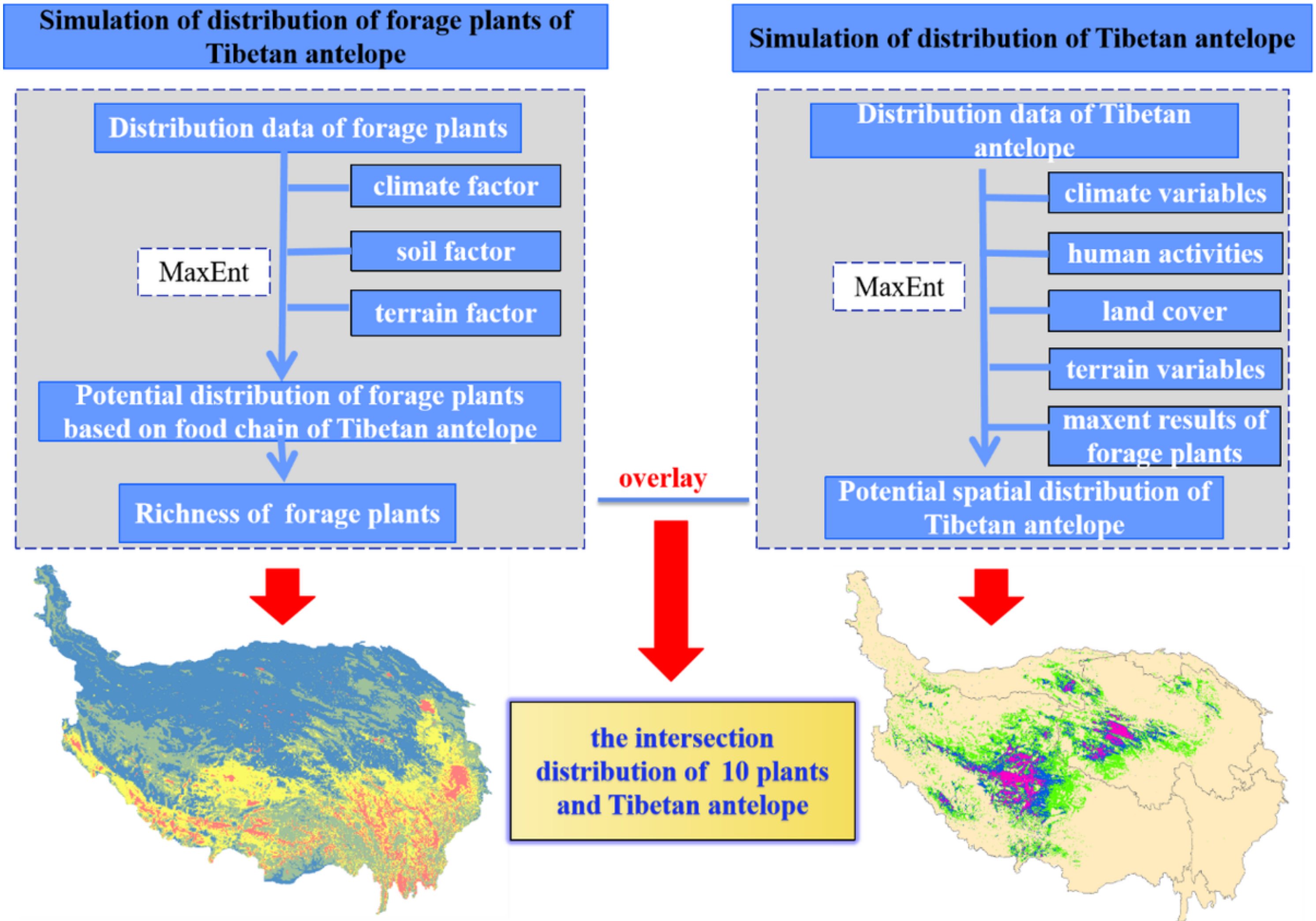


Figure 2

Flow diagram of methodology adopted

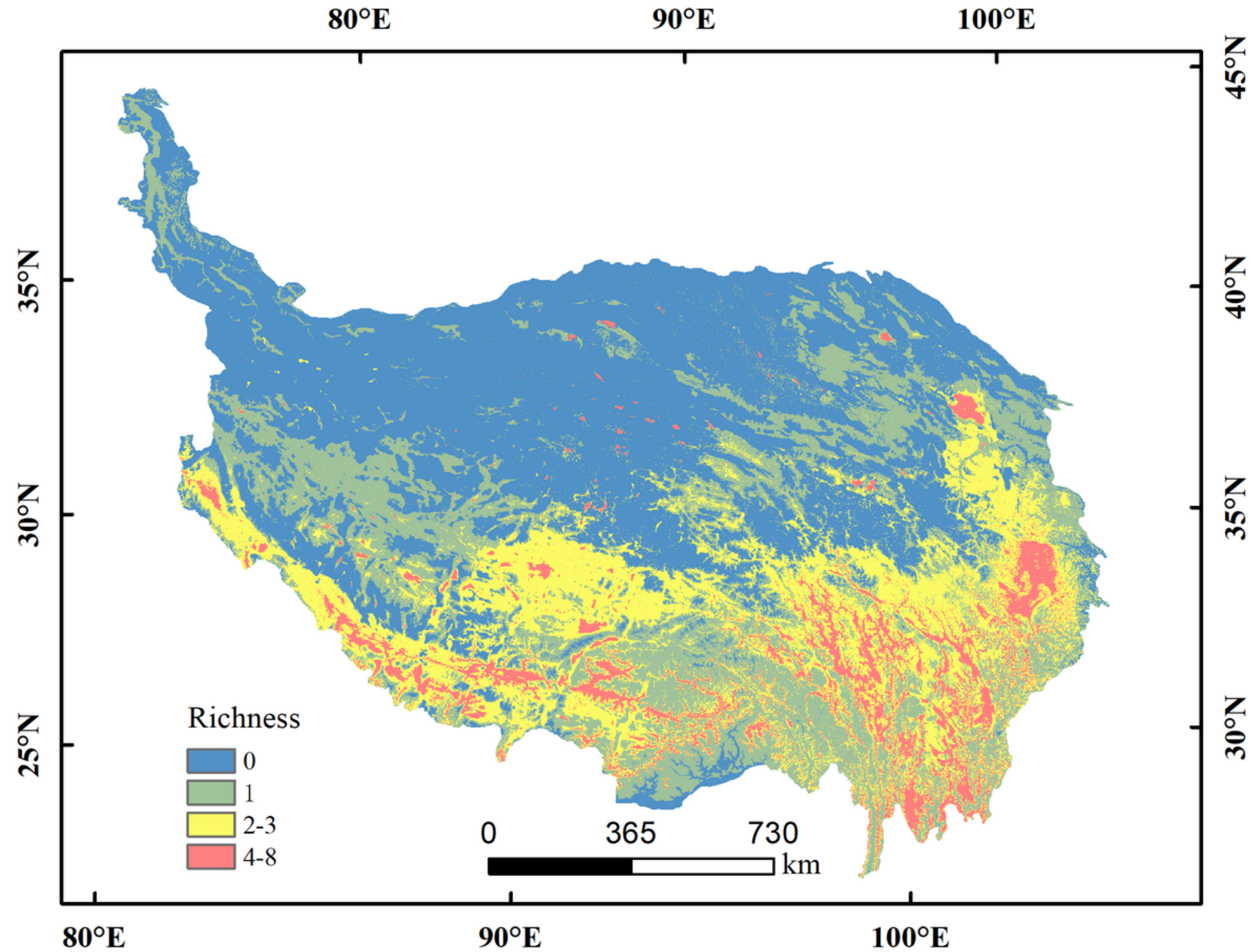


Figure 3

The current richness distribution of 10 plants eaten by the Tibetan antelope on the QTP.

