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Perspective

Sustainable wildlife protection on the Qingzang Plateau

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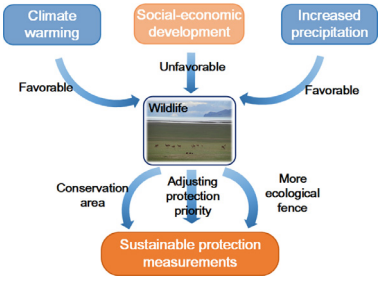
HIGHLIGHTS

- Climate change favours wildlife recovery on the Qingzang Plateau.
- Social-economic developments are boosting pressure on wildlife recovery.
- Fences need to be constructed in a more ecological way.
- More conservation areas are recommended on the Qingzang Plateau.

GRAPHICAL ABSTRACT



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ABSTRACT

Besides its ecological services to China and even Asia, the Qingzang Plateau (QP) hosts a rich variety of wildlife species. During the last century, wildlife population decreased quickly on the QP, driven by human interventions. Recently, wildlife has witnessed rapid recovery mainly propelled by a series of wildlife conservation policies. However, some cautions merit attentions to sustain wildlife restoration and conservation on the QP. This paper casted an overview of environmental and social-economic changes on the QP affecting wildlife subsistence. Results show that QP has been warming, which can benefit wildlife recovery by easing extreme low temperature stresses. The fast growing social economy across the QP lays a solid economic foundation for investing on wildlife protection. Measures such as establishing conservation areas, constructing wildlife pathway corridors, and encouraging herdsman moving out from wildlife rich regions, have boosted wildlife recovery. However, wildlife recovery is constrained by the limited carrying capacity of the ecosystem, left by domestic livestock. Additionally, fences intended to delineate conservation areas or to separate each type of grassland use, have brought about profound side effects on wildlife through fragmentation of their habitats. It is recommended to set up the fence in a more ecological way, which can be achieved by bypassing the wildlife frequent pathway and using materials devoid of steel barb. Only considering both opportunities and problems simultaneously, can the wildlife protection on the QP be sustained.

1. Introduction

The Qingzang Plateau (QP) exists as a gigantic land body in western China. As ecological barrier for China and source of water for most major rivers in Eastern and Southern Asia, the QP has fundamental ecological significance to China and even Asia. Among the ensemble of ecosystem services, the accommodation of a rich variety of wildlife species is one of the most critical aspects for the QP. As a unique geographical unit on the globe, the QP also features a variety of extreme environments such as low temperature, low air pressure, strong radiance, frequent strong winds and snowstorms, supporting unique species. There are over 5,000 types of fungi, 12,000 vascular plants, approximately 1,300 vertebrates and 4,100 insects on the QP (Jia et al., 2010). These species provide a valuable gene bank for wild and domestic cultivations. The QP provides

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over thousands of medicinal plants, accounting for more than 3.2% of the medicinal plants in China (Jia et al., 2010). In Xizang region of the QP, amphibian, reptiles, bird and mammal account for 22%, 17%, 42% and 34% of the national total, respectively (Ge, 1993).

As a relatively young plateau, the QP's recent lifting and transition from palaeo created environments for quite a few new and unique species, including *Saussurea*, *Rhododendron*, *Primula*, *Gentiana* and *Pedicularis* species. Also, many mammal species were saved from innumerous geological disasters by the particular geomorphology of the QP, for example *Picoides tridactylus, Thermophis baileyi, Pantholops hodgsoni, Vulpes ferrilata,* and *Ochotona curzoniae* (Zhang and Zheng, 1985). The QP is also the original site for many mammal species. For example, there are 25 species of *Ochotona* worldwide and 16 of them occur on the QP (Myers et al., 2000).

Most wildlife on the QP has declined since last 60 s due to stress caused by the triple pressures, i.e. reducing living space due to expanded livestock grazing, aggravated poach activities, and grassland degradation. Many mammal species are listed as endangered, especially *Bos mutus, TetraogaIlus tibetanus, Equus kiang, Panthera uncia, Procapra przewalskii, Grus nigricollis* and *Cervus elaphus* (Myers et al., 2000). Since mid-90 s, the importance of wildlife protection has been gradually acknowledged and a series of wildlife protection measures were formulated and implemented, which effectively halted and reversed the wildlife declining trend. Natural environments have also been improving to favor wildlife recovery on the QP since the 60 s, such as increased vegetation coverage, expanded wetlands and advanced start of vegetation growing season (Zhang et al., 2013). Facilitated by these steps, wildlife has been recovered gradually on the QP. However, the forward road for wildlife to be fully recovered on the QP is still bumpy. The side effects of some protection measures are emerging gradually.

Owing to its unique topography and high elevation, the QP has experienced higher average temperature increases than Northern hemisphere (Tao et al., 2014). Then, how this climate warming would affect wildlife? In order to assure the accommodation of recovered wildlife on the QP, an evaluation of the regional resource carrying capacity to accommodate a population growth must be performed. To be sustainable, the dilemma and opportunities faced by wildlife need to be screened out. Only with a thorough overview, wildlife protection can move forward along a prospering direction. In meeting these needs, we evaluate the upside and downside effects of each environmental and social-economic factor on wildlife on the QP. Specifically, the objectives are (a) to identify benefits and constraints of changing climates and social-economic developments on wildlife on the QP; and (b) to recommend sustainable wildlife protection measures on the QP. The recommendations can be the theory basis for wildlife protection on the QP.

