Journal of Environment Sciences (2023), **Volume IX**, 104-117
https://doi.org/10.3126/jes.v9i1.56485

Identification of mammalian indicators of climate in Chitwan Annapurna Landscape (CHAL) to assess climate change

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Abstract

The consequences of climate change on species and ecosystems are evident, and the landscape of Nepal does not remain unaffected. Himalayan region is climate sensitive, even a tiny fluctuation in climate can markedly affect numerous species and their habitats. Moreover, the Himalayan region is inhabited by some of the most threatened and endangered biodiversity on Earth, including habitat specialists and endemic species, which may accelerate the extinction of some species. Hence, species affected by climate change should be monitored and identified as faunal indicators of climate change in (Chitwan Annapurna Landscape) CHAL. For that, we compared studies conducted by the National Trust for Nature Conservation (NTNC) and World Wildlife Fund for Nature (WWF Hariyo Ban Program). First, we identified the common and overlapping species. Second, we identified the critical species for climate monitoring based on habitat range, elevation, role as habitat specialist/generalist, and impact observed in previous studies based on the species occurrence in that region. Species with a long-life span, specialist habitat type, and short home range are exposed to climate change for extended periods, making them more vulnerable as per the literature. In particular, our results demonstrate that the one-horned rhinoceros found in the lower belt of Nepal and snow leopard, and pika, being habitat specialists, with low reproductive rate and cannot tolerate change in temperature experience a high impact owing to climate change and can be used as indicators of climate change. In addition to that Assasames Monkey and elephant has medium impact and hence can be considered as the indicator to monitor climate change. However this study does not incorporate specific species-based study regarding the impact of climate change which is required to assess climate change sensitivity to facilitate global wildlife protection.

Keywords: *biodiversity, Himalaya, Chitwan Annapurna Landscape, climate change, faunal indicator, mammals.*

Introduction

Climate change has recently been recognized as a threat to the entire world and a problem for the twenty-first century. Climate change is already having an impact on wildlife at local (Thapa et al., 2015), regional (Aryal et al., 2014), and global levels (Habibullah et al., 2022). Moreover, high-altitude, cold deserts, such as the trans-Himalayan region, are among the most vulnerable ecosystems to climate change (Xu et al., 2009; Dong et al., 2009). The contrasting biodiversity of Nepal has suffered a moderate to high impact owing to climate change (Shrestha et al., 2014). The general trajectories and rates of response of species and natural communities to ambient changes in climate can be predicted through the analysis of various data sources and use of various types of climate models (Dawson et al., 2011). Yet, the specific impacts of climate change on natural ecosystems, including ecosystem processes and service delivery, remain unclear (Parmesan, 2005). Recent assessments have predicted that the average annual temperature in the Himalayan region will increase faster than the global average, and precipitation patterns are also expected to change (Li et al., 2013; Shrestha et al., 2012; Xu et al., 2009). Román-Palacios et al. (2020) showed that extinction occurred at locations with change in mean annual temperature, but more significant increases in maximum annual temperature. Such impacts are already visible in Nepal, field studies have detected upward shifts in tree species along the tree-line in the Nepalese Himalaya (Gaire et al., 2011, 2013; Shrestha and Devkota, 2010; Vijayprakash and Ansari, 2009). Forest covers over 22% of the land in Tibetan Plateau which is expected to expand by the end of the century (Ni, 2011). Because different species have different physiological tolerances and dispersal adaptations, the individual species that comprise natural communities will likely respond and shift at different rates (Lavergne et al., 2010). The loss of native vegetation occurs discontinuously and leads to the breakup of the original land cover into distinct patches, separated by a matrix of land converted to a variety of anthropogenic land uses (Ewers and Didham, 2006; Fahrig, 2003). These native patches become smaller and more isolated from each other as the loss of native vegetation progresses. This long-standing, intense, and global process of native vegetation conversion has created a social demand for scientific support in mitigating the effect of habitat loss and fragmentation on biodiversity and ecosystem services (Haila, 2002). Some species of birds, reptiles, amphibians, and butterflies require particular habitats, hosts, food sources, and environmental conditions also known as habitat specialist species (e.g., temperature, shade/sunlight, moisture, and humidity). Such habitat specialist species will be most sensitive to change (Magura et al., 2020).