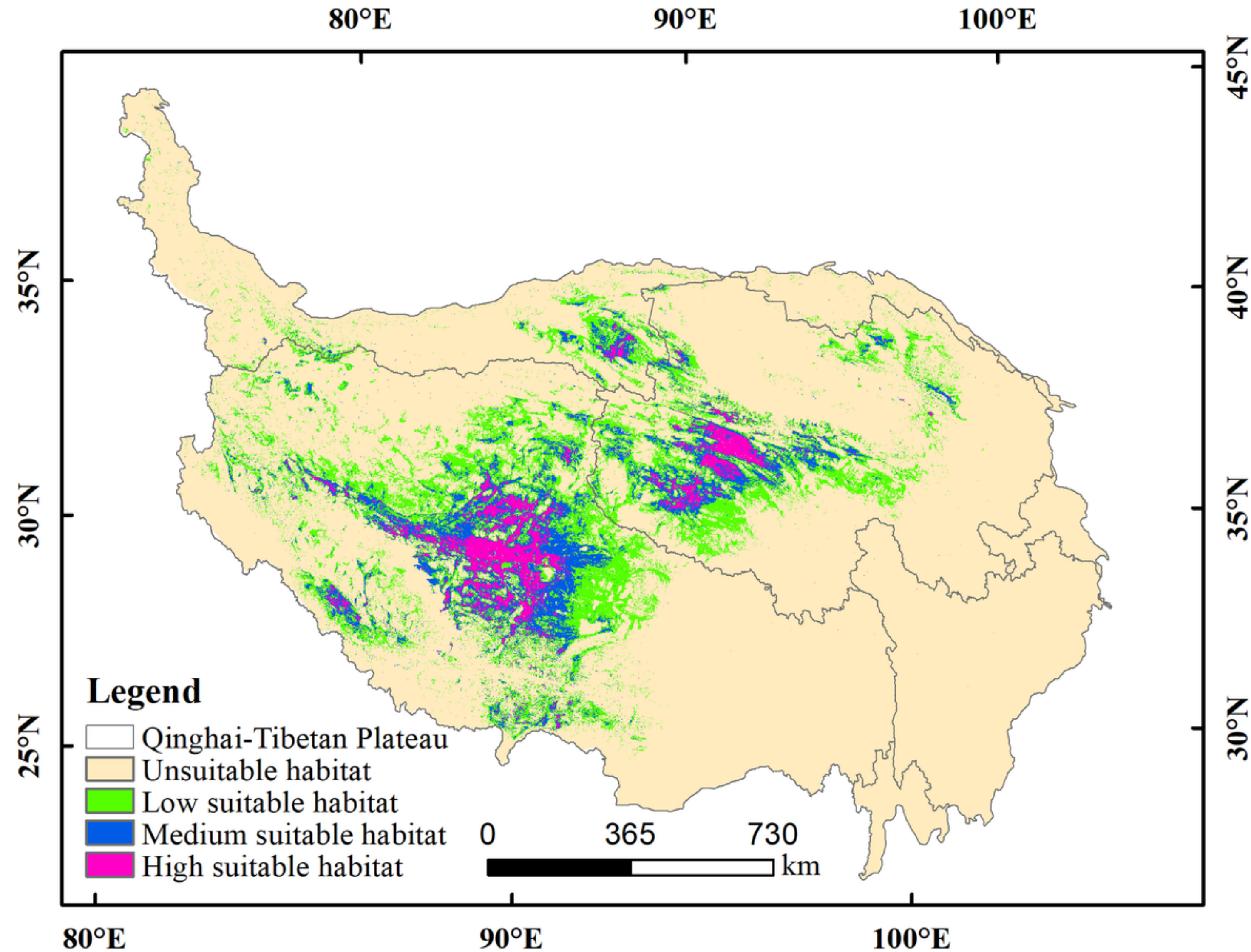


Figure 4

The potential distribution of Tibetan antelope under current climate circumstace.

