The Effects of Climate Change on Snow Leopards at the Hengduan Mountain Region

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Abstract. Snow leopard is one of the top predators and umbrella species of Hengduan Mountain (HM) region. Conserving snow leopard is vital in preserving this biodiversity hot spot. Climate change (CC) is imposing negative influences on snow leopard populations. This research combines and analyses recent research papers on this topic. It turns out that snow leopards are generally influenced by CC in three ways. Firstly, climate change enables forest to move to higher elevation to occupy grasslands, the main habitats of snow leopards. Therefore, snow leopard habitat shrinks and suffers greater fragmentation. Secondly, climate change makes grasslands more vulnerable to degradation, thus threatening preys of snow leopards. Thirdly, CC causes leopards to move to previous snow leopard habitats. As a result, there are risks of competition between snow leopards and leopards. This research appeals for more observation to better analyse snow leopard’s response to climate change.

1. Introduction
Like many mountain regions, HM region, which is one of the world biodiversity hotspots, is a vital ecological function area that provides a variety of ecological services whereas is vulnerable to CC[1]. In today’s context of global warming and the increase of direct human influences, protecting the ecosystem of the HM region becomes more important and urgent than ever before. It is been proved that the top predators have the functions of controlling prey populations and promoting biodiversity in the ecological perspective as well as calling for public concern on conservation, gathering financial support and delimiting preserve areas in the perspective of conservation[2]. In the HM region, snow leopards are the dominate top predators that can play the role mentioned above. As an endangered species of IUCN Red Book, snow leopards are being heavily affected by habitat fragmentation, food resource starvation and food chain cracking[3]. Up to now, there is a number of research articles available, including those about the genetic diversity, population, habitat and ecology of snow leopard. This article is intended to make a discussion based on the former studies to draw a conclusion about how snow leopards of HM region are and will be influenced by global CC, thus giving suggestions to future studies and policy making related to snow leopards and the ecosystem of HM region.

2. Analysis

2.1. The effect of climate change on snow leopard habitats
Snow leopard adapts rugged mountain habitats at high elevation including grassland, shrubland, bare areas, ice cells and agricultural mosaic, which are especially vulnerable when facing global CC. Snow leopards scarcely choose forests, which are mainly consisted of conifers, as habitat. However, as the climate change causes the local environment to meet the requirement of forest growth, snow leopard
habitats may convert into forest. This upwards movement of timberline causes areas suitable for snow leopards to shrink toward higher altitude, thus causing decrease in area and fragmentation[4]. Basically the regional vegetation dynamics is driven by precipitation and temperature. As figure 1 shows, from 2000 to 2015, the climate in HM region tends to become warmer and drier[5].

![Figure 1. Trend of precipitation and temperature of HM region from 2000 to 2015][5].

Conifers at middle and high altitudes, which are sensitive to low temperatures in winter, are benefiting from the increase in temperatures in winter. The growth of conifers is also being promoted by the rising temperatures in summer[6]. According to the anticipation of models, 10% to 30% of snow leopard habitat in the Himalaya will loss by 2050. However, there is a increase of precipitation due to global CC at the Himalaya, while climate at HM becomes drier from year 2000 to 2015[4,5]. Therefore conifers at HM may not benefit from CC as much as those at the Himalaya do. Despite this drying trend at present, precipitation will increase by 10% by 2070, and conifers at HM would benefit from climate change[6,7]. Although the temperature and landscape may make areas at higher elevation become adaptable for snow leopard, thus enabling them to move upwards, oxygen deprivation limits snow leopards from forming stable population beyond 5500m. New habitats formed at higher elevation are unlikely to offset the loss at lower elevation[4,7]. Based on the IPCC scenario RCP8.5, by the year 2070 snow leopard habitats at HM will completely loss[7]. Although the habitats of snow leopards in HM are divided into patches, it is proved that natural barriers, apart from wide rivers, hardly stop snow leopards from diffusion[8]. According to DNA test results shown in table 1, snow leopard populations are able to communicate with each other. As a matter of fact, populations in HM can be considered as part of the Tibetan Plateau population unit[3]. However, since the climate change will amplify habitat fragmentation, it remains unclear whether the populations of snow leopards will be able to communicate with each other in the future.
Table 1. Results of snow leopard fecal DNA test