Climate change is also likely to intensify the uncertainty surrounding the long-term water supply of the Himalayas and Tibetan Plateau. This, in turn, will impact biodiversity as well as the lives and livelihoods of the local population (Xu et al., 2009). Forrest et al. (2012) revealed that the habitat of the snow leopard may be lost owing to a shifting tree-line and consequent shrinking of the southern edge of the Himalayan range. Also, the study of Koju et al. (2021) in the central Nepalese Himalaya indicated that the population density of pika species has decreased. However, while many climate change studies have concentrated on community and individual perceptions (Fox, 2002), there is a lack of information specifically related to faunal indicators of climate change in high-altitude ecosystems.

Therefore, this study is done as the follow up study of the World Wildlife Fund (WWF) Nepal/Hariyo Ban Program in CHAL region after identification of mammalian species. Indicator species were chosen based on a list of desirable features that cause changes in species behavior owing to climate change. Apart from literature, expert opinions were taken into consideration. In light of previous studies on faunal indicators, the lack of Nepalese data on faunal indicators prevents a thorough investigation. During the selection of indicator species, previous research, threat analyses, and species conservation action plans developed by the Nepalese government were used as a guide (Table 1). This study aims to establish a baseline for faunal (mammal) ecology that is particularly affected by climate change, and hence act as an indicator of climate change in the future, which could be imperative to conservation planning in Nepal and elsewhere. Climate indicators are species that have a direct or indirect impact on the ecosystem that is dependent on climatic conditions. This study identifies six mammalian climate change indicators in Nepal that have an impact on its native terrestrial biological systems. Additionally, we discuss how this approach can be useful to integrate the potential effects of climate change into conservation strategies for other high-conservation-value mega species.

Materials and Methods

Study area

High mountains of the Himalayas comprise the northernmost region of Nepal, with rugged terrain, deep gorges, glaciers, and snow-capped mountain peaks (Shrestha et al., 2019). This study was conducted in the Chitwan Annapurna Landscape (CHAL) area (Fig. 1), located between 27.16° and 29.30° N, and 82.70° and 85.70° E in central Nepal, covering a total area of 32,090 km². The CHAL area encompasses the Gandaki/Narayani River Basin, which includes the rain shadow area of the trans-Himalayan area, and the snow-capped mountains of Annapurna, Manaslu, and Langtang in the north; out of the four physiographic regions of Nepal are represented in the studied landscape. The CHAL area has a vast elevation gradient (from < 100 to > 8000 m above sea level) with a climate ranging from tropical (Tarai), through subtropical, temperate, and subalpine, to alpine (High Himal), including a trans-Himalayan cold and dry climate similar to Tibet. The study area comprises two conservation areas (Annapurna and Manaslu), two national parks (Chitwan, also a World Natural Heritage Site, and Parsa), one hunting reserve (Dhorpatan), and two Ramsar wetland sites (Beeshazari and Pokhara lake systems).

CHAL support some Nepal's most threatened and endangered biodiversity, including habitat specialists and endemic species (Basnet et al.,2000) and high biodiversity value, being an essential transit route for migratory birds, and is home to endangered species, such as the snow leopard, red panda, and Himalayan black bear (Gautam et al., 2013). CHAL, thus contains topographic, climatic, ecological, and socio-economic variations along

