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Research article

CONSERVATION PLANNING AT COUNTRY BORDERS: A CASE STUDY ON THE DAURIAN STEPPE IN CHINA AND EASTERN MONGOLIA

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ABSTRACT: There is an urgent need to make long term conservation strategies in areas with global biodiversity significance where the economic development is fast. One major challenge for developing the strategies in the national boundary areas is the inconsistency of data from different countries. The Daurian steppe in the Northeastern China and the Eastern Mongolia has the best and most intact steppe ecosystem in the Palearctic that still supports stable herds of larger vertebrates (e.g. millions of Mongolian gazelle (Procapra gutturosa)). Based on a biodiversity conservation project (being carried out during 2006-2009), we conducted systematic conservation planning in this transboundary region, dealing with inconsistent information of species occurrences and threatening factors in the two countries. We selected two focal species, the Mongolian gazelle and the white-naped crane (Grus vipio), as conservation targets. We used watershed as planning unit, calculated cost values of every planning unit based on human footprint index and road density. Climate change vulnerability and ratio of protected areas were used as other sources of cost. The conservation targets of every planning unit were quantified using the range maps in Mongolia and point occurrences in China. Combining the values of conservation cost and targets, we proposed conservation priority areas for the two species. In summary, the two species are more abundant in Eastern Mongolia, where will suffer more severe climate change. The planning units with high conservation priority are mostly located at the border of China and Mongolia. Effective conservation of the priority areas we suggested would secure the long term survival of the Mongolia gazelle and the white-naped crane, as well as many other associated species and ecosystems.

Key words: Climate Change; Conservation Priority; Human Activity; Mongolian Gazelle; Protected Area; Watershed; White-Naped Crane.

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INTRODUCTION

Setting conservation priority areas is the key step for effective strategic conservation [1]. Worldwide, strategic conservation is limited by the availability of information regarding biodiversity distribution, conservation status, and trends [2-4]. There are also serious limitations in knowledge of threatening factors (e.g. human disturbance, climate change) to support resource management decisions [5]. In the past 15 years, systematic conservation planning has been developed to overcome those limitations [6-11]. The idea of systematic conservation planning is to maximize conservation efficiently by balancing the goal and cost in planning units [6]. The goal, cost, and planning units are three key terms in the context of conservation planning. The goal is a quantitative indices system defining how much the conservation targets should be protected. Conservation targets are usually ecosystems and endemic or endangered species.

Conservation cost is the capital value to be paid for effectively protecting biodiversity in the area, or in another point of view, the threating factors to conservation targets. Both the capital value and the threating factors represent the difficulty of conservation at the planning unit. The planning unit is the geographical unit in which the values of targets, goals and cost are quantified. Through this systematic framework, users can identify areas of biodiversity significance that collectively contain sufficient numbers of the native species populations and ecosystems at lowest cost (or with minimum threats), so as to support their long-term persistence.

When the distribution of conservation targets crosses political (e.g. country) boundaries, researchers usually face more challenges, such as the inconsistence of the data between the two adjacent countries [12]. There has been an increasing awareness of the importance of transboundary coordination, yet the actual practices of transboundary cooperation is far from enough [13, 14, 15].

The Daurian steppe in the Northeastern China and the Eastern Mongolia has the best and most intact steppe ecosystem in the Palearctic that still supports stable herds of larger vertebrates (e.g. millions of Mongolian gazelle) [16]. The Daurian steppe is the temperate grassland composing of two terrestrial ecoregions, Daurian forest steppe and Mongolian-Manchurian grassland [17]. At present, the Daurian steppe is threatened by the fast development of Inner Mongolia, China [18, 19] and ongoing mining activities in Mongolia [16]. Furthermore, the Daurian steppe is very vulnerable to future climate change [16, 20]. As such, there is an urgent need to develop conservation strategies for protecting this unique and internationally biodiversity significant steppe ecosystem.

In this paper, we selected conservation priority areas on the Daurian steppe by systematic conservation planning for two focal species, the Mongolia gazelle (*Procapra gutturosa*) and the white-naped crane (*Grus vipio*). Our study area includes Hulunbeir prefecture in Inner Mongolia Autonomous Region, China, and three provinces in Eastern Mongolia, i.e. Dornod, Hentii, and Sükhbaatar (Figure 1). This area represents more than 95% of the habitat of Mongolia gazelle [16, 21] and more than half of the breeding habitat for white-naped crane [22, 23].

The Mongolia gazelle and the white-naped crane are two representative native species on the Daurian steppe [21, 22]. The Mongolian gazelle occurs on the temperate grassland and the white-naped crane occurs in the wetland regions. The Mongolian gazelle is a medium-sized antelope. It is the most numerous large animals in Asia, with the total population at about 0.4-2.7 million individuals [24]. The white-naped crane is a large bird of the crane family. Its population is estimated at about 6,500 individuals [25]. The Daurian steppe is its breeding area, crossing the Eastern Mongolia, the Northeastern China, and the adjacent areas of Russia. Different groups of the white-naped crane migrate to the area in spring from their overwintering sites near the downstream Yangtze River, China, the Demilitarized Zone in Korea and on Kyūshū Island in Japan. This crane is categorized as Vulnerable in the IUCN Red List because it is believed to be experiencing an on-going population decline, due to the loss of wetlands to agriculture and economic development on the Daurian steppe [25].

We set conservation priorities for the Mongolian gazelle and the white-naped crane as the first step of the long term systematic biodiversity conservation on the Daurian steppe.

MATERIALS AND METHODS

To carry out systematic conservation planning, we defined planning units, compiled the information of species distribution and abundance, and estimated conservation cost. Then we integrated the values of conservation targets and cost to calculate conservation priority index.