2. Challenges for wildlife recovery on the QP

2.1. Climate changes at a velocity above the northern-hemisphere average

The QP covers an area of 2.5 million km^2 with a mean elevation over 4,000 m, which is the largest alpine plateau in the world (Yu et al., 2012). Air temperature has been increasing at a rate of 0.47 k/10 a from 1982 to 2015, but apparent temporal variations were implicit (Fig. 1). The increasing magnitude can be split into two stages. During the stage of 1982–1998, the temperature increasing velocity was 0.49 k/10 a, much stronger than the later stage of 0.21 k/10a in1999–2015. The increasing magnitude of temperature for the period of 1982–2015 and its inner-period of 1982–1998 are both stronger than the global averages (Liu et al., 2019).

Changes in temperature and precipitation demonstrated high spatial heterogeneities (Fig. 2). During 1982–2015, temperature rising magnitude was greater in northern QP than in southern QP. The northern QP is the region where Qiangtang wildlife conservation is distributed. Snowstorms and frigidity are still the two primary lethal climate events for wildlife on the QP (Hu et al., 2018).

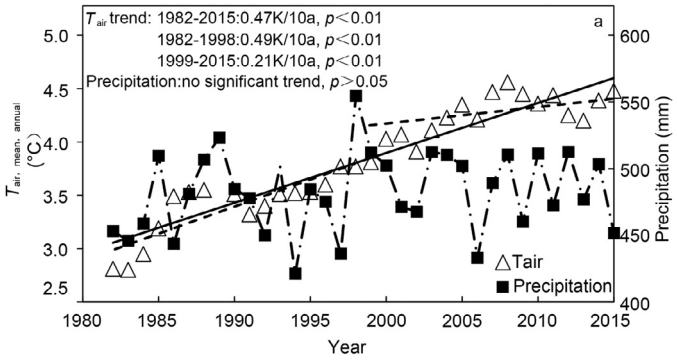

Fig. 1. Temperature and precipitation change trends on the Qingzang Plateau from 1982 to 2015. T_{air} denotes air temperature measured two meters aboveground.

So, the stronger temperature rising might favor wildlife recovery by reducing the stress of extremely low temperatures on the northern QP. Precipitation displayed a non-significant trend for the entire QP during 1982–2015. However, it demonstrated an increasing trend in southern QP, and a decreasing trend in northern-central QP during 1982–1998. During 1999–2015, precipitation displayed an apparent increasing trend in northeastern QP, while a decreasing trend in southern-central QP was recorded (Fig. 3). It merits our attention that precipitation in eastern part of the Northern QP has decreased during the two periods. The drying climates would go against wildlife recovery to a certain extent. Corresponding measures are recommended in combating adverse effects stemmed from drought effects.

2.2. Accelerated social-economic developments

The QP comprises mainly Xizang autonomous region (Xizang) and Qinghai province, as well as a small proportion of Sichuan and Gansu provinces (Fig. 6D). Approximately 60% of the QP is covered by grasslands (Yu et al., 2012). Grasslands provide food resources for livestock, which are the primary revenue industry of the local farmers and herdsmen. Due to data unavailability, we only counted Xizang for social-economic analysis. Total population increased from circa 2.0 million to 3.4 million during 1988–2016, and gross domestic product (mostly from livestock) gained exponential growth (R^2 = 0.99). The total livestock, composed primarily of yak, pig and sheep, continuously grew from 1988 to 2013, then witnessed a sharp drop caused mainly by decreasing population of sheep (Fig. 4).

The built-up areas in Xizang and Qinghai provinces expanded from 170 km^2 in 1995 to 250 km^2 in 2010, then sharply increased to 330 km^2 in 2017. Road length stretched from 30,000 km in 1960 to 40,000 km in 2000, and quickly extended to 160,000 km in 2018. The railroad stretched from 0 km in 1965 to 1000 km in 2017, and quickly increased to 3000 km in 2018 (Zhang et al., 2019). Human activity is mostly concentrated in eastern QP (Fig. 5), while rare roads are constructed in the vast west plateau. Although Xizang people inherit the traditions of protecting wildlife and never rely on wildlife for income, the fast growing livestock and urban sprawling would inevitably squeeze the habitats of wildlife.