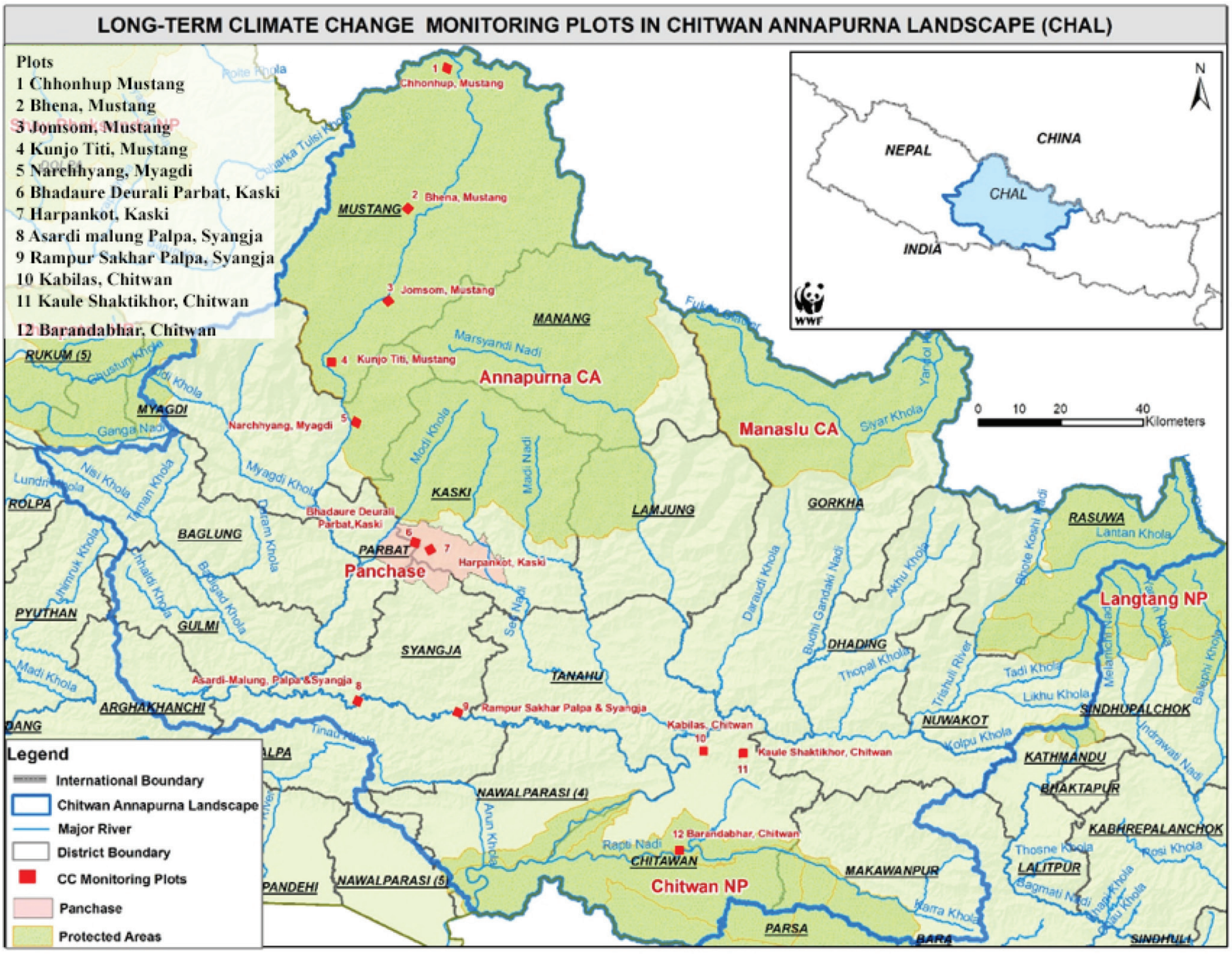

Figure 1: Location of climate change monitoring plots in the CHAL area. (Source: WWF, Nepal)

an elevation gradient within Nepal. To establish baseline data for the conservation of biodiversity in this area, we took the data from 12 permanent monitoring plots, set up by HBP (each 2 km^2) within the CHAL (Fig. 1) which represents Siwalk region (205 masl) to High Mountain (4740 masl).

Methodology

Our study was based on information collected primarily from the field through an accepted scientific procedure whereby data on mammals and birds were obtained using detailed surveys along a transect. Transects were arranged to cover representative habitats and altitudes within each plot area. The total length of each transect was 7.7 km. Transects were constructed following man-made trails owing to the rugged geographic terrain. Based on the size of the study area, the number of sampling plots was calculated. The equipment used for mammals was a camera trap, Sherman trap, or tube trap, while a mist-net or bat detector vernier caliper was used for bat counting. Binoculars were used for bird counting; other pieces of equipment (camera, compass, measuring tape (20 m), field notebook, first aid kit, and gloves) were also used. Moreover, previously published findings and data were considered and thoroughly examined in this research.

To determine the overlapping and common species in the 12 plots in 2015 and 2019, commonly occurring species were noted. The similarity index was calculated using the Jaccard index (1912) (cited in Leydesdorff, 2008) (Equation 1) to assess the similarity of the species between two given years. The Jaccard index gives the proportion of species out of the total species list of the two sites, which are common to both sites:

$$SJ = ca + b + c\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where, SJ is the similarity index, c is the number of shared species between the two sites, and a and b are the number of species unique to each site.