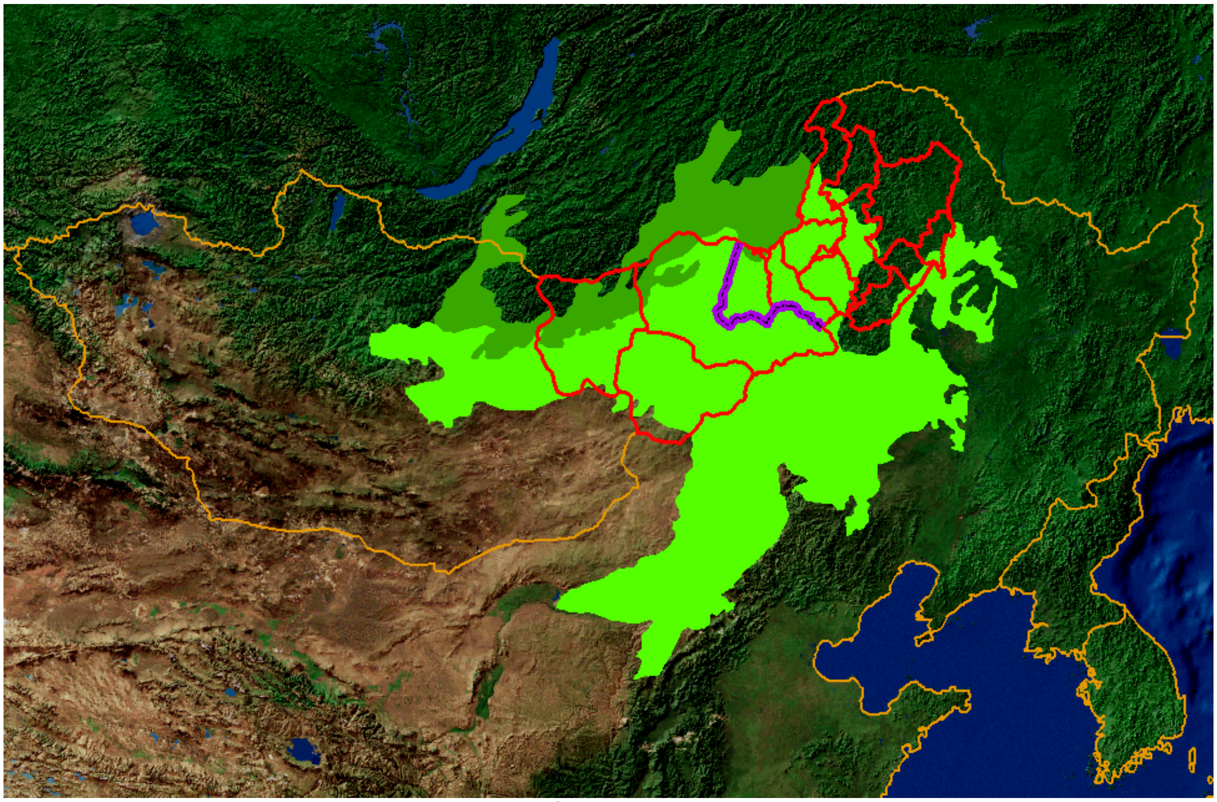

Figure 1: The study area (enclosed in red lines) for the conservation planning on the Daurian steppe. The bright green area is the Mongolian-Manchurian grassland ecoregion; the green area above Mongolian-Manchurian grassland is the Daurian forest steppe ecoregion. The purple line is the country border between China (to the right) and Mongolia (to the left). The red lines are borders of counties in China and borders of provinces in Mongolia.

Planning unit

The most common method of delineating planning unit for terrestrial ecosystems is to generate hexagons [8, 26], which provides an uniform structure (with the same shape and area) for quantifying targets and cost. However, the boundary of the hexagons is artificial, which usually makes no sense to other people, especially the local communities. Watershed is the standard planning unit for freshwater ecosystem [27, 28]. Here we used watershed as the planning unit for terrestrial ecosystem, because: (1) watershed has geographical meaningful boundaries such as mountain ridges, river confluences, etc.; (2) water supply/drainage is important for the Daurian steppe ecosystem, especially for species such as the white-naped crane [16].

The watersheds on the Daurian steppe were delineated on the basis of the digital elevation model (DEM) derived from the Shuttle Radar Topography Mission (SRTM) dataset (90 m resolution) [29] using HydroSHEDs developed by the WWF-US [30, 31]. The upstream watersheds have natural boundaries, whereas the remaining mainstream parts (narrow and long areas along the rivers) were artificially cut into small sections with similar size of the upstream watersheds. In total, there are 1572 watersheds delineated, and the average size is 435.5 square kilometers (Figure 2).

Species distribution and abundance

We conducted field surveys in both spring and fall from 2006 to 2009 in Hulunbeir prefecture, the east part of the Daurian steppe in China. The survey sites are 33 predefined routes in Hulunbeir. The birds were observed using binoculars, and they were counted directly [32]. The white-naped crane scatters in Huihe nature reserve and Dalai Lake nature reserve in the breeding season, with the maximum 17 individuals in one group observed in 2007 at one survey route [32]. From 2006 to 2009, 264 individuals-times (some individuals were recorded several times over years) of the white-naped crane were recorded during the surveys (Figure 2). As for the Mongolian gazelle, a small yet stable population (less than 100 individuals) lives in Dalai Lake nature reserve, and 215 individuals-times (some individuals were recorded several times over years) were recorded during the surveys (Figure 2).