2.3. Fallen resource carrying capacity for wildlife

We used Carnegie-Ames-Stanford Approach (CASA) model to calculate ecosystem Net Primary Productivity (NPP). The model was forced by Normalized Difference Vegetation Index (NDVI) of MOD13Q1 (https://ladsweb.modaps.eosdis.nasa.gov) and meteorological data interpolated from China Meteorological station data (http://data.cma.cn/) (Zheng et al., 2020a, 2020b). Then the three-year (2014–2016) average aboveground NPP was summed for each county

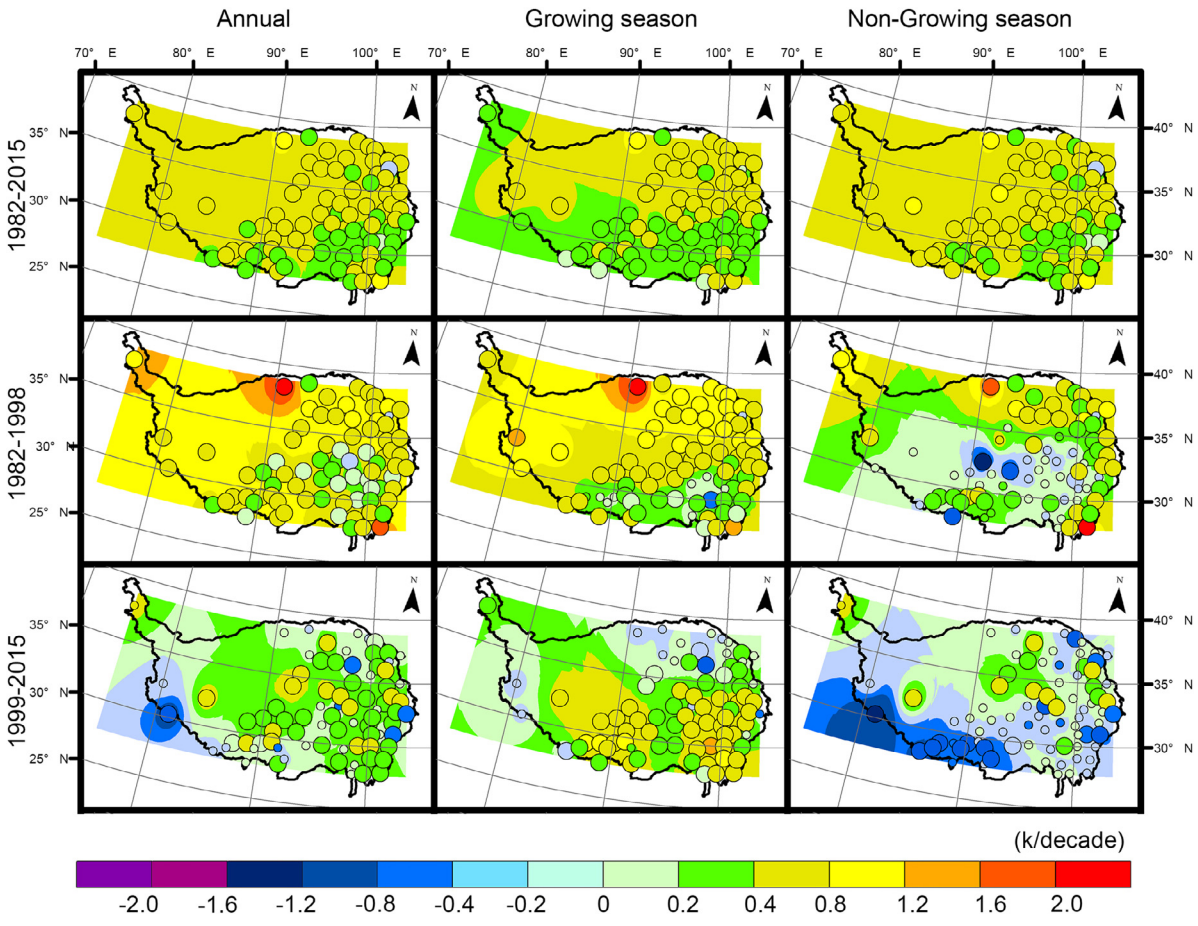

Fig. 2. Spatial patterns of temperature change trends from 1982 to 2015 on the Qingzang Plateau.

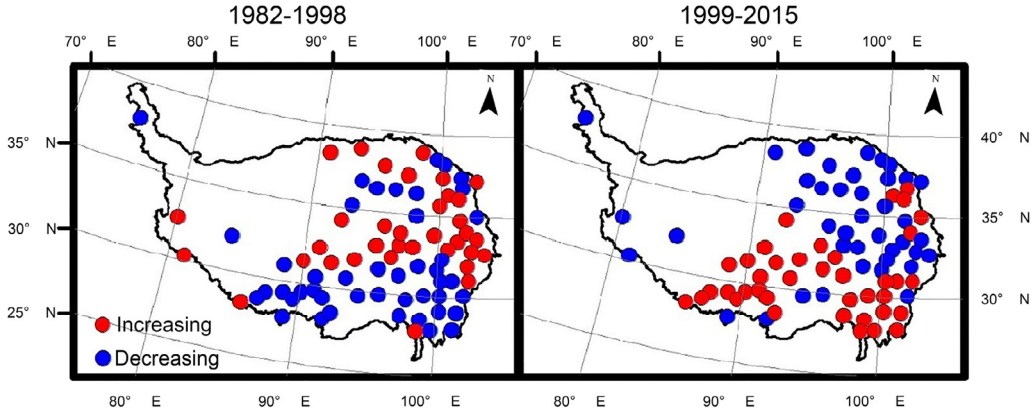

Fig. 3. Spatial patterns of precipitation change trends on the Qingzang Plateau.

of Xizang (Fig. 6A). Based on food resources required by each sheep unit, we generated a map demonstrating grassland carrying capacity for Xizang (Zhao et al., 2015). Grassland carrying capacity is the highest along the Qinghai-Xizang railway belt, with an average value of 100 sheep units per km^2. In the southeast, vegetation is composed primarily of forest, so grassland carrying capacity is low. The carrying capacity demonstrates an overall decreasing pattern from east to west. In central Xizang and along the southern belt of Xizang, the carrying capacity falls in the range of 40-–80 sheep units per km^2. In west Xizang, the carrying capacity is the lowest and carries only less than 20 sheep unit per km^2.