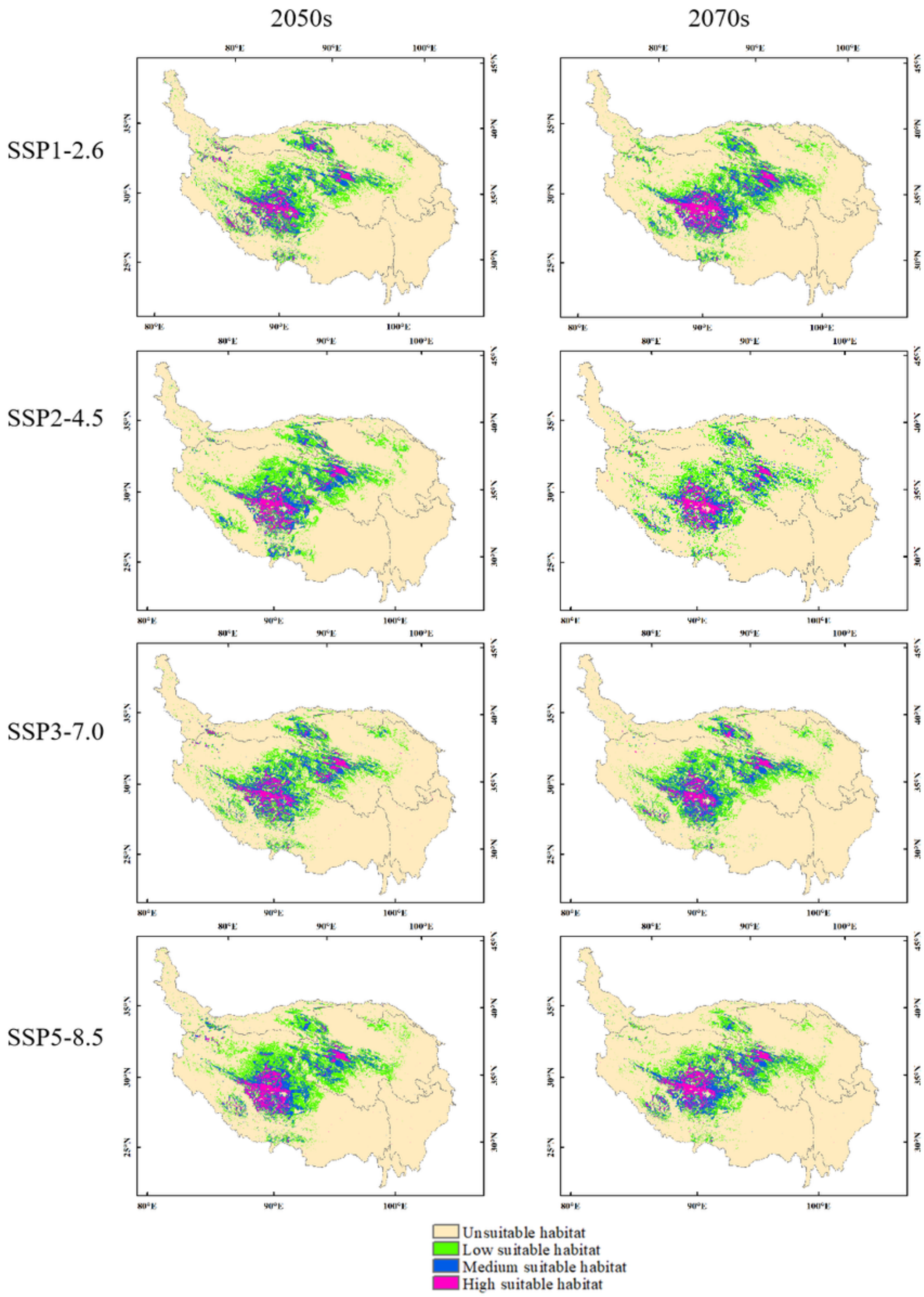


Figure 5

The potential distribution of Tibetan antelope under different climate scenarios.