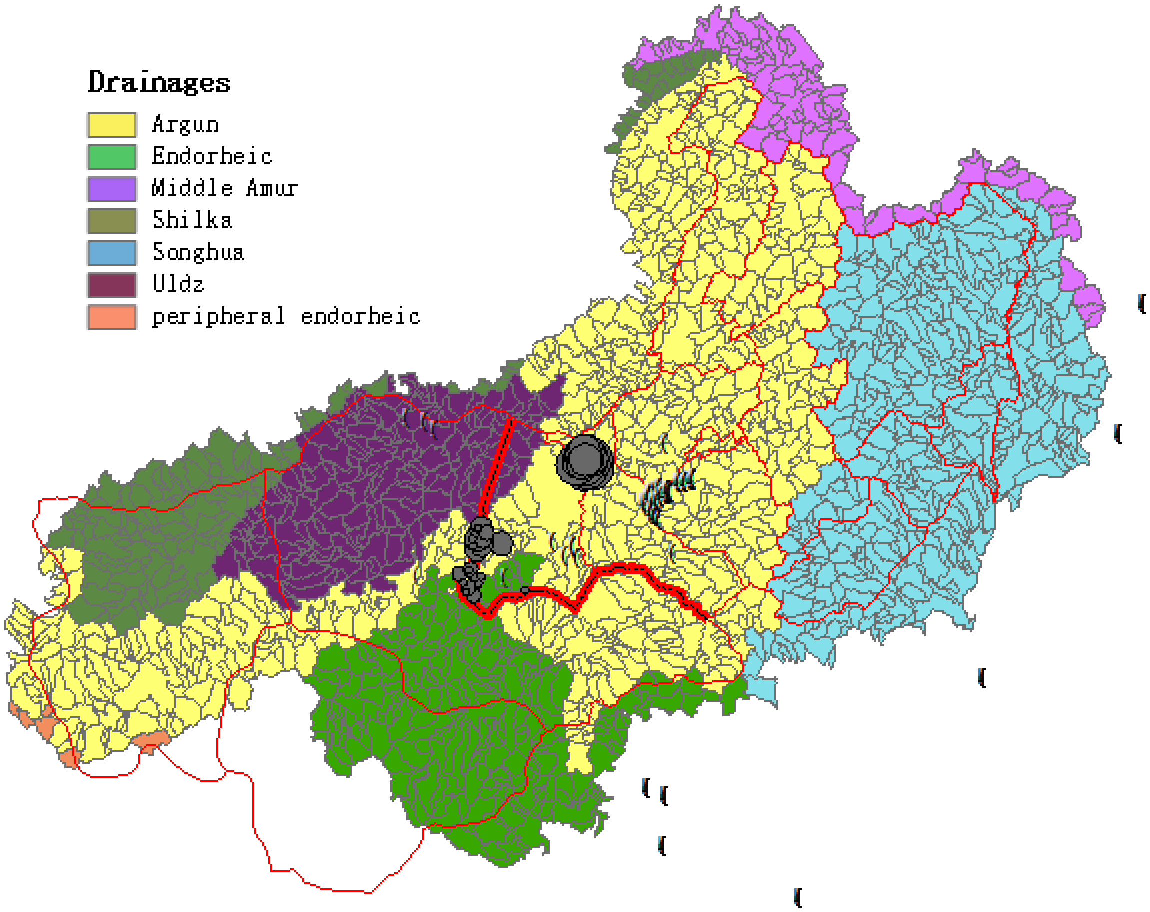

Figure 2: The planning units (watersheds enclosed in gray polygons) in the analysis of conservation planning for the Daurian steppe. Argun, Shilka, Songhua, and Uldz are drainages at the upper Amur river basin. The thick red line is the country border between China (to the right) and Mongolia (to the left). The thin red lines are borders of counties in China and borders of provinces in Mongolia. The dark grey dots show the occurrences of the Mongolia gazelle (the sizes of the dot represent the group size ranging from 1 to 100); the light grey dots show the occurrences of the white-naped crane.

The distribution of the Mongolian gazelle and the white-naped crane in Mongolia were provided by the WCS (Wildlife Conservation Society) Mongolia program, who has conducted long term investigation on the two species. The summer ranges and calving areas of Mongolia gazelle were delineated by the WCS staff and the Protected Areas Administration of Eastern Mongolia, representing the key habitat for this species [33]. The breeding area of white-naped were delineated by the WCS Mongolia program [33].

We overlaid the point occurrences (for the China part) and distribution maps (for the Mongolia part) of the Mongolia gazelle and the white-naped crane with the planning units (i.e. watersheds), and defined three levels of habitat suitability: very suitable watershed, suitable watershed, and unsuitable watershed (Figure S1). The values 2, 1, and 0 were given to the three levels respectively. The standards for defining the levels are: (a) Very suitable watershed: with over 10 breeding adult individuals of the white-naped crane in the watershed, or stably used by the Mongolian gazelles in China; or defined as key breeding areas of any one of the two species in Mongolia. (b) Suitable watershed: with 1-10 breeding adult individuals of the white-naped crane, or frequently used by the Mongolian gazelles in China; or defined as important habitat of either of the two species in Mongolia. (c) Unsuitable habitat: watersheds are used by neither the Mongolian gazelle nor the white-naped crane. The simple ordinal levels would overcome (by average) the problem of the two error types induced by data inconsistency, i.e. the point occurrences in China would have omission errors and distribution maps in Mongolia would have commission errors [34].

Conservation cost

We estimated the human activity and climate change vulnerability of each planning unit, and combined them as conservation cost. Meanwhile, we also calculated the ratio of protected areas in each planning unit. Protected areas usually have rich biodiversity and low human impacts, which represent current conservation effort. Protected areas can compensate conservation cost in planning units [35].

1. Human impacts

We used the human footprint index [36] to estimate the conservation cost of every planning unit. The index provides an integrated value representing impacts of human population density, accessibility, land transformation, and electrical power infrastructure at the resolution of one square km [36]. However, we realized the human footprint index is out of date by 10-20 years based on our experiences during field surveys. We incorporated the current maps of road (highways and local roads) in China [37] and in Mongolia (National basic geographical data downloaded from ESRI™ website) (Figure S2), and calculated the road density in each planning unit. We standardized the values of human footprint index and road density to the range of 0-100 respectively, and average the two factors as the cost of every planning unit (Figure S3).

2. Climate change vulnerability

Climate change would have various impacts on species [38], and we tried to identify the most important one. Based on the report of IPCC (Intergovernmental Panel on Climate Change), the weather of Daurian steppe would become drier in the future [39]. We believe the trend of aridity is one of the major threats to the Daurian steppe. We compared the differences of annual total precipitation (Figure S4), minimum and maximum temperature (Figure S5), and aridity index (Figure S6) between current (1950-2000) and future (2080) periods. The temperature and precipitation data were derived from the WorldClim dataset (CCCMA/CGCM2 model, emission scenario A2A, 10 arc-minutes spatial resolution, time period 2080) downloaded from WorldClim website (http://www.worldclim.org/futdown.htm). The aridity index was calculated following the standard of Köppen's climate classification system [40]. This system is suitable for regions where rainfall occurs mainly in the hot season. The Daurian steppe is one of such regions. The aridity index is:

$$\text{Aridity} = (T + 14)/P$$

Where *T,* is the mean annual temperature in degree Celsius, and *P* is the annual rainfall accumulation (in centimeters). When the aridity is over one, the region is classified as an arid region [40].

The change of aridity index represents the combined effect of rising temperature and decreasing precipitation in the figure. We define the areas with higher aridity index are more vulnerable.

3. Protected areas

The data of protected areas in Mongolia were downloaded from the website of World Database on Protected Areas (http://www.wdpa.org). There are 12 protected areas on the Daurian steppe, including four Strict Protected Areas, five Nature Reserves, two National Conservation Parks, and one Natural Monument (Figure S7). Besides, there are four regions that were proposed to be new protected areas by the Dornod Environmental Protection and Tourism Agency and the Protected Areas Administration of Eastern Mongolia. These proposed protected areas have distinctive biodiversity significance and are likely to be approved by Mongolia government in near future. China has a different protected area system, categorized by administrative levels, i.e. national nature reserve, provincial nature reserve, and county nature reserve. The boundaries of most provincial and county nature reserves have never been delineated in a geographic information system (GIS). Supported by the EU-China Biodiversity Conservation Programme, we delineated all nature reserves in Hulunbeir, including five national nature reserves, 19 provincial nature reserves, and 16 county nature reserves [41] (Figure S3). We calculated the ratio (percentage of area) of protected areas in each planning unit, including the existing and proposed protected areas (Figure S8)