Using annual record data of Tibet Statistical Bureau (2020), we generated a map showing actual livestock number (standard sheep unit) for each county of Xizang (Fig. 6B). The carrying capacity and actual livestock number exhibit an analogous pattern, decreasing from eastern Xizang grasslands to western parts. The highest actual livestock density occurs in the regions around Lhasa, with a density value exceeding 100 sheep units per km^2. Along the east-west decreasing gradient, the livestock density is approximately 40 sheep units per km^2 in counties such as Shengzha, Zhongba, Nima and Anduo, where the actual domestic livestock density is a little bit lower than the grassland carrying capacity. In the wild-vast west Xizang, the actual livestock density is approximately 20 per km^2, which exceeds the ecosystem carrying capacity.

We further calculated their difference as [carrying capacity] – [actual livestock number] to infer the food resources left for wildlife (Fig. 6C), which can be counted as the remaining carrying capacity.

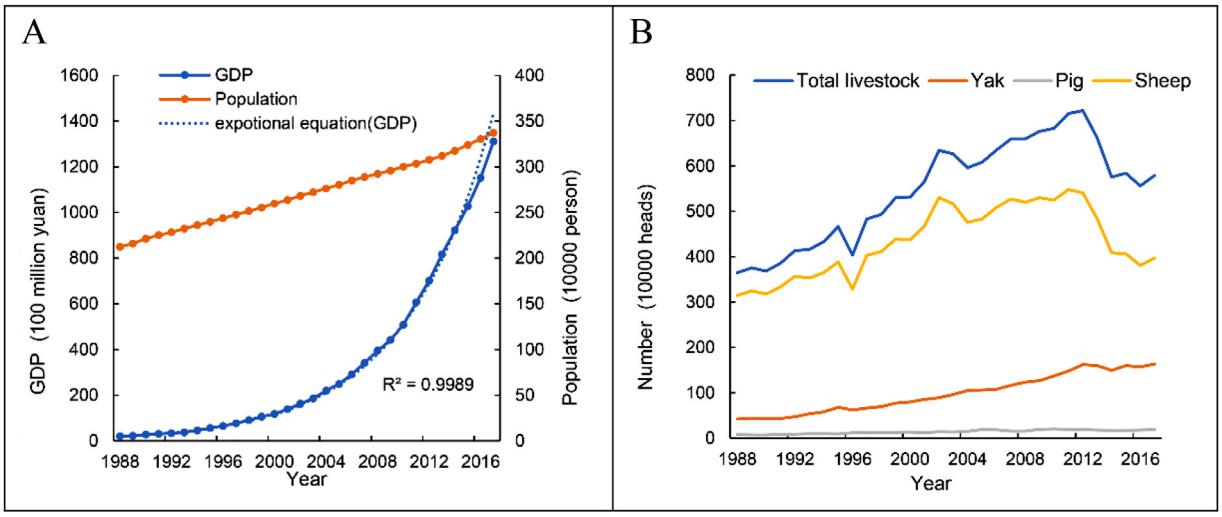

Fig. 4. Social and economic developments for Xizang autonomous region (Xizang) of the QP. A: Gross Domestic Products and population growth for Xizang; B: total number of livestock growth, including only the three main types (i.e. yak, pig and sheep).

