Impact of Climate Change on Snow Leopards in the Himalayas

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Abstract.

Nowadays, there are no more than 8000 snow leopards worldwide. Habitat loss and habitat fragmentation, reduced prey numbers, etc., have become the main reasons for the decline in snow leopards, leading to the extinction of snow leopards. Many current studies are focusing on the distribution, behavior, and prey of snow leopards and the threats they meet. But even though we know the snow leopards well and have tried our best to protect them, they are still facing some threats, such as climate change. This article studies how climate change acts in the Himalayas, which is the main habitat for snow leopards, the reasons for climate change, and how climate change affects snow leopards. Climate change causes warming, changes in precipitation, and glaciers retreating in the Himalayas. These reduce the area of snow leopards' territories and decrease the number of prey. Therefore, cubs' fertility and survival rates decline, exacerbating snow leopards' extinction.

Keywords: Snow leopards; climate change; Himalayas

1. Introduction

The Himalayas are called the „Third Pole of the Earth" because of their cold height, remoteness, and vast glacier reserves. It is also called the „Water Tower of Asia'" because of the vast water storage capacity of the lakes and wetlands on the plateau. There are 19 major rivers in the Himalayas, the largest being the Indus and the Brahmaputra, each with a catchment area of approximately 259,000 square kilometers. Also, this area is covered by a large area of glaciers. There are 17,845 glaciers in the entire Himalayas, with an area of 34,658.8 square kilometers and an ice reserve of 3,688.37 cubic kilometers.

This region is vulnerable to global changes and typical ecologically fragile areas [1]. The temperature in the Himalayas increases faster than the global average [2]. Studies from Uttam Babu Shrestha. et al. [3] have shown that the Himalayas have warmed since 1975. And because of the warming, Himalayan glaciers are retreating. This is already happening on many small glaciers (<0.2 km^2) at a rate of 10-60 meters per year. Had disappeared. Vertical glacier movements of up to 100 meters have been recorded over the past 50 years. Due to the retreat of glaciers, the number and size of lakes in the Himalayas are also increasing. In addition, the tree lines have advanced due to global warming.

This causes the shrinking of the habitat of some herbivores, resulting in the dynamic and number of them decreasing, which makes the competition between predators more intense. And this may cause a decrease in the number of some predators, such as snow leopards.

Snow leopards prefer dry, cool, steep mountainous areas with many bare rocks. They often move through environments with permanent ice and snow, alpine bare rock, and cold desert areas. They usually live in the high mountains at 2500 to 5000 meters. In summer, they can be found at 3000 to 6000 meters. And they will move down in winter, at 2000 to 3500 meters. They are the highest-altitude carnivore. They mainly feed on goats, sheep, and sometimes gorals and prey on small animals such as rabbits. Because they are at the top of the plateau ecological food chain, they are also the most sensitive to environmental changes.

The former habitat of snow leopards is no longer suitable as there is not enough prey, and the climate there has changed (warmer, change in precipitation, more extreme climate events). So, they need to migrate to another habitat that is more favorable for them. However, the suitable habitats for them have shrunk due to climate change. So, actually, the area of territories of snow leopards decreases. Now, they are patchily distributed in mid-Asia, covering an area of approximately 1.23 million square kilometers. The shrinking of snow leopards' habitats causes interspecific and intraspecific competition. Besides, increasing tree lines and lowering the water table decreases the dynamic and number of prey for snow leopards. These two factors result in less food availability for snow leopards, which will cause reduced fertility rates, survival rates, and genetic variation of snow leopards.

Nearly one-third of the world's population lives in snow leopard habitats or downstream areas. The ice and snow stored in the mountains provide important water sources for downstream rivers. Snow leopards are „the barometer of the health of high-altitude ecosystems." So, protecting snow leopards is protecting the ecosystem in the

Himalayas, a biodiversity hotspot. Therefore, protecting the Himalayan ecosystem is also very important for human survival. As an important part of this system, snow leopards are worthy of in-depth exploration in this article. This article will start with the impact of climate change on the Himalayas and discuss the impact of climate change on the distribution, reproduction, and food of snow leopards based on recent research. In addition, feasibility recommendations for protecting snow leopard diversity will be presented.