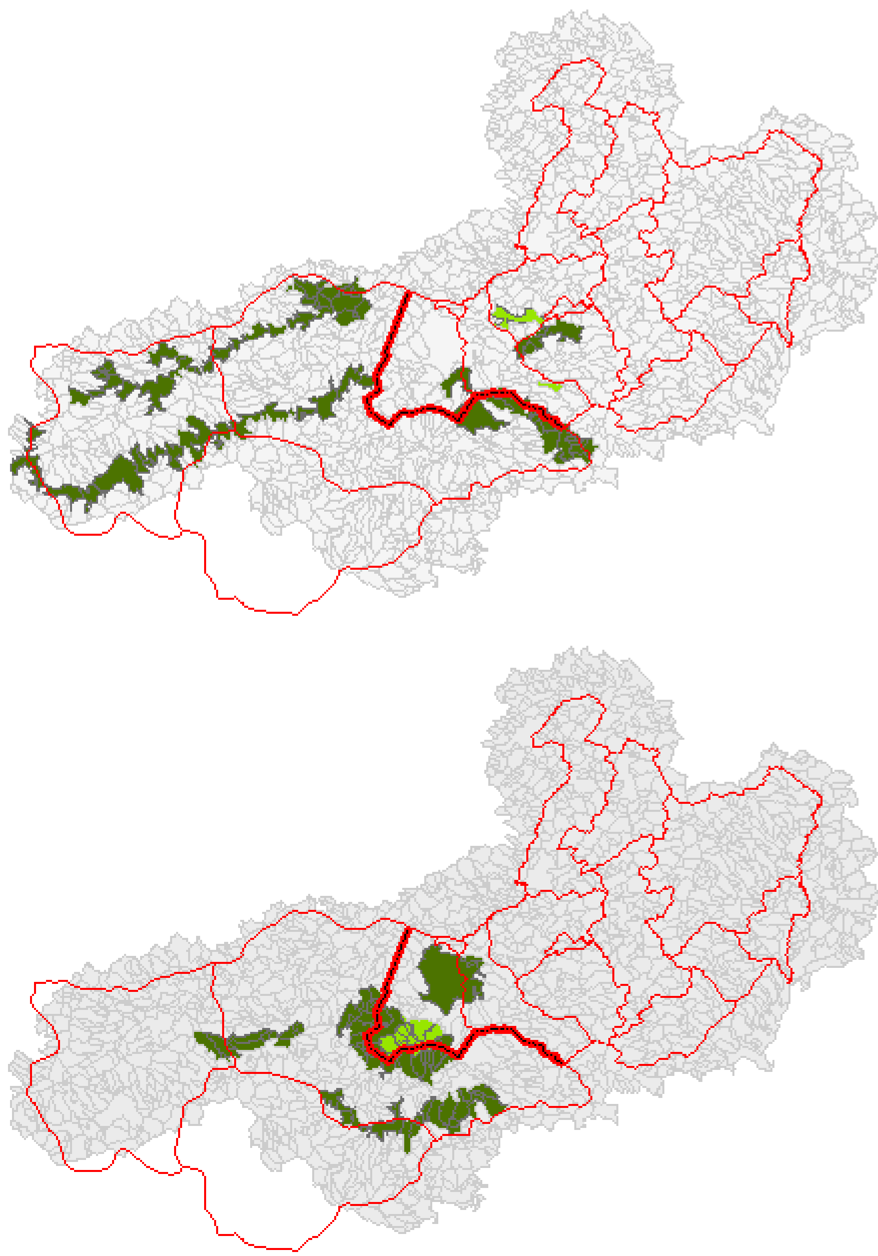

Figure S1: Habitat suitability of the watersheds for the white-naped crane (above) and the Mongolian gazelle (below). Dark green: very suitable habitat; green: suitable habitat; grey: unsuitable habitat.

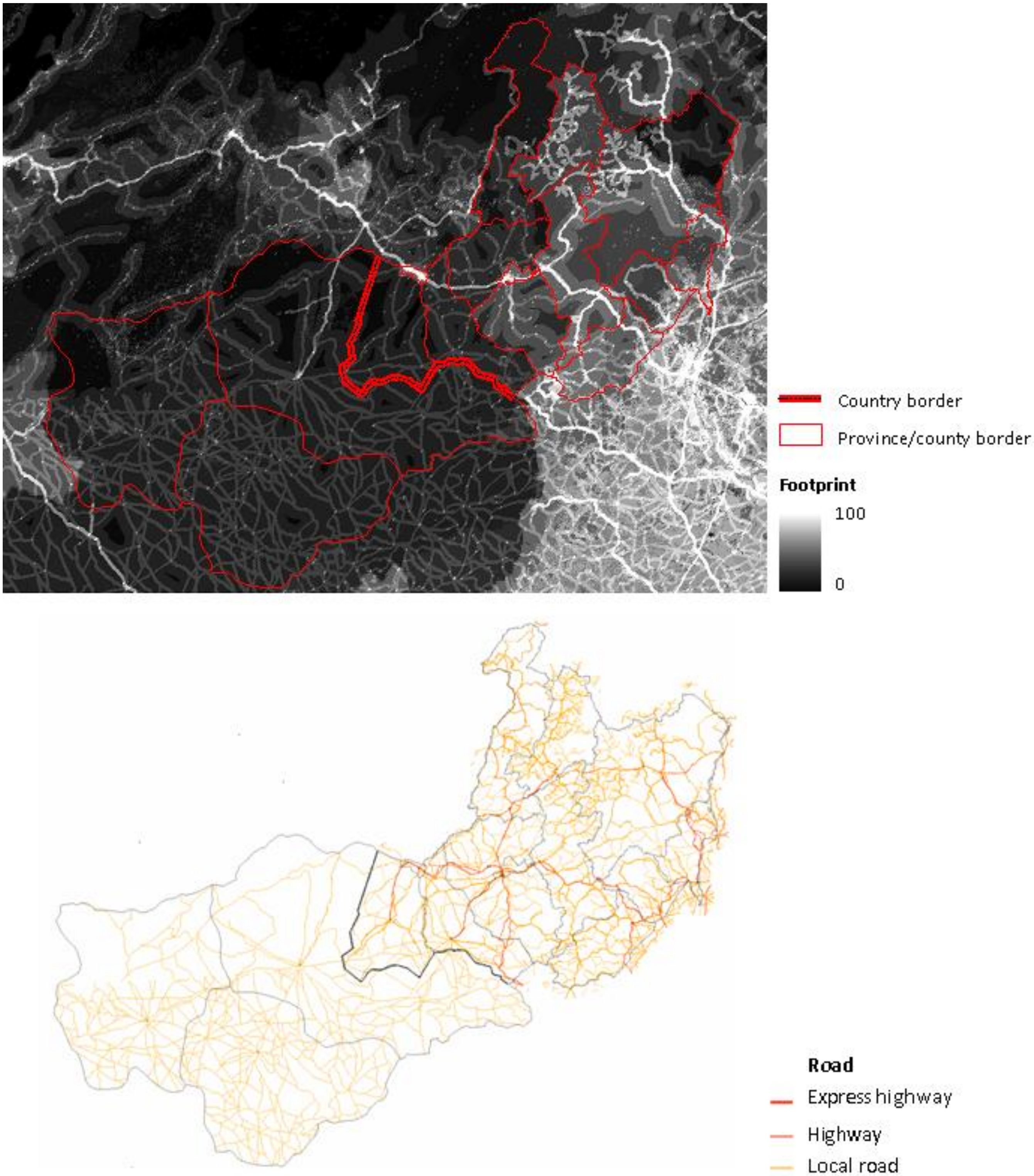

Figure S2: Human footprint index [34] (above) and road (below) in the study area. The high value of human footprint index means high human impact.