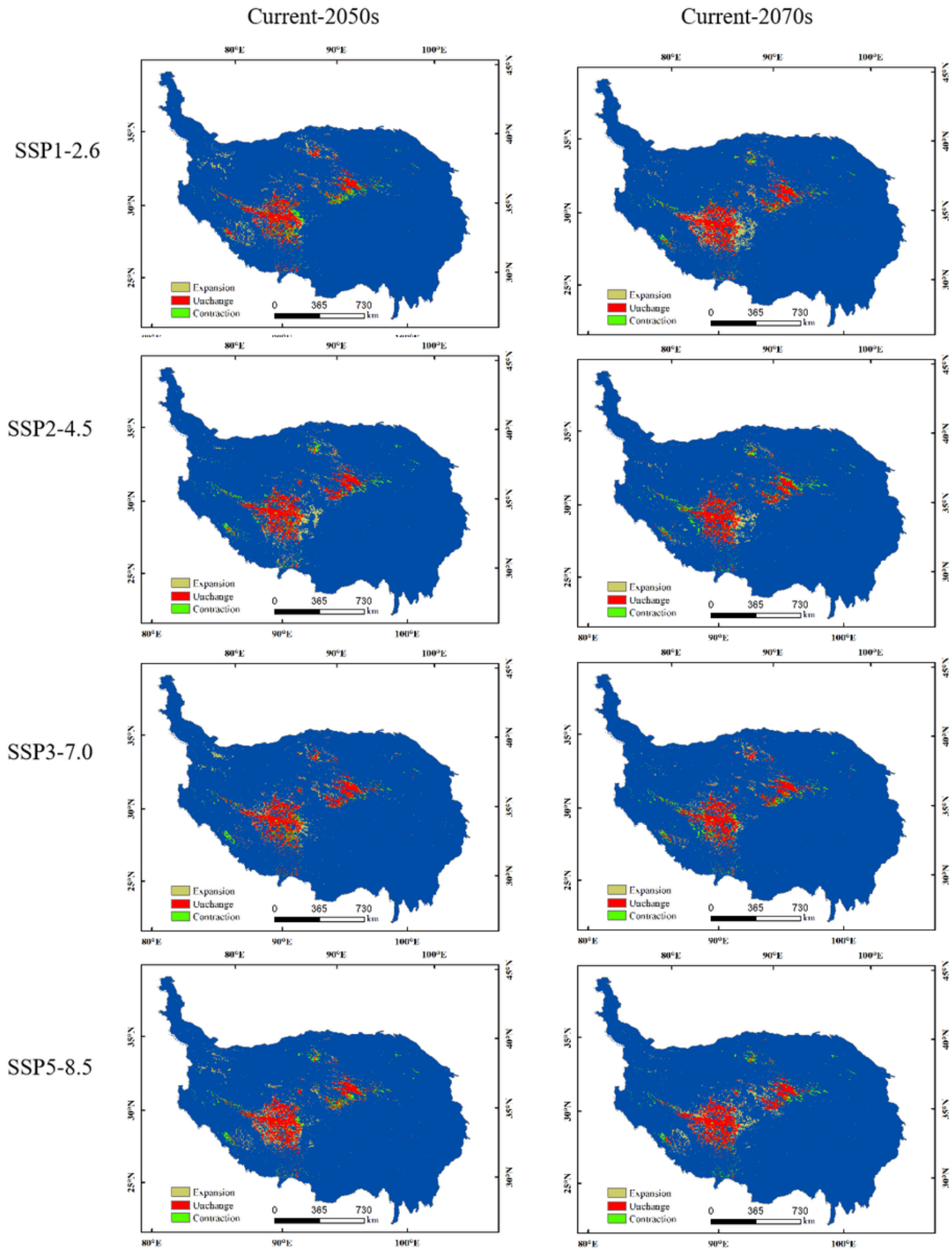


Figure 6

Changes of potential suitable areas of Tibetan antelope from current to future climate scenarios.