2. Climate Change in Himalayas

2.1 Warming

Many studies in the past 100 years have shown that the temperature in the Himalayas has increased significantly due to global warming since the warming trends in areas at elevations over 2000m are greater than in areas at elevations under 2000m). And the rate of warming in the Himalayas is faster than the global average (about three times faster). Studies from Uttam Babu Shrestha. et al. [3] have shown that the Himalayas have warmed at a rate of 0.06~0.08°C yr−1 since 1975. The IPCC predicts that the average annual temperature of the Asian continent, including the Himalayas, will rise by about three °C by the 2050s and about five °C by the 2080s [4,5].

2.2 Precipitation

As shown in figure1, a Study by Mifta Ul Shafiq et al. has shown that the Himalayas's precipitation has decreased since 1980. The annual rainfall has decreased alarmingly, approximately -7.9mm/year. The seasonal changes are -9.12, -5.58, and -1.09mm/year in winter, spring, and summer, respectively. Only the precipitation in autumn rises at 0.5mm/year.

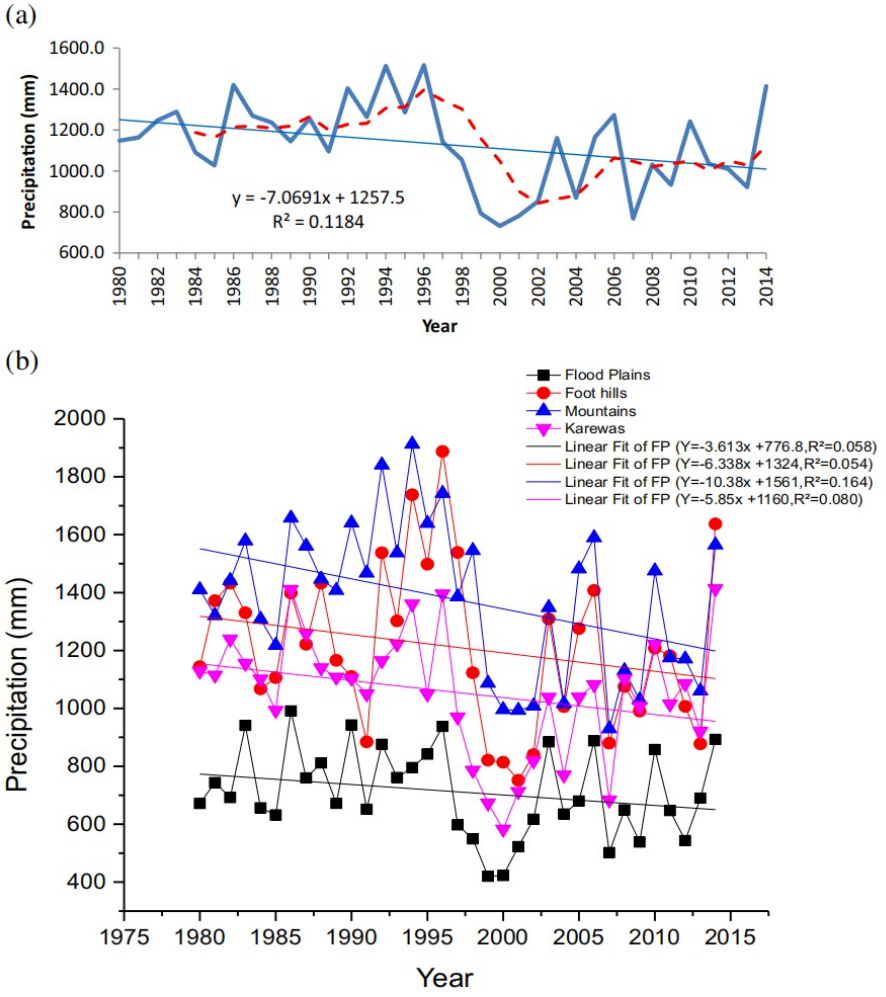

Figure1. The trend of precipitation in the Himalayas.from1980 to 2014 [6].

2.3 Glaciers Retreating

As shown in the figure2, the study from Irfan Rashid et al. has shown that the Machoi glacier in Kashmir Himalaya has retreated from 1972 to 2019 using remote sensing methods and field observations. The results indicated that

the area of the glacier has significantly declined.