Identification of climate change indicator species

Climate change indicator species were identified using the presence absence data. The species present in the data were then analyzed further in two phases. First, we conducted a preliminary plot-wise review of animals (mammals) to establish analytical questions and discover the conservation status of the recorded animals. Second, indicator species were chosen based on the literature, expert opinion, and a list of desirable characteristics that cause changes in species behavior owing to climate change. Previous research, threat analysis (threats to the species due to CC as per several research), and species conservation action plans created by the Government of Nepal were taken as references during the selection of the indicator species for mammals. Similarly, for bird species, migratory species were the main focus of the selection process, but we did not restrict ourselves to these species alone.

After selecting major indicator mammal species, they were ranked based on the impact caused. Various variables were selected for this purpose. The variables and rank of the mammals were based on the habitat range, elevation, role as habitat specialist/generalist, and impact seen in previous studies (Table 1).

Results and Discussion

Common species

The study of animals in the CHAL in 2015 was compared with that conducted in 2019. Between 2015 and 2019, the population is seen high in all plots except plot 9. Likewise, the population of mammals also increased in most plots.Similarly, the highest number of common mammals was in plot 5, while plots 2, 3, and 6 had no mammals in common. The detailed comparison of species can be found in ANNEX I.

Table 1: Variables and rank for indicator species (mammals)

S.N.	Variables	References	Ranking
1	Home range/elevation range	Abe, 1982; Chalise, 2003; Jackson, 1996; Kafley et al., 2009; Khan & van Strien, 1997; Koirala et al., 2016; Oli, 1997; Paudel et al., 2012; Simcharoen et al., 2014; Smith et al., 1998	High altitude (home range small)
			Mid altitude (home range medium)
			Low altitude (home range high)
2	Habitat (generalist/ specialist)	Aryal et al., 2010; Khatiwada & Haugaasen, 2015; Patel et al., 2016; Regmi et al., 2020.	Generalist
		Aryal, 2009; Baral et al., 2003; Giri, 2009; Subedi et al., 2013; Koju et al., 2021; Regmi et al., 2020	Specialist
3	Food requirements	Kazmi et al., 2021; Achyut & Kreigenhofer, 2009	Generalist/carnivore
		Darcan, 2018; Malakoutikhah, 2020	Specialist/herbivore
4	Observed impact (as per other studies)	Dahal, 2011; Harwood, 2001; Prasain, 2018; Subba et al., 2017	Direct/high
		Forman et al., 2008; Karki et al., 2009; Zomer et al., 2014	Medium
		Durant et al., 2007; Eriksson et al., 2009; Shrestha et al., 2018	Indirect/low
5	Habitat type		Wetland/snow
		Llorens, 2008; Seebacher et al., 2015; Şekercioğlu et al., 2012	Alluvial plain
			Terrestrial
6	Impact indicator		High
		Laidre et al., 2008	Medium
			Low

Table 2: Species comparison between 2015 and 2019

Plot	Year	Total Mammals	Common Mammals
1	2015	8	2
	2019	3	
2	2015	2	0
	2019	4	
3	2015	6	0
	2019	5	
4	2015	7	1
	2019	7	
5	2015	11	11
	2019	12	
6	2015	4	0
	2019	11	
7	2015	4	2
	2019	11	
8	2015	5	2
	2019	12	
9	2015	6	2
	2019	11	
10	2015	6	1
	2019	14	
11	2015	2	2
	2019	14	
12	2015	13	7
	2019	13	

Identifying common/overlapping species in the plots

The larger mammal, on the other hand, occupies extensive areas because their habitat overlaps with those of other species; this is clearly necessary for their survival. The dispersion of mammals depends on their need for water; those that do not require water can remain within a particular habitat, whereas those in need of water migrate during dry seasons (Lamprey, 1963). Plot 5 had the most common mammals (11), while plot 10 had the fewest (1). There were no common mammal species in plots 2, 3, or 6 (Figure 2).