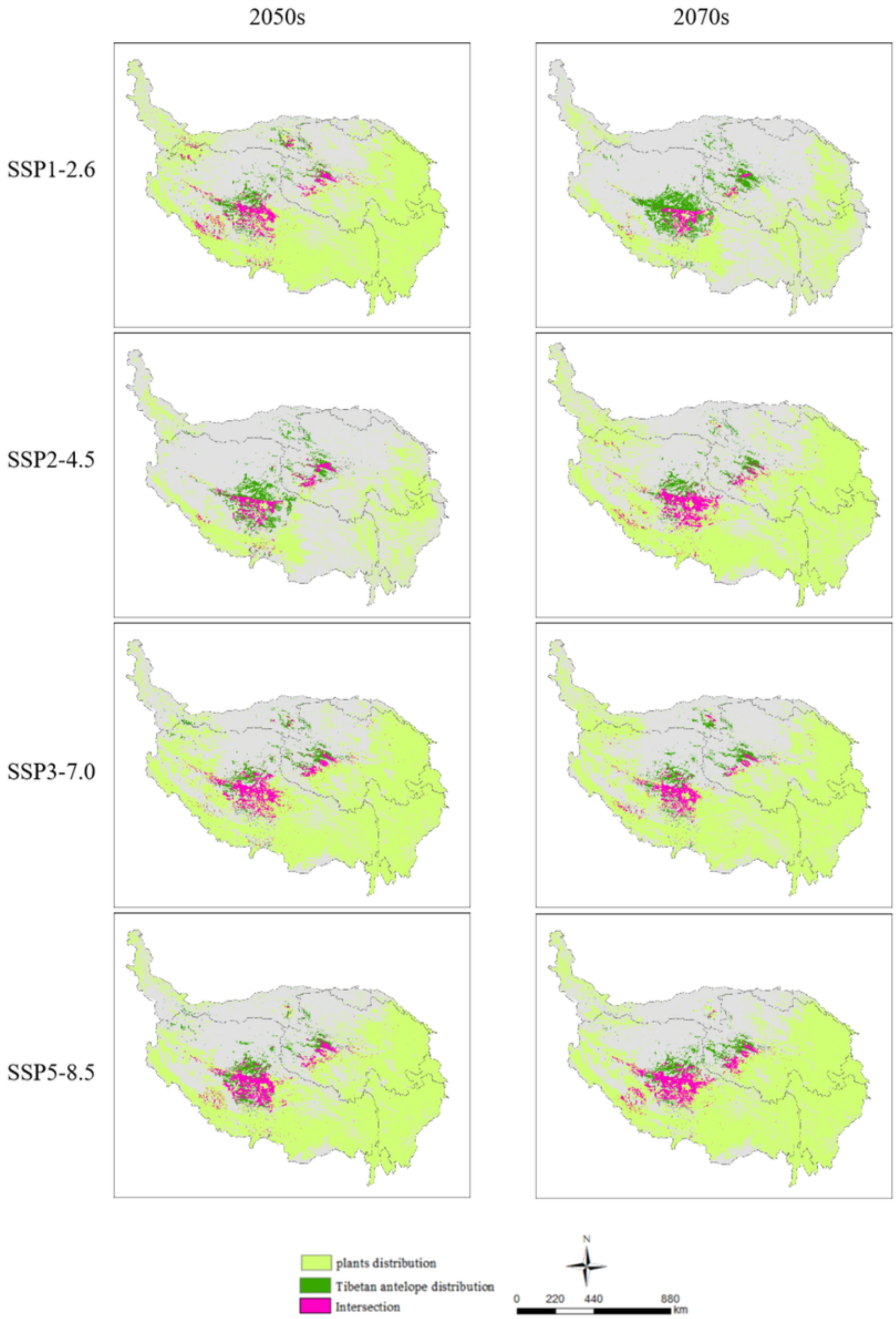


Figure 7

Changes of the intersection distribution of Tibetan antelope and 10 plants under the future climate scenarios.