| Sample location | Amount of sequences (Snow leopard) | Diverse site | Haplotype | Haplotype diversity | Nucleotide diversity | Average nucleotide differences |
|-----------------|----------------------------------|-------------|-----------|---------------------|----------------------|-----------------------------|
| SJY             | 29                               | 5           | 5         | 0.727               | 0.010                | 1.002                       |
| Nanqian County  | 7                                | 3           | 3         | 0.667               | 0.012                | 1.238                       |
| Zhiduo County   | 15                               | 1           | 3         | 0.629               | 0.066                | 0.629                       |
| Zdou County     | 3                                | 1           | 3         | 1.000               | 0.009                | 1.000                       |
| Qumalai County  | 6                                | 3           | 3         | 1.000               | 0.022                | 2.333                       |
| Yushu County    | 10                               | 0           | 1         | —                   | —                    | —                           |
| QT              | 5                                | 5           | 3         | 0.700               | 0.021                | 2.200                       |
| Shenzha County  | 2                                | 0           | 1         | —                   | —                    | —                           |
| Bang County     | 3                                | 5           | 3         | 1.000               | 0.025                | 2.667                       |
| RNS             | 14                               | 7           | 5         | 0.659               | 0.017                | 1.813                       |
| Akesal County   | 4                                | 13          | 9         | 0.776               | 0.015                | 1.552                       |
| Total           | 48                               | 14          | 9         | 0.776               | 0.015                | 1.552                       |

SJY: Sanjiangyuan National Nature Reserve (Qinghai Province)
QT: Qiangtang National Nature Reserve (Tibet Autonomous Region)
RNS: Randhan area (Dangdian, Gansu Province)

2.2. The effect of climate change on prey
Snow leopards’ prey are mainly large ungulate animals including blue sheep (Pseudois nayaur), Asiatic ibex (Capra sibirica), Himalayan tahr (Hemitragus jemlahicus), and argali (Ovis ammon). Marmots (Marmota himalayana) are also snow leopards’ prey. Like snow leopards, they rely on the grasslands and shrublands at alpine areas and hardly perch areas under timberline. Upwards movement of timberline cause the habitat of prey to shrink. There is no independent model to predict the tendency of the shrink of the habitat of prey species. However, it can be estimated that species response differently[4]. Generally, these species are all being drove to higher elevation by moving timberline. Apart from decrease in habitat area, these species are exposed to grassland degradation which is the result of both CC and human activities. It is clear that temperature rise negatively influences the grassland, while precipitation positively influence the grassland by increasing soil moisture, thus making the grassland less vulnerable to degradation[9]. In the HM, where the climate is becoming warmer and drier, grasslands is becoming more vulnerable to degradation[5]. When these grasslands are heavily grazed, they are more likely to degrade. Wild herbivores are either faced with food shortage, or be driven to further to higher elevation, to sub-optimal habitats with higher survival pressure[8].

2.3. Potential competition between leopards and snow leopards
Unlike most snow leopard habitats, where the snow leopard is the only large predator of the area, HM supports other large predators in the same region, including leopard (Panthera pardus), clouded leopard (Neofelis nebulosa), Eurasian lynx (Lynx Lynx), brown bear (Ursus arctos), Asiatic black bear (Ursus thibetanus), dhole (Cuon alpinus) and gray wolf (Canis Lupus)[10], as it is shown in figure 2. These species previously conquer different elevation of the mountains to minimize competition between species. As climate change causes their habitat areas to shift and form overlaps, such strategy may become less useful.
In Nepal, although barking deer, the main food source of leopard, account for 18% of leopard’s food, it is observed that blue sheep, another main food source, account for 6% of leopards’ food[12]. It is also reported that leopards and snow leopards in central Himalaya both feed on Himalaya tahr. Dietary overlap between this two species in this area is as high as 69%[15]. As a result, it can be suggested that snow leopard and leopard have the potential of competing with each other.