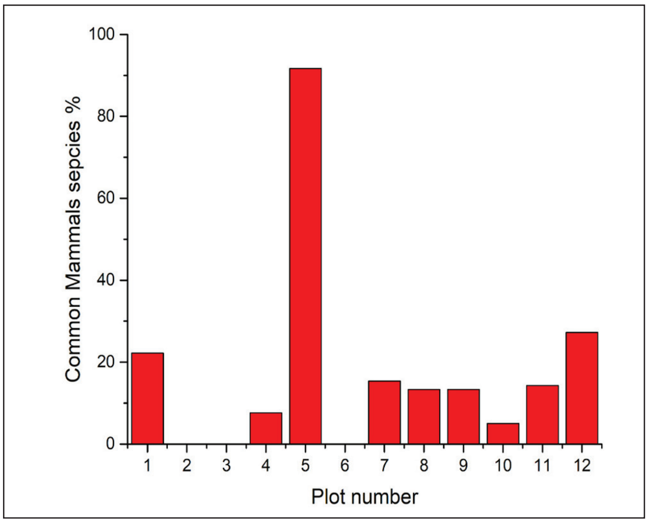

Figure 2: Plot-wise common mammal percentages.

Indicators of climate change monitoring

Climate change impacts the terrestrial ecosystem, which struggles to adapt to new conditions (Williams et al., 2003a). Some of the known impacts of climate change on the forests and biodiversity of Nepal include shifts in agro-ecological zones, prolonged dry spells, higher incidences of pests and diseases, increased emergence and quickened spread of invasive alien plant species, increased incidence of forest fire in recent years, changes in the phenological cycles of tree species, shifting of the tree-line in the Himalaya, and wetland depletion (MoEST, 2010).

The mammal species that could be considered indicators of climate change monitoring are listed in Table 3. This shows that the one-horned rhinoceros, snow leopard, and pika, being habitat specialists, suffer a high impact from climate change and can be used as indicators of climate change.

Table 3: List of climate change indicator species.

SN	Mammals	Indicator ranking
1	One-horned rhinoceros	Medium
2	Bengal tiger	Low
3	Asian elephant	Medium
4	Pika	High
5	Snow leopard	High
6	Monkey	Medium

A shift in acceptable habitats for terrestrial organisms is one of the most likely effects of climate change (Thuiller et al., 2011). The details of mammal species that experience the impacts of climate change are listed below:

Pika species (*Ochotona sp.*)

Climate change can cause an increase in the high migration of high-altitude endemic animals such as pikas. Warmer temperatures disrupt the natural habitat of the pika, driving the creatures to seek refuge in colder climes higher in the mountains. While pikas used to be present at 2180 m asl at Ulleri, ACA (Abe, 1971), they might have migrated to higher elevations in recent years due to change in microclimate/habitat as microclimate seems a major influential factor in pika distribution (Shrestha and Gurung, 2019). Pikas are extremely sensitive to temperature fluctuations, and rising average minimum temperatures have harmed their natural environment. Temperature is considered as important limiting factors (Thapa et al., 2019). Pikas have been lost from lower-elevation areas that were hotter and drier, and lower-elevation habitats that lacked a thermal refuge (Beever et al., 2010). Research has indicated that alpine mammals such as pikas are vulnerable to climate change (Moritz et al., 2008). In addition to that low reproductive Because pikas are sensitive to heat stress and rely on access to cooler microclimates to behaviorally thermoregulate, the pika can be considered a climate change indicator (Beniston, 1994).

One-horned rhinoceros (*Rhinoceros unicornis*)

Rhinoceros are considered habitat specialists and are confined to tall grasslands and riverine forests on the alluvial floodplain of the Himalayan foothills, where water and green vegetation are accessible all year (Jnawali, 1995; Dinerstein, 2003). They are habitat specialists, requiring mud pools for wallowing to regulate body temperature; hence, wallowing locations must be available, and these may be affected by any change in the climate. Specialist species are more vulnerable to climate change compared with generalist species (Brown, 1995; Pimm et al., 1995). In addition, the climate is likely to impact the abundance of food resources and spatiotemporal availability of water for this species (Pant et al., 2020). Other impacts of climate change includes, the expansion of invasive alien species, such as *Mikania micrantha*, into rhinoceros habitat may degrade the prime habitat of rhinoceros (Subedi, 2012; Murphy et al., 2013), as will the occurrence of extreme events, such as floods, forest fires, and droughts (Pant et al., 2020; Sharma, 2019). Therefore, rhinoceros in Nepal are likely to be 'moderately vulnerable' to the impacts of climate change (Pant et al., 2020).