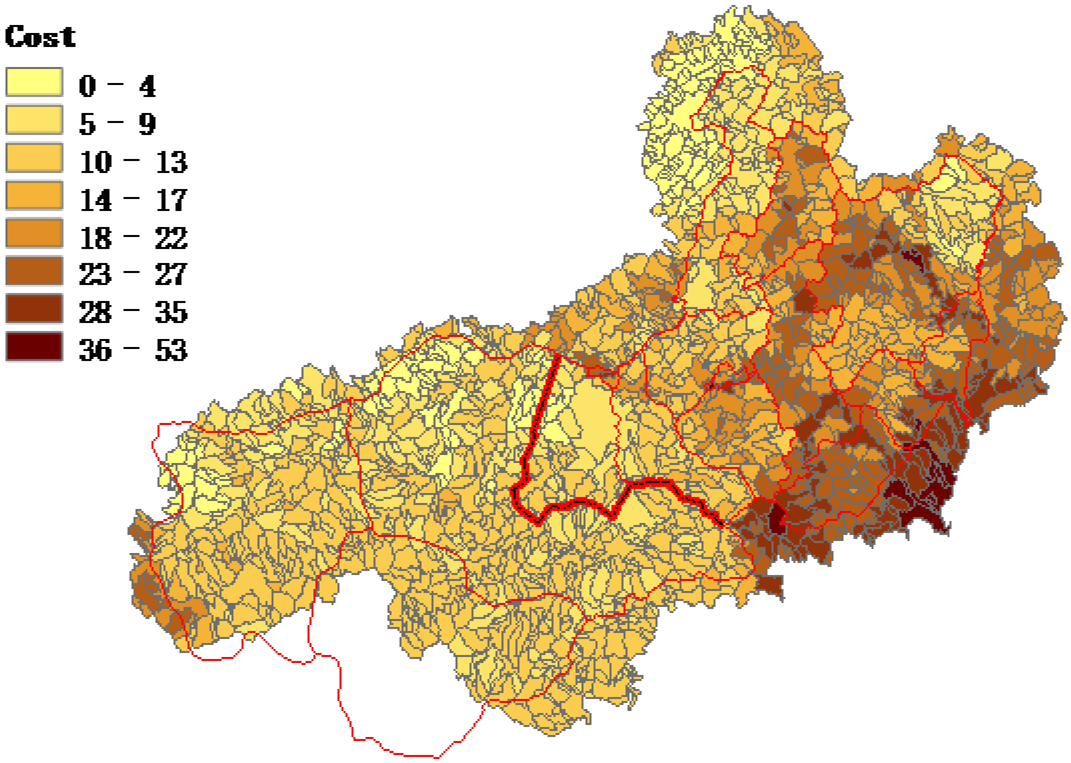

Figure S3: The cost values for each watershed as the index of human impacts. The cost is the average value of human footprint index and current road density in each watershed.

Conservation priority

Conservation planning analysts usually use specific tools to select planning units in order to satisfy conservation goals with minimum cost in the spatially heterogeneous area. Marxan [42, 43] and C-PLAN [44] are two popular tools [7, 45], which can efficiently select priority areas from up to hundreds of thousands planning units. In this study, we used watersheds as planning units. The number of watersheds is only 1572. To make it clear and transparent, we simply summed the values of conservation target and cost in each planning unit to obtain the priority index (Figure 3). The equation is:

$$priority = T_{white\text{-}naped\ crane} + T_{Mongolia\ gazelle} - C_{cost} + C_{ratio\ of\ protected\ area} - C_{aridity}$$

where T represents conservation targets, and C represents conservation cost. T is the habitat suitability levels (0, 1, or 2) of the two species in each watershed. C_{cost} is the human impact index (Figure S3); $C_{aridity}$ is the climate change vulnerability index (Figure S6); $C_{ratio\ of\ protected\ area}$ is the proportion of protected areas including both current protected areas and proposing protected areas (Figure S7).

The values of cost (C_{cost} , $C_{ratio\ of\ protected\ area}$ and $C_{aridity}$) were standardized as:

$$C_{adj} = (C - min(C)) / (max(C) - min(C)) \times 2$$

where $min(C)$ is the minimum value of the variable C, $max(C)$ is the maximum value of the variable C. As such, the two conservation targets and three cost variables have the same range (0-2), i.e. they are equally weighted.

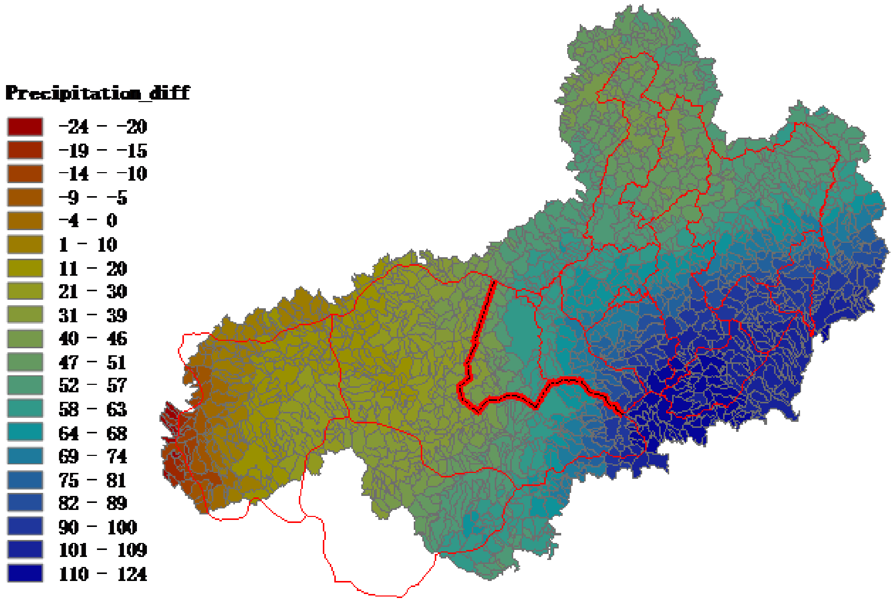

Figure S4: The difference of annual total precipitation (unit: mm) between current (1950-2000) and future (2080) periods on the Daurian steppe based on the World Clim dataset (CCCMA/CGCM2 model, emission scenario A2A).