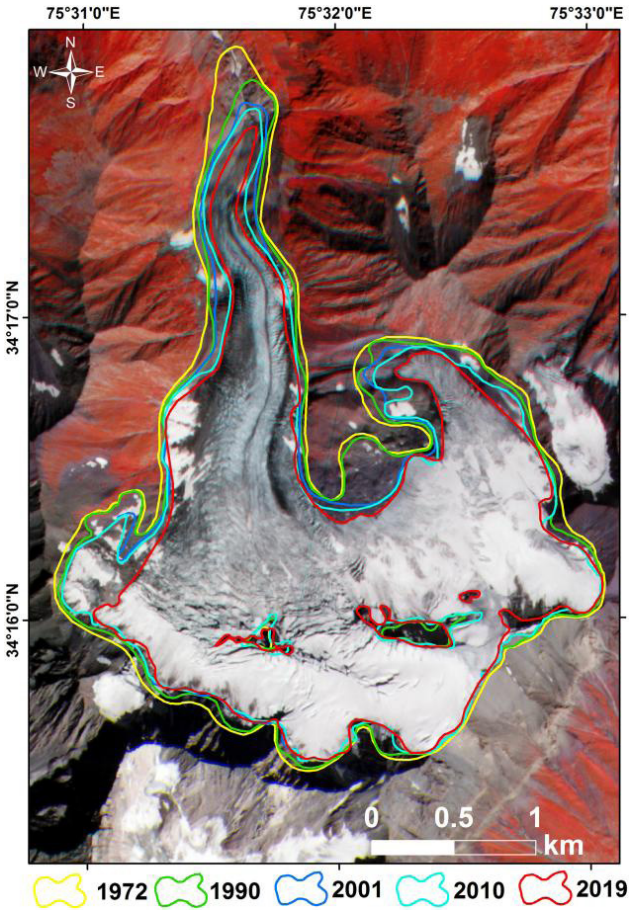

Figure2. Change in the area of Machoi Glacier from 1972 to 2019 [7].

3. Reasons for Climate Change

Climate change is a significant or abnormal change in long-term average weather patterns in a particular region or across the globe and its impact on the planet. There are many reasons for climate change, such as volcano eruptions, changes in the sun, and the processes occurring in the core of the Earth. However, research shows that climate change is primarily due to human activities since the mid-20th century [8].

Since industrial evolution, human beings have released many greenhouse gases(such as CO2 and CH4) into the atmosphere through the combustion of fossil fuels, animal husbandry, and so on. Due to deforestation, fewer trees are able to absorb CO2 from the atmosphere, further enhancing the greenhouse effect. The effect of the atmosphere being able to allow radiation from the sun to pass through and reach the ground, but because of the enhancement of the greenhouse effect, the accumulation of too many greenhouse gases in the atmosphere does not allow a large amount of short-wavelength radiation to escape into space, resulting in an increase in Earth‘s temperature [9].

Damage to the ozone layer will also cause climate change. Over the past half-century, human activities associated with the rapid development of industry and agriculture have released large amounts of nitrogen oxides into the atmosphere. In addition, according to statistics, in 1973, about 4.8 million tons of these two types of CFCs were produced worldwide, most of which were released into the lower atmosphere and entered the odor layer. CFCs are very stable in the troposphere and can exist unchanged in the atmosphere for long periods. It gradually diffuses into the ozone layer and undergoes a chemical reaction with ozone. Removes ozone and reduces the concentration of the ozone layer [10].

4. How Climate Change Affects Snow Leopards

4.1 Habitat Suitability

Treeline advance is mostly caused by climate change. Warming in the Himalayas results in glaciers melting, which increases soil moisture. This is good for the growth of trees and the establishment of seeds. The study from Shalik Ram Sigdel et al. shows that tree recruitment in the Himalayas has increased in recent decades. Tree recruitment was primarily associated with fast temperature increases in the second half of the 20th century. As spring and summer become warmer due to global warming, seed germination improves and increases seeds‘ survival rates at treeline, promoting tree recruitment. However, spring precipitation is the most important factor in treeline advancing, which appears to be a decreasing trend in the Himalayas. However, the precipitation and temperature interacted to control the treeline shifting [11]. So, treeline can still advance due to global warming.

On June 6, 2022, the Institute of Tibetan Plateau, Chinese Academy of Sciences, announced that the average height of the Himalayan tree line is 3,633 meters, and the tree line in the eastern region is about 800 meters. Several meters higher than the west. The study also predicts that tree lines in the eastern, central, and western Himalayas are expected to rise by 140 meters, 45 meters, and 6 meters by the end of this century.