Royal Bengal tiger (*Panthera tigris tigris*)

Although climate change is causing catastrophic habitat loss for Bengal tigers in mangrove habitats (Rahim et al., 2015; Mukul et al., 2019), being a landlocked country, the combined effects of climate change and sea-level rise may not have such a significant impact in Nepal. However, different climate change-related indirect consequences may persist. Habitat degradation triggered by the invasion of alien invasive species, especially *Mikania micrantha* and *Lantana camara*, drying up of wetlands including ox-bow lakes, decrease in prey, and extreme weather conditions, such as protracted droughts and enhanced floods and flash floods, are likely to become more common as climate variability increases (DNPWC, 2016). Changes in temperature and precipitation, resulting in shifts in plant phenology, winter severity, drought and wildfire conditions, invasive species distribution and abundance, predation, and disease can directly or indirectly affect tiger prey such as ungulates (Malpeli et al., 2020). Also, rising temperature and changes in precipitation patterns may result in substantial shifts or changes in wetlands, grasslands, and forest types and their species compositions (Thapa et al., 2016), as the Tiger species has been trapped in high altitudes of 2511 m (Thapa et al., 2022) and 3100 m (Bista et al., 2021).

Snow leopard (*Panthera uncia*)

The snow leopard is adapted to rugged mountain habitats at high elevations, including grassland, shrubland, bare areas, ice patches, and agricultural mosaic, which are especially vulnerable when facing global climate change (Forest et al., 2012). The predicted loss of snow leopard habitat in the Himalayas is predicted to be 30%, mainly along the southern distribution range, to alpine zones. The endangered snow leopard inhabits the rugged and fragile landscape of the Himalayas (Jackson, 1984) and is one of the largest predators in this energy-deficient, high-altitude environment. These species are vulnerable wild mammals native to mountainous regions of 12 Asian countries. The snow leopard faces numerous overlapping threats, including being killed by herders retaliating against livestock losses, illegal wildlife trade, loss of prey and habitat, and climate change. Ripple et al. (2014) revealed that one of the major limiting factors resulting in a decrease in the number of *Panthera* species is altitude. However, altitude does not directly impact habitat suitability, it indirectly influences *Panthera* distribution through temperature (Aryal et al., 2014). A further study by Aryal et al. (2016) acknowledged that annual mean temperature is the major climatic factor responsible for controlling the distribution of snow leopards in energy-deficient, high-altitude environments.Potential Range Shift of Snow Leopard in Future Climate Change Scenarios by Li et al. (2022) found that snow leopards would move northwest by about 200 km in 2070 in two global climate models for different representative concentration pathways. Also, climate can markedly affect predators through its impact on the relative timing of food requirements and food availability (Durant et al., 2007) as the prey of the snow leopard like blue sheep will be reduced under future climate change (Aryal et al., 2016) which leads to food availability.

Asian Elephant (*Elephas maximus*)

Suitable habitat for Asian elephants is vulnerable to climate change. Under future climate scenarios, the prime habitat of Asian elephants is predicted to decrease (Li et al., 2019). Kanagaraj et al. (2019) also showed that owing to the combined effects of climate change and human pressure, the habitat now accessible to Asian elephants will be destroyed by the end of this century. According to model estimates by Kanagaraj et al. (2019), changes in climatic water balance, followed by changes in temperature and other continuing human-induced disturbances, will be the primary drivers of future changes in elephant distribution in India and Nepal, and there will be a shift towards higher elevation seeking available water (Moritz et al., 2008). Elephants will face a shortage of natural food if the range of woodland diminishes owing to climate change, forcing them to forage on farmland (Li et al., 2018). Although Asian elephants occur across a range of diverse habitats and feed on a variety of abundant vegetation, owing to their limited dispersal ability, long gestation period, modest reproductive rate, and relatively moderate genetic variety within the species, they have a low adaptive capacity to changing climate and are thus considered vulnerable to climate change (WWF, 2021).