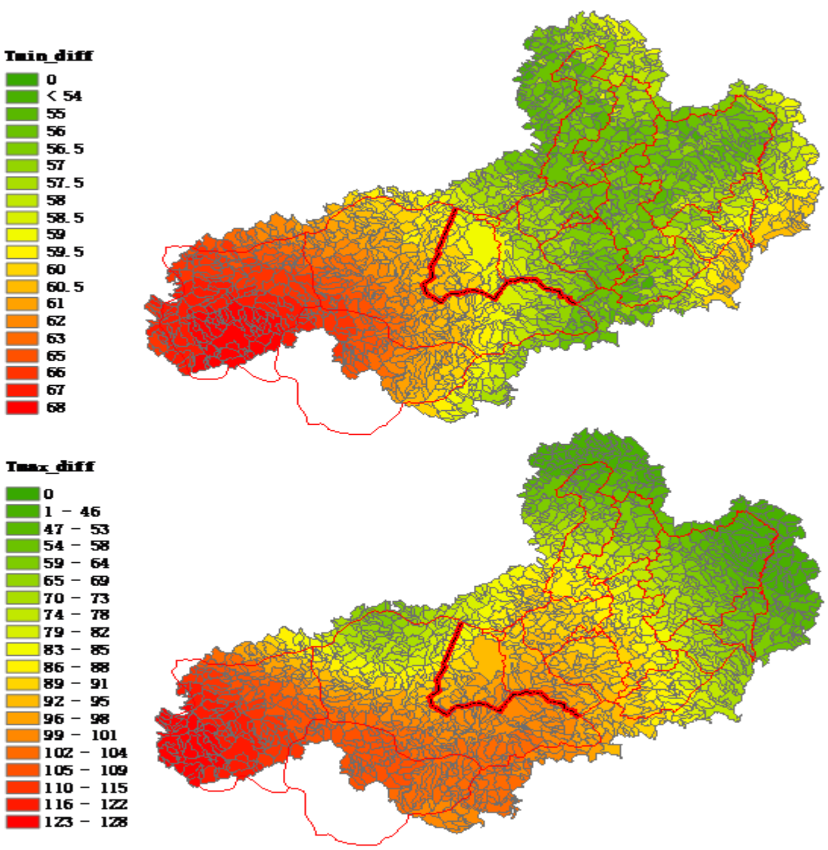

Figure S5: The difference of annual minimum temperature (above) and maximum temperature (below) (unit: 0.01 degree Celsius) between current (1950-2000) and future (2080) periods on the Daurian steppe based on the World Clim dataset (CCCMA/CGCM2 model, emission scenario A2A).

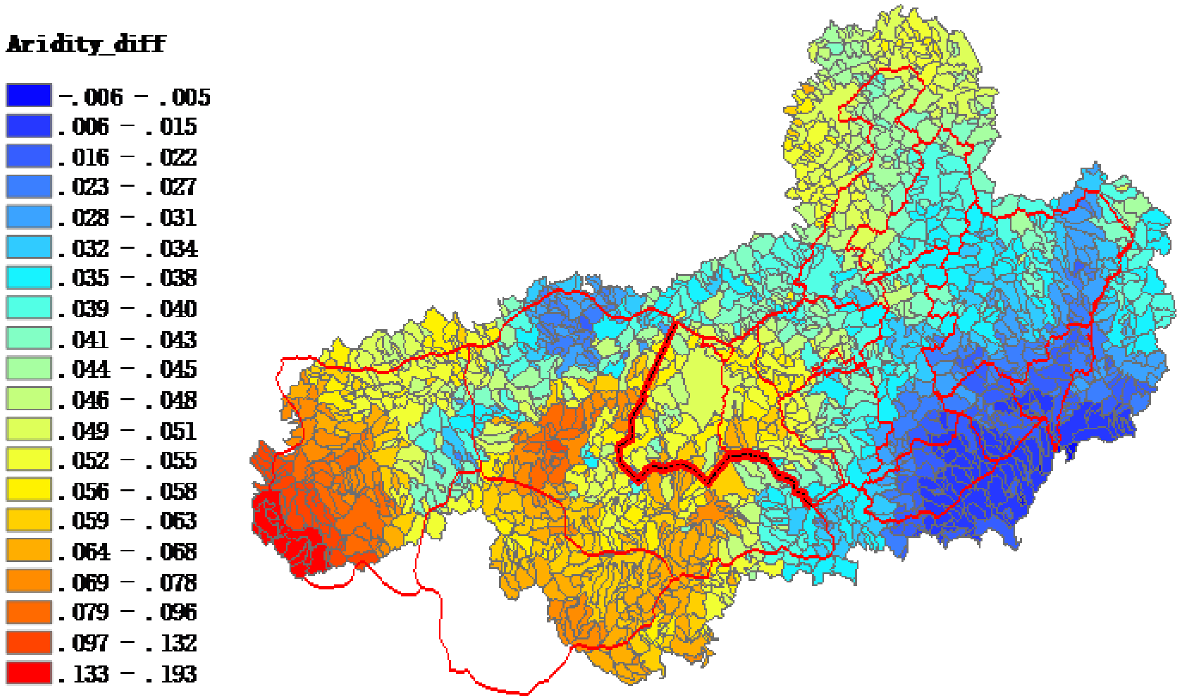

Figure S6: The difference of aridity between current (1950-2000) and future (2080) periods. The aridity is calculated as: Aridity = (T + 14)/P, where *T* is the mean annual temperature in degree Celsius, and *P* is the annual rainfall accumulation (in centimetres).