Leopard in Tibet and east Asia has hunting strategies relying on the existence of forest [13], thus their activities are theoretically limited to the forest areas. Leopard habitats are now expanding together with the upward movement of timberline as a result of the CC[14]. Snow leopards may choose to move upwards to avoid potential competition with leopards[15]. The inter-specific aggression between leopards and snow leopard is now being avoided by habitat separation[15]. However, in other parts of the world, it shows that leopards are good at adapting to different landscapes[13,14]. In some areas of HM, where sparse forest and open grassland mix, it is not rarely recorded that leopards and snow leopards appear at the same site[11].

The mean body weight of snow leopard is lower than that of the local leopards[13], making snow leopards be at a disadvantage in the potential conflicts. Failing the competition may fasten the loss of snow leopard at low elevation.

Based on the current theory that predators with a large dietary overlap and similar size are likely to compete, the risk of competition between snow leopards and leopards is high. However, it is needed to find out whether snow leopards and leopards have already formed ways of preventing unnecessary conflicts.

2.4. Summary of climate change’s effect on snow leopards

From 2000 to 2015, climate in HM region tends to become warmer and drier. In the IPCC scenario, temperature as well as precipitation will rise. Three ways in which snow leopard in HM is being influenced by climate change can be summarized. Firstly, rising temperature enables timberline to move upwards, causing the adaptable open areas suitable for snow leopards to shrink. Although snow leopards are able to overcome moderate habitat fragmentation, it remains unclear whether they will fail to do this for the fragmentation is amplified by CC. Secondly, the rising temperature amplifies grassland degradation, which is mainly caused by overgrazing, thus threatening the snow leopard’s prey. Thirdly, the expand of forests enables leopards to invade snow leopard habitat, what will
potentially lead to the competition between these two species. Due to the disadvantages of snow leopards in weight and size compared to local leopards, such competition may aggravate the further loss of their habitats. The effect of CC on snow leopards is shown in figure 3.

![Figure 3. climate change’s effects on snow leopards.](image)

3. Conclusion

3.1. Conservation actions

In the research, what is significant is that human activities are also causing serious damages to snow leopard populations. To minimize the negative effect on snow leopards in the context in which climate change is inevitable in a time period, reducing negative human influence is a direct and possible solution.

It is for sure that snow leopards are able to cross most natural barriers but not artificial ones, including grazing enclosures and roads[8]. To reduce the climate’s effect on habitat fragmentation, building ecological gallery and controlling road and enclosure construction is important in ensuring the communication between snow leopard populations.

Although CC makes grassland easier to degrade, most degradation events are directly caused by overgrazing. Livestock not only degrades habitats of snow leopard’s preys and drive them to suboptimal areas, but also spread diseases, thus threatening their populations. Wildly built enclosure fail to reduce degradation in many areas. The positive result of “replacing pasture with grassland” project is for sure, but the extensive use of enclosures requires discussion.

3.2. Future study directions

The prediction of forest and grassland’s response to climate change needs to be tested by collecting data in the future because according to current studies, CC in HM has somehow surpassed any scenario provided by IPCC[4].

As some areas may be climatically suitable for forests but are actually too steep for forest growth, the results of timberline movement requires further discussion[1].

Recently generalized camera trap and tracking necklace technology can be used to further investment of snow leopards. For example, tracking necklace and camera trap can identify individuals of snow leopards and record their movement, thus determining whether snow leopards can travel between habitat fragments.
Although might have been aggravated by CC, the phenomenon of coexistence of snow leopard and leopard might have lasted for long in HM. Whether they have formed methods of avoiding conflicts, and how climate change will affect their relationship are important for researchers to solve, when studying their relationship.

In present investigations, sites suitable for snow leopards without obvious prove for their presence are being discovered. New distribution is also being revealed. Potential distributions of snow leopards around HM needs to be proved.

Apart from snow leopard and leopard, other large and middle predators in HM, including clouded leopard, Eurasian lynx, brown bear, Asiatic black bear, dhole and gray wolf, receive poor concerns. Researches on them are much less than those done on leopards and snow leopards. Since the comprehensive research covering these specie can provide valuable information on ecology and conservation, more studies on these species are appealed for.

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