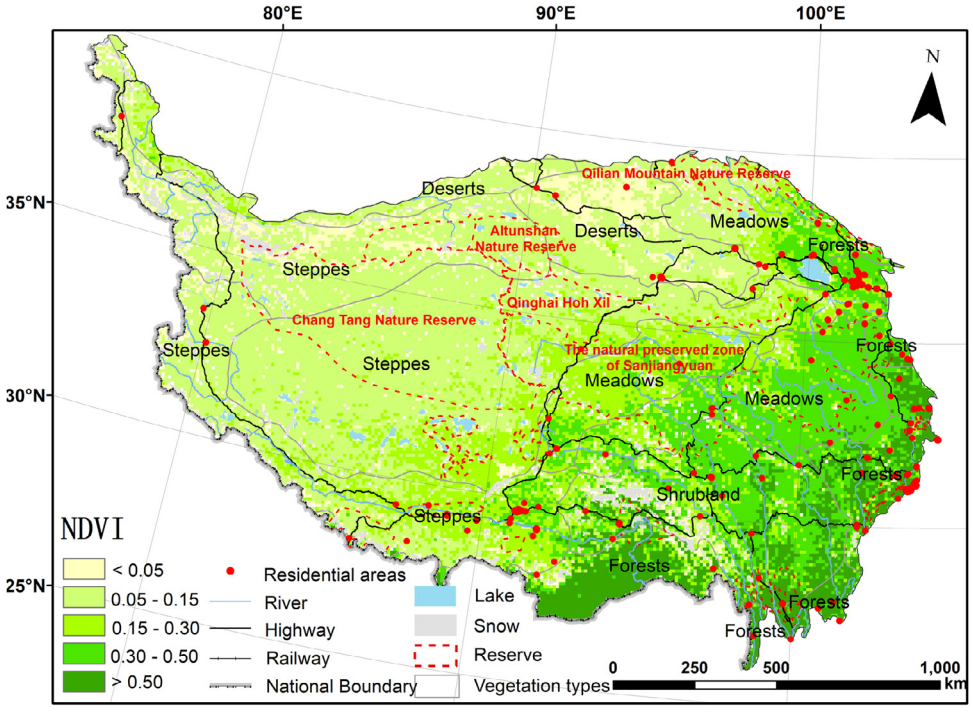

Fig. 5. Vegetation pattern on the Qingzang Plateau. Railway, road, conservation areas and residential areas are shown on the map.

The difference map shows that actual livestock has reached full capacity of regional food availability in southern, western, and eastern Xizang, while some spaces for wildlife remain in Northern Xizang and north-central Xizang. Specifically, several counties around Lhasa are affected by severe overgrazing. From Lhasa and Naqu toward west, counties of Naqu, Bange, Shengza still have moderate carrying capacity left for wildlife animals. Further to the west, domestic livestock almost reaches the upper limit of grassland carrying capacity. Domestic livestock has exceeded the grassland food capacity in the two furthest west counties of Ritu and Gee.

We didn't compare the remaining carrying capacity with total wildlife population due to their data shortage. However, the inferred difference demonstrates grasslands in northern and north-central Xizang are not over-grazed by domestic livestock, where most wildlife conservation regions are distributed. Currently the conservation areas are distributed primarily in those remote regions non-inhabited by human beings. Those regions overlap pretty much with low vegetation productivity. To accommodate growing wildlife population, we can correspondingly consider the regions in the central Xizang, where favorable climates nurture relatively high productivity vegetation. Also, these regions have an average altitude of approximately 5000 m (e.g. Shuanghu region), and are unsuitable for human living. Thus, they can be reserved for wildlife conservation areas.

The conflict of domestic livestock competing with wildlife on food resources around the conservation areas awaits to be resolved. The greatest threat to wildlife on the QP still stems from intensifying human activities. Although illegal poach has been prevented to a great extent, grazing livestock are encroaching deep into remote regions of the QP. The modern means of transport and extended road network open new pathways for human access to those physically harsh environment regions. There are frequent collisions between wildlife feeding and domestic livestock grazing. In addition, although the rapidly growing number