When forests ascend into the alpine areas, the snow leopards‘ preferred habitat, the living space of snow leopards will be reduced by 20% to 70%. The study by Jessica L. Forrest et al. predicted that the total area of snow leopards would lose 8.94%, 18.7%, and 28.9% under IPCC-4 climate scenarios of low emission, medium-low emission, and high emission, respectively [12].

4.2 Distribution

Snow leopards prefer to live in cold and dry areas where only grasses and shrubs can grow. They typically travel through rugged terrain of cliffs, rocky outcrops, and canyons. This habitat has a lot of cover and good visibility, allowing them to spot and sneak up on prey [13]. With ascending treeline, the habitat for snow leopards has shrunk. Research has shown that snow leopards also migrate uphill. But if they have limited space to roam, their habitat will effectively shrink, even as they compete with leopards for that limited space. Besides, climate change also forces tigers and leopards to migrate towards the north in search of suitable habitat, encroaching snow leopards‘ habitat [14].

4.3 Food Availability

4.3.1 Food preference for snow leopards

Snow leopards are carnivores and require about 1.5 kilograms of food per day. A study conducted in the Annapurna Sanctuary from 2014 to 2016 analyzed hair from potential prey in snow leopard feces. The study found that 21% of the snow leopard‘s prey consisted of wild animals such as blue sheep and Himalayan Tahr sheep, which accounted for 18%. Most of the snow leopard‘s prey was domestic (79%), with cattle alone accounting for 44% of the domestic prey. Regarding relative biomass consumed, yaks are the most important summer and winter prey species. Therefore, Tahr sheep, blue sheep, and yaks are the main prey of snow leopards and are consistently seen throughout the year in the study area [15].

4.3.2 Less prey caused by climate change

Achyut Aryal et al. predicted the niche overlap of snow leopards and blue sheep in the Himalayas by calculating the niche overlap between the predicted habitats of snow leopards and blue sheep using ENMTools. The Schoener‘s D index value indicates the level of niche overlap between snow leopards and blue sheep. The higher the value, the higher the level of niche overlap. The results show that the average D value is expected to decrease to 0.806 in 2030 and 0.764 in 2050, indicating a lower degree of overlap and a higher degree of discordance between snow leopards and blue sheep [16].

The decrease in blue sheep is largely attributed to climate change. Blue sheep inhabit treeless slopes, alpine meadows, and shrub zones above the timberline [17]. Advancing of treeline causes the shrinking of their habitat and reduces food availability, which leads to a drop in the number of blue sheep.

Moreover, an increase in temperature can also reduce the number of yaks. The study from S. Sapkota et al. measured the risk of heat stress in yak by measuring the temperature-humidity index (THI). The results show that the THI of yak has increased even during winter, which means that the yak is at high risk of heat stress, which may have a bad impact on physiology, production, immune function, and disease risk. Heat stress has been shown to affect the entire estrus cycle by lowering the concentration of luteinizing hormone and suppressing the LH surge while simultaneously stimulating early luteinization and increasing progesterone production. Heat stress also affects egg development and disrupts normal follicular function [18]. These factors lead to a decrease in the number of yaks.

4.3.3 Increasingly intense competition between snow leopards and other predators due to climate change

Competition between snow leopards and other predators is expected to intensify. Experiments examining interactions, seasonal overlap between predators, and commonalities in prey selection among snow leopards, leopards, and woolly wolves in the upper Bhagirathi Basin in the western Himalayas of India revealed that snow leopards and wolves are heterogeneous and use different habitats. Between the two species, promoting coexistence. In contrast, common leopards hurt winter space use in snow leopards. Currently, limited prey resources due to prey scarcity, limited space due to snow cover, and similar winter activity patterns may result in intense competition, causing snow leopards, woolly wolves, and leopards to avoid each other at spatial scales. There is. However, due to climate change and habitat changes, spatial overlap between snow leopards and common predators is expected to increase. In this case, wolves and snow leopards can coexist in geographically different environments, providing sufficient prey. However, changes in tree limits can cause intense competition between leopards and snow leopards, which can negatively affect snow leopards [19].

4.4 Reproductive Behaviour

4.4.1 Reproductive behavior of snow leopards

The female snow leopards mature at three years old, while the males mature at three. Their estrus period lasts five to eight days between January and mid-March. Because of the short estrus period, male snow leopards tend not to find another mate after one mating, meaning snow leopards have a relatively lower fertility rate than other predators. After mating, the female will be pregnant for 93-110 days. Then, they will find a safe and quiet cave to give birth to the babies between April and June and raise them alone. The cubs can eat solid food when they are two months old. Then, they learn behaviors like hunting

from their mother at three months old. When they are 18 to 22 months old, they will leave their mother and become independent [19].

