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ORIGINAL PAPER

Impact