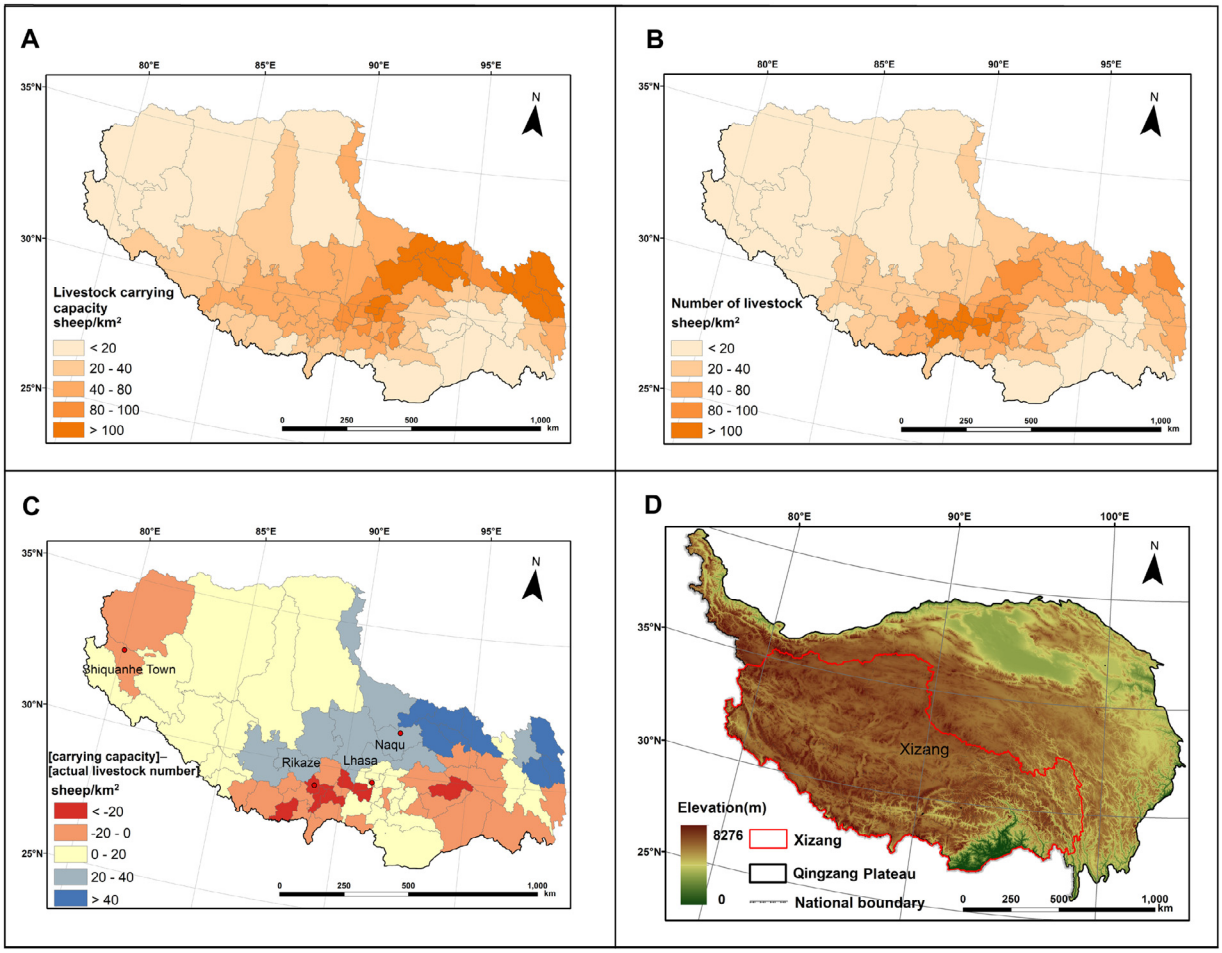

Fig. 6. Vegetation carrying capacity (A), livestock density (B), and the carrying capacity left for wildlife (C) for Xizang autonomous region (Xizang) of the QP, boundary of the Xizang autonomous region (D).

Table 1
The five primary conservation areas on the Qingzang Plateau.

Name	Region	Area (km^2)	Altitude (m)	Locations	Main inhabited wild animals
Altunshan	Xinjiang Uygur Autonomous Region	4.5×10^4	> 4600	36°00′N – 37°49′N, 87°10′E – 91°18′E	Pantholops hodgsoni, Bos grunniens and black-necked crane, etc.
Chang Tang	Xizang Autonomous Region	29.8×10^4	> 5000	32°12′N – 36°29′N, 79°59′E – 90°26′E	Pantholops hodgsoni, Bos grunniens and Equus kiang, etc.
Qilian Mountain	Gansu Province	2.65×10^4	> 3000	36°43′N – 39°36′N, 97°25′E – 103°46′E	Snow leopard, white-lipped deer and Bos grunniens, etc.
Qinghai Hoh Xil	Qinghai Province	4.5×10^4	> 4600	34°11′N – 36°10′N, 89°15′E – 94°03′E	Pantholops hodgsoni, Bos grunniens and Equus kiang, etc.
The natural preserved zone of Sanjiangyuan	Qinghai Province	39.5×10^4	> 4400	31°39′N – 36°16′N, 89°24′E – 102°23′E	Pantholops hodgsoni, Bos grunniens and snow leopard, etc.

of tourists mostly visit the city and the conveniently accessible scenic areas, an increasing proportion of them choose to visit the non-frequented remote regions, which would inevitably cause disturbances on wildlife.

3. Opportunities for wildlife recovery on the QP

To recover and conserve wildlife on the QP, a series of measures have been implemented since the 1990s. Among them, the largest investment was on the establishment of national and provincial reserves. Currently, the QP hosts five main conservation areas, including Altunshan, Chang Tang, Qilian mountain, Qinghai Hoh Xil, and Sanjiangyuan (Table 1). Each conservation area has its corresponding key species to protect.

Qiangtang National Reserve is the largest conservation area. This reserve was established in 1993 and classified as national wildlife reservation area in 2000. It is home to several endangered species of antelopes, wild yak and wild ass (kiang). Within the national reserve, poach and grazing are strictly forbidden. In addition, the state and local governments implemented a series of “grazing for green” projects since 2000, whose overall objectives are to protect grasslands from overgrazing and recover degraded grasslands. During the 12^{th} plan of five years, the Xizang province invested 1.1 billion Chinese Yuan in the project. By 2012, the grasslands protected from livestock grazing cover 60,000 km^2 in Xizang province, corresponding to approximately 50% of its area (Fig. 7).

Recently, governments took further grassland recovery and wildlife protection steps, to improve living conditions of herders and also lower grazing pressure from livestock. Local herders are encouraged to move out from regions higher than 5,000 m in elevation, where no perma-