4.4.2 Reduction of habitat of snow leopards reduces fertility rate and survival rate of cubs

As the number of prey decreases and the competition with other predators and among snow leopards becomes more intense due to climate change, snow leopards have less food availability. With less energy gained, the sperm activity of snow leopards will decrease [20]. A study by Jason R. Herric et al. showed that the ejaculations of snow leopards that fed whole prey once a week contained a higher proportion of normal sperm (37.2%) than that of snow leopards that fed the whole prey less than once per week (27.5%). As shown in Table 1, the study also found that some nutrient intake is correlated to the proportion of normal spermatozoa. Total sperm count was positively correlated with weekly polyunsaturated fatty acids, phosphorus, retinol, and copper intake. The amount of normal sperm also has a negative relationship with manganese, retinyl acetate, magnesium, and margaric acid. With less active sperms, less successful fertilization happens, resulting in a reduction of the fertility rate of snow leopards [20].

Table1. Nutrient variables are correlated to the number of sperm cells per ejaculate [20]

Ejaculate trait/weekly nutrient intake	R2	P-value	Associate
Total sperm (x106) per ejaculate			
Polyunsaturated fatty acids	0.86	0.0003	Positive
Phosphorus	0.27	0.06	Positive
Manganese	0.21	0.06	Negative
Retinol	0.23	0.08	Positive
Proportion of spermatozoa with normal morphology			
Retinyl acetate	0.38	0.03	Negative
Magnesium	0.29	0.04	Negative
Magaric acid	0.31	0.06	Negative

In addition, if a female can‘t gain enough food and energy during pregnancy, the fetus may die or develop into a stunted individual with restricted nutrients and energy. Those stunted cubs are usually weak and unhealthy. They are highly likely to die from diseases or infections when they‘re still young [21].

The shrinking of habitat forces snow leopards to live with organisms they have not lived with before. Those organisms may carry some diseases that snow leopards have never had. If those diseases infect snow leopards, they might die from those diseases as their immune system has never met those diseases and, therefore, cannot fight them [22].

4.4.3 Habitat fragmentation leads to inbreeding and reduction in genetic variation

The dynamic of prey for snow leopards has decreased due to increasing tree lines and lowering of the water table. Therefore, each snow leopard needs more space to search for food, making them far away from each other, resulting in habitat fragmentation. This fragmentation will isolate individual snow leopards from one another, reducing genetic diversity and the health of the species [23].

5. Conclusion

Climate change causes warming, changes in precipitation, and glaciers retreating in the Himalayas. These result in advancing treeline, which takes up the habitat for snow leopards and their prey, such as blue sheep. Also, climate change makes tigers and normal leopards forced to migrate to snow leopard territories. This means that snow leopards must compete with them for food and space. The decrease in dynamic and number of prey further enhances the competition. With less food, snow leopards cannot gain enough energy, which will reduce the activity of sperms, therefore reducing the fertility rate. Besides, the fetus may die if females cannot get enough energy from food during pregnancy, and cubs may not survive as they don‘t have enough food, therefore decreasing the survival rates of cubs. Moreover, the decline in the dynamic of prey makes snow leopards far away from each other, causing habitat fragmentation, reducing the genetic diversity and enhancing the extinction of snow leopards.

Snow leopards are top predators in alpine ecosystems.

They help to control the number of organisms in the middle and lower reaches of the food chain through predation, thereby maintaining the stability of the alpine ecosystem. So, without snow leopards, the ecosystem in the Himalayas will break down. The rivers originated in the Himalayas and provided water for almost 1/3 of the people on Earth. So, protecting snow leopards is protecting ourselves.

However, there are still some questions that are still unclear. For example, where will the snow leopards migrate because of climate change, and how will the change in precipitation affect the treeline? The terrain and climate in the Himalayas are not suitable for conducting research, and there are many areas there that human beings cannot reach currently, so studying the movements and territories of snow leopards is very difficult. As for the precipitation, the clouds are hard to predict, and the activities in the atmosphere are too complex to study, so we are not able to explain how climate change affects precipitation and how precipitation affects treeline.

In future studies, people should prioritize controlling climate change, which is basically the main reason for the extinction of snow leopards. And studying how snow leopards reproduce, and prey under climate change can help us better protect them.

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