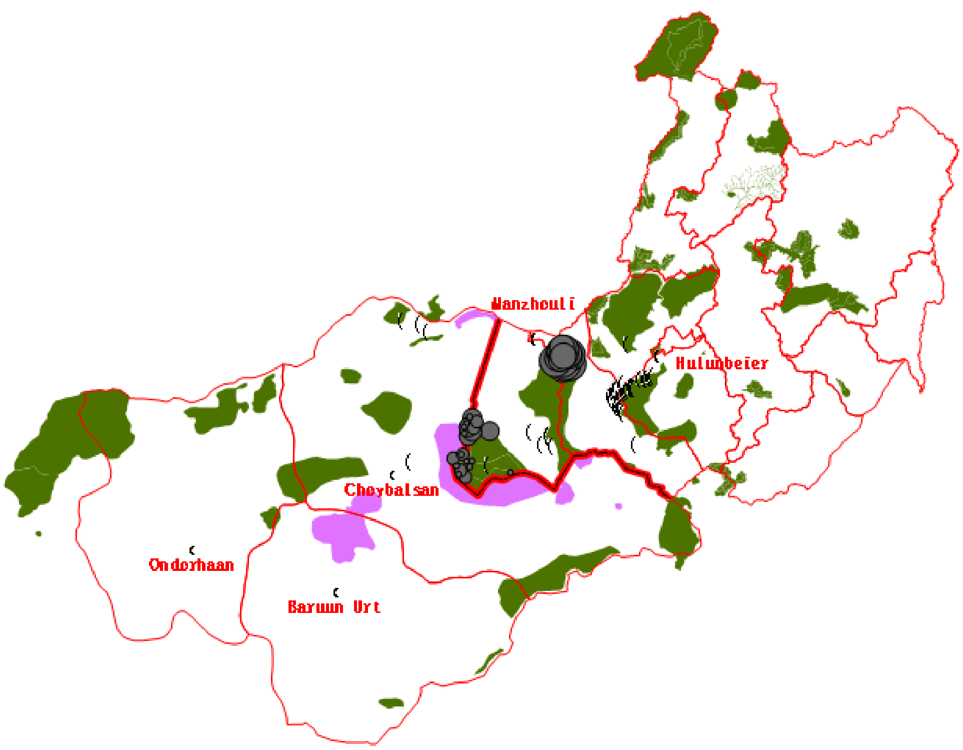

Figure S7: The existing protected areas (green) and proposed protected areas (pink), as well as the occurrences of the Mongolia gazelle and the white-naped crane. The dark grey dots show the occurrences of the Mongolia gazelle (the sizes of the dot represent the group size ranging from 1 to 100); the light grey dots show the occurrences of the white-naped crane.

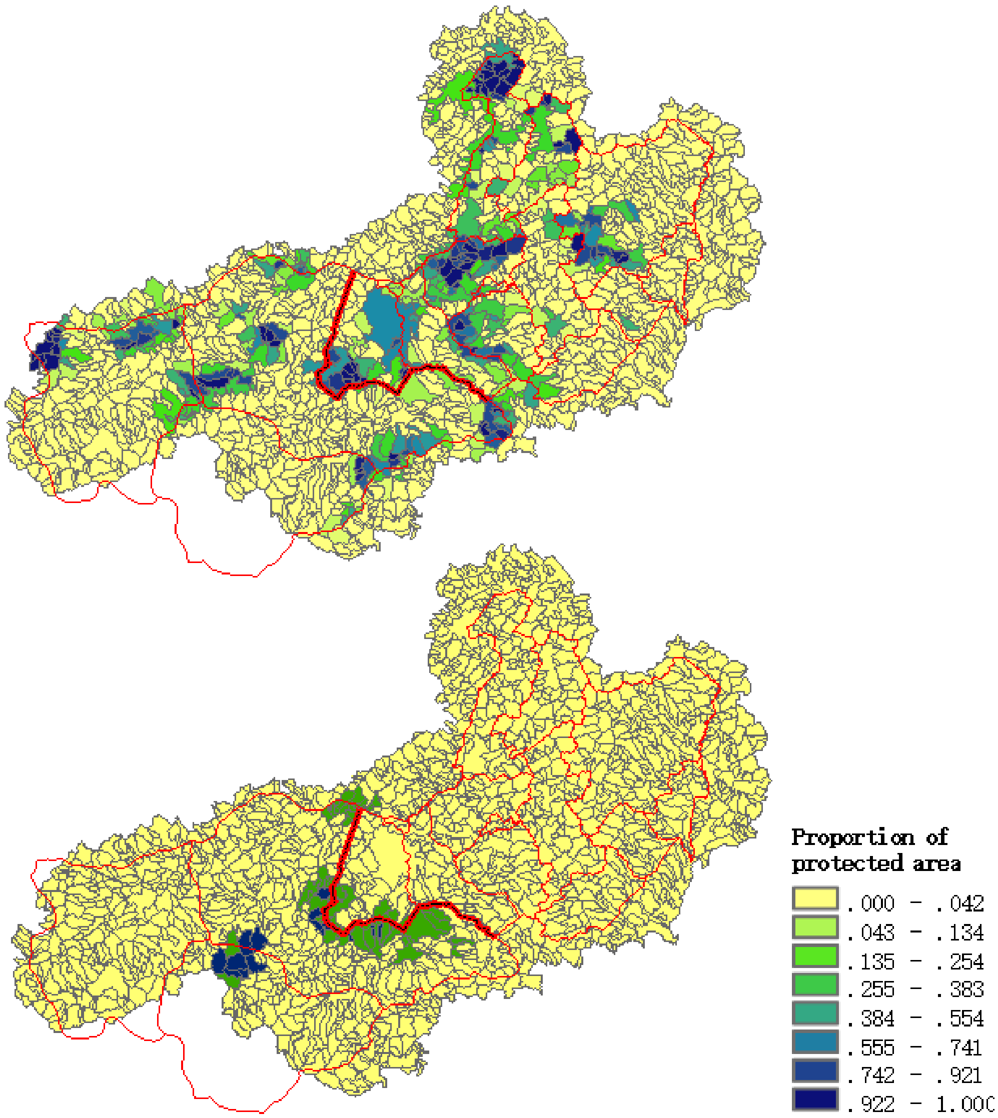

Figure S8: The proportion of existing protected areas (above) and proposed protected areas (below) in each water shed.

RESULTS

On the Daurian steppe, each of the 1572 planning units has a priority value, and 43 units (red polygons in Figure 3) have the priority value over three, indicating those are the best watersheds for long term conservation of the Mongolia gazelle and white-naped crane. Among the 43 planning units, 23 units are at the country border, eight units are in China and 12 units are in Mongolia; the total size of these units is 29,424 km^2, covering 14,753 protected area. There are 151 planning units having the priority value over 2 (red and orange polygons in Figure 3), having the total area of 79,111 km^2, supporting over one million Mongolia gazelle and over 100 breeding pairs of the white-nape crane. The result is the combination of the spatial distribution of (a) the abundance of the white-naped crane and the Mongolian gazelle (Figure S1), (b) human impact (Figure S2), (c) climate change vulnerability (Figure S6), and (d) the existing and proposed protected areas (Figure S7). The conditions of biodiversity conservation between China and Mongolia are quite different on the Daurian steppe, although the areas in the two countries are adjacent and they are in the same ecoregion. Human impacts in China are more severe than those in Mongolia. In China, Hulunbeir prefecture occupies an area of 253,000 square km, with a human population of 2.7 million [41]. The mean human density in China is 10.7 person / square km. In Mongolia, the population density is much lower. For example, in Dornod province, the easternmost province in Mongolia, lives only 73.9 thousand human population in its 123,600 km^2 area [46].