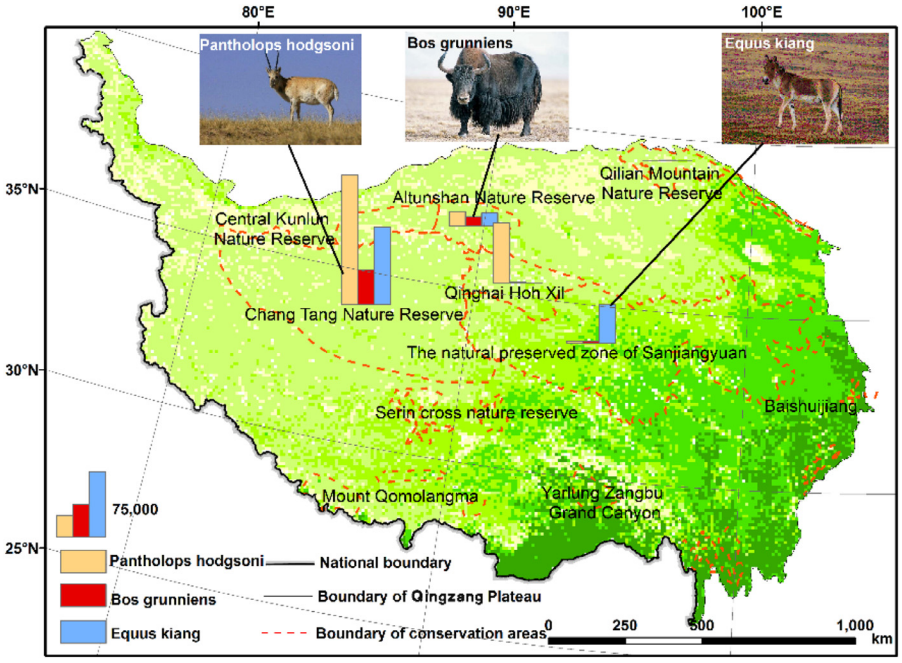

Fig. 7. Distribution of the three main wildlife (*Pantholops hodgsoni, Bos grunniens, Equus Kiang*) in the three largest wildlife conservation areas on the Qingzang Plateau. The bar height is proportional to the population size of each wildlife.

nent residents lived prior to 70 s of the last century. In 2019 alone, 2,900 herders have moved out from Shuanghu to Lasha river regions (www.tibet.cn, accessed on 12/20/2020). This large scale migration would save the rich variety of ranch resources for wildlife and facilitate wildlife habitat improvements. Wildlife would also be exposed to less disturbances from human activities.

Wildlife prefers extensive and highly connected landscape for their habitats. To meet this demand, establishing national parks or conservation areas should receive increasing attention. Within national parks, domestic grazing is strictly prohibited, since livestock would damage extensive grasslands. Then establishing national parks and completely banning domestic grazing, while compensating herders by moving to relatively comfortable living environments, would achieve win-win situations. National park system will overcome the limitation of protecting one individual resource. For example, the mission of forest conservation is to protect forest, but it neglects the interactions among each ecosystem element. Forest regeneration and seed dispersal depend on animal movement; insects can destroy forests, while birds prey on insects and protect forests. National park system emphasizes protection of endangered species, also the mutual respect between human being and nature. Guided by national park system, comprehensive protection and limited utilization are naturally integrated. Protection is enforced and supervised by specialized departments to ensure its efficiency (Sun et al., 2020).

4. Pathways to improve wildlife protection

4.1. Adjusting wildlife protection priority

The “grazing for green” measures have substantially improved the ecological and environmental conditions on the QP. Mostly caused by global warming, vegetation coverage on the QP has increased constantly from the 1980s to the 2010s (Zhang et al., 2013). The start of vegetation growing season has advanced significantly in most grassland areas on the QP (Huang et al., 2016), which can provide accrued food resources for wildlife. Another noteworthy phenomenon is that wetlands have expanded on the QP as a result of increased melting glacier under global warming (Xue et al., 2018). Wetlands are the water drinking sites for wildlife, and enlarged wetlands hypothetically provide enriched access for wildlife to water resources. Propelled by the improved habitat environments, wildlife population size has also increased steadily in the past decades. For example, the wild yak and antelope population size have both experienced large increases in the past decades (Li et al., 2019). Within the Qiangtang National Reserve, the population size of ungulates increased from 80,000 to 150,000 (antelope species), wild yak increased from 20,000 to 40,000 and wild ass increased from 50,000 to 90,000 (Li et al., 2019). From 1992 to 2003, along the southern border of Qiangtang reserve, the antelope population increased 66% from 3,900 in 1991 to 5,890 in 2003 (Fig. 7).

In the last century, wildlife population size has dramatically decreased due to livestock invasion and poaching, especially for the large predators. In the present, although wildlife population has recovered to a moderate extent, some issues are still pending. The most prominent one is the unbalanced food network. Animal species in the bottom of food network, such as Pika population, are exploding, since their predators are severely lacking. Similar situation is observed with the antelopes, since the recovery rates of their predators are widely lagging behind. Protection measures should invest relevant efforts in these large predator animals, which are conventionally favorable targets for poach.

4.2. Eco-friendly fence

The establishment of conservation areas and implementation of the “grazing for green” project involves erecting fences, the most commonly used practice. These fences are efficient for wildlife protection and protection of vulnerable grassland vegetation from overgrazing (Somers et al., 2012). Additionally, fences are also used in contracted lands to set aside grasslands for rotated winter usage. The primary function of fence lies in their separation of wildlife and human dominated systems. Fence can protect wildlife populations from overhunting, poach and overall reducing human-wildlife conflict. Until now, there is a total of 2,000 km of fences in Qiangtang National Reserve alone. The totally fenced area in the Xizang province in 2011–2015 amounted to 30,000 km^2 (Tibet Statistical Bureau, 2020).