Assam macaque (*Macaca assamensis*)

The distribution of Assam macaque could be reduced owing to adverse changes in the global climate. Climate change poses one of the most significant threats to global biodiversity (Araújo, 2014) and will impact the geographic distributions and population dynamics of species. Climate change threatens endangered species and challenges current conservation strategies. Although the Assam macaque is categorized as near-endangered globally (Boonratana et al., 2008), in Nepal it is designated as endangered owing to its restricted distribution of fewer than 22,000 km^2 with an estimated area of occupancy of approximately 914 km^2; it is experiencing a continuing decline in population and in the areal extent and quality of its habitat (Molur et al., 2003). Aryal et al. (2016) suggested that these Assam species cannot respond to the condition of rapid climate change and habitat loss. Also the species have low genetic diversity and shallow genetic structure (Khanal et al., 2018), narrow elevation range (Chalise, 2013) and habitat specialist (Khanal et al., 2019). These species mainly eat crops (maize, rice, wheat, millet, and cardamom fruits); changes in weather patterns make it challenging to determine sowing and harvesting schedules and hamper suitable crop selection (Palazzoli et al., 2015). Another negative impact is an extensive decrease in soil fertility through the loss of carbon from the soil owing to reduced soil moisture. This could in turn result in a reduction in crop yield and agriculture productivity (Chettri et al., 2009) and affect species indirectly.

Conclusion

In this study within the time range of two periods 2015 and 2019 common species in the 12 plots with variation in the elevation range set by HBP are calculated. Plot 5 shows more overlapping species in temporal scale with 11 common mammal species. In some plots (2, 3 and 6) none of the common species were recorded. With the reference for identifying the indicators of climate change, pika and snow leopard have the highest impact. Similarly, one horned rhinoceros, Assames Monkey and Asian elephant have medium impact. And the Bengal tiger might have low impact. Those species with specialist habitat type, food requirements, low rate of reproduction, low genetic diversity can generally be considered as species which can be used for the monitoring of climate change. As this study uses the presence of species in the CHAL area by HBP with further use of previously conducted research and findings, further research with prediction of habitat with impact due to climate change is warranted.

Acknowledgments

The authors would like to acknowledge the World Wildlife Fund for Nature (WWF-Hariyo Ban Program) for providing species presence-absence data. Author would like to thank the Second Tibetan Plateau Scientific Expedition and Research Program for providing the grant. This research has been funded by the Second Tibetan Plateau Scientific Expedition and Research Program (STEP) (grant no. 2019QZKK0103).

Supplementary Materials

ANNEX-I

Table: Details of all 12 plots

Plot No.	Location (District)	GPS Coordinates		Altitude (m)	Habitat-Vegetation	Remarks
		Latitude	Longitude			
1	Lo Manthang; ACAP	29.288	83.921	>4000m	Alpine Rangeland	Potential for invasion by subalpine conifer
2	Bhena; ACAP	28.984	83.815	3500-4000	Schrubland of Juniper	Ecotone between subalpine scrub and alpine vegetation
3	Jomsom ; ACAP	28.784	83.761	3000-3500	Grassland & Alpine Forest	Shrublands and grasslands, with some Juniper dominated forests
4	Lete; ACAP	28.653	83.617	2500-3000	Mixed broadleaf-conifer forest	Ecotone between subalpine conifer and wetland
5	Narchyang;ACAP	28.521	83.674	1500-2500	Chirpine forest	Possibility of forest conversion
6	Chitre, Kaski-Parbat	28.257	83.813	2000-2500	Subtropical broadleaf and Chir pine forest	Potential climate refugia
7	Bhadaure Tamagi; Kaski	28.24	83.85	1000-1500	Subtropical broadleaf mixed with confier	Climate vulnerable subtropical broadleaf and evergreen forest
8	Asardi (Palpa)	27.918	83.654	380-1050	Subtropical hill forest	Climate refugia
9	Tilakpur (Syangja)	27.887	83.899	315-700	Subtropical hill forest	Climate vulnerable
10	Kabilas (Chitwan)	27.786	84.509	500-1000	Subtropical broadleaf forest	Climate vulnerable subtropical broadleaf forest
11	Kaule (Chitwan)	27.779	84.595	1500-2000	Subtropical broadleaf forest	Cliamte resilient subtropical broadleaf forest
12	Khorsor , Barandabar (Chitwan)	27.571	84.442	181-201	Subtropical broadleaf forest	Important climatic corridor for many species

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