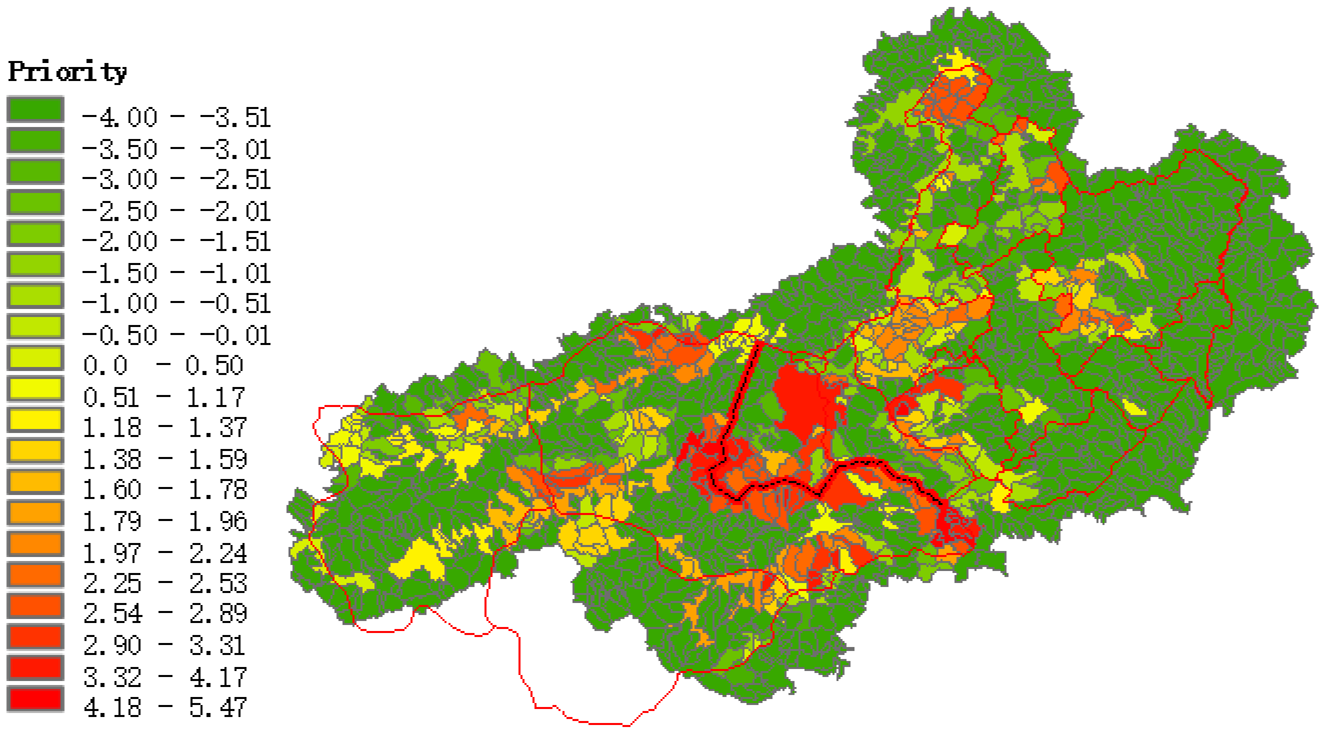

Figure 3: The priority index of the planning units for protecting the Mongolian gazelle and the white-naped crane on the Daurian steppe based on the habitat importance of the two species, human impact, climate vulnerability (aridity), and proportion of protected areas. The areas with high priority (red area) are the areas with high species density, low human impact, lower changes of aridity in the future, and high proportion of protected areas.

The mean human density in Dornad is 0.6 person / square km. With a very low level of human impact, the majority of the Mongolia gazelle and white-naped crane are in Mongolia. In China, two national nature reserves, Dalai Lake nature reserve and Huihe nature reserve, have effective management on the habitat and support stable (yet small) populations of the two species.

DISCUSSIONS

We identified the places with high density of the conservation targets and low human impact and low climate vulnerability on the Daurian steppe. We believe that conservation activities in these places have the highest likelihood of success. Our study is the first effort of transboundary conservation planning for the Daurian steppe. This study focused on two species, the Mongolian gazelle and the white-naped crane. The two species are highly mobile. They need a large region for their long term survival. Transboundary cooperation is the key solution for their continuous protection. We do not have sufficient data in the Russian part of the Daurian steppe, so that we excluded Russia from our study area. There is only a small population of Mongolian gazelle in Russia (less than 1% of the total population), which can be ignored. However, the population of white-nape crane in Russia is large [22, 23], and we will try to incorporate that population in our future analysis.

Collecting sufficient data is the key step for conservation planning. As to the Mongolian gazelle, although millions of individuals are wondering on the Daurian steppe, the published reports are very rare, and there are almost no published data of the species at the database such as GBIF. The white-naped crane is hard to find in its breeding season, so the information of its occurrences is also very limited. Based on our survey in China [32] and WCS's report [33] for the species ranges in Mongolia, we combined the point occurrences and range maps for the Mongolian gazelle and the white-naped crane on the two sides of China-Mongolia border. Our survey results represent the whole population of the Mongolian gazelle in China. WCS's report is based on its long term professional studies, representing the best knowledge of the two species in Mongolia. Conservation planning practitioners usually use specific models to set priority areas. For up to thousands of conservation targets, Marxan or C Plan is usually used to satisfy conservation goals for the targets with minimal area [7].

For a few conservation targets, a number of algorithms are available for species distribution modeling [47], which can generate habitat suitability index for delineating priority areas [48]. In this study, we quantified the conservation targets and cost values in 1572 watersheds, and simply summed the values to produce the priority index. Such a simple method is good enough for only two conservation targets and countable planning units, and it is especially suitable for interpreting the conservation planning processes to local government officers and local residents.Many species are vulnerable to climate change in the world [49], as well as in China [50] and in Mongolia. We indicated that climate change would play different roles in the two countries on the basis of WorldClim dataset (CCCMA/CGCM2 model, emission scenario A2A). In 2080, precipitation would decrease in Mongolia and increase in China within the Daurian steppe (Figure S4). The increase of temperature on the Daurian steppe is not very high, ranged from 0 to 1.28 degree Celsius (Figure S5). The Mongolia part of the Daurian steppe would be drier than the China part in the future (Figure S6). It might switch from temperate grasslands to semi-arid grassland, and become less suitable for the Mongolian gazelle and the white-naped crane. The regions with higher climate change vulnerability have lower conservation priority in our analysis.

We did not take into account the issue of connectivity in our analysis. Connectivity may not be important for the white-naped crane (which is highly mobile), it will be the key issue for the Mongolia gazelle. Currently millions of gazelle freely wonder in Mongolia (the connectivity of the grassland is very good so far), and a small population is enclosed in a nature reserve in China. Connectivity is going to be a problem because the habitat is becoming fragment due to mining and road construction. However, we do not have good data to quantify the connectivity at present. At next step we will include connectivity in conservation planning.

We proposed priority areas (Figure 3) aiming to develop a long term conservation strategy for the Daurian Steppe. We overcame the unbalanced situation between the two countries and carried out transboundary systematic conservation planning focusing on two representative species. Our results would be valuable for introducing the standard conservation action and conservation planning procedures to local government agencies in both China and Mongolia, initiating a science-based, adaptive approach to clarify and fill information gaps, and helping them to develop their portfolios and plans using their data and expert input. Effective protection of the priority areas we selected would secure the long term survival of the Mongolia gazelle and the white-naped crane, and many other associated species and ecosystems.

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