Fencing can be efficient and cost effective, but its detrimental effects on wildlife are also apparent. Some of these detrimental effects are immediate, and some effects can be potentially long-lasting. As fence is normally constructed with barbed wires, it can directly cause wildlife

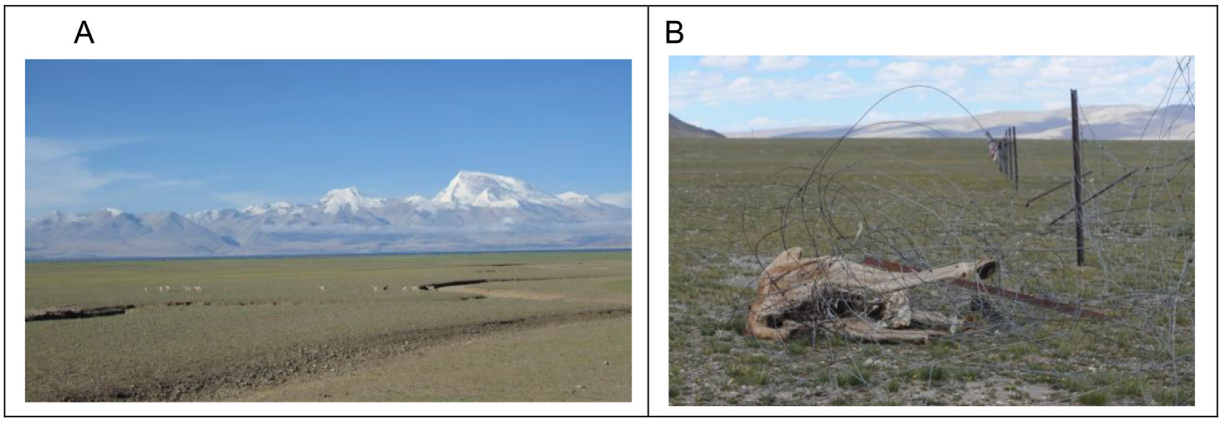

Fig. 8. Wildlife and fence on the Qingzang Plateau. A: Antelope groups on the Qingzang Plateau; B: Antelope entangled by fence.

mortality. Wild ungulates can possibly be entangled by barbed wire and starve to death, or die directly after collision with fence. For example, during 2003–2010, environmentalists have saved at least 10 Przewalski's gazelles that were injured by or stuck on fences (Chinanews website, accessed on 12/20/2020), while the current global population of Przewalski's gazelles is approximately 1,000 (Fig. 8).

Fencing can also increase the predation rates of wild ungulates, as fence can be obstacles preventing wildlife from escaping. Since predator and prey possess distinct capabilities in circumventing fence, prey is exposed to a higher predation risk in regions with fence presence. Aside from direct mortality, more indirect and even greater threats are the negative effects related to habitat loss and wildlife avoidance behavior. Fence fragments wildlife habitat and restricts their movement and foraging range. Based on the ecological meltdown theory (Terborgh et al., 2001), small and isolated populations in fragmented islands are prone to higher extinction rates.

Considering the various side-effects on wildlife, extreme caution is merited when planning fence construction. To minimize their impacts on wildlife, the following countermeasures are recommended in designing fence structure and placement. Fence can be made from alternative materials, such as kinked mesh materials. The barbs on fence can be removed to minimize their effects on wildlife. Fence might be lowered or made permeable to allow protected wildlife to jump over or cross in some key corridor zones. For the fences already placed in areas critical for wildlife, they should be completely removed. Ideally, no fence should be placed in areas critical to wildlife breeding activities. In areas with rich wildlife resources, no-fence policy should be adopted to protect and recover grasslands. In the national reserve, fence application should be completely abolished. Whenever fence is unavoidable, fence layout can overlap or follow the general route of existing barriers, such as ditches, rivers, roads, or water bodies, which is an option to minimize habitat fragmentation. Fence construction also involves high cost, especially in remote areas (Creel et al., 2013). Funds saved by avoiding fence can be invested in other aspects such as grassland restoration and conservation. To fully and effectively lessen the potential side effects caused by fence, we need to improve our understanding on wildlife movement patterns and on what creates barriers to wildlife movement. In regions where wildlife movement is frequent and necessary, wildlife corridors/underpasses need to be devoid of fence to allow for their free travel and access to important habitats and water source areas.

5. Conclusions

Under unprecedented climate warming and social-economic development on the Qingzang Plateau, wildlife in the region is facing golden opportunities and also some challenges. In addressing these opportunities and challenges, the following protection and recovery measures are recommended.

(1) Climate warming in general favors wildlife survival on the QP since winter snowstorm and freezing are still the primary fatal natural factors for wildlife. Warming can ease the frigidity pressure to some extent, though high spatial heterogeneities are exhibited. Drought caused by rising temperature and decreasing precipitation in the southwest QP have created some difficulties for wildlife.
(2) Social-economic development heightens human disturbance pressure on wildlife, but also solidifies the economic foundation for implementing the series of wildlife protection measures. The latter one is critical for wildlife recovery and conservation on the QP.
(3) Due to the moderate or heavy livestock grazing, the food resource carrying capacity left by domestic livestock is limited for wildlife on the QP. To resolve the conflict between feeding domestic livestock and growing wildlife population, enclosing regions for national park and strengthening protection executions are urgent.
(4) The conventionally adopted measures, primarily fence, need to be designed in a more ecological way, including their distribution locations and the materials used.

Consideration of all the above mentioned measures is required for wildlife restoration and conservation on the QP, and thus achieving its sustainable goal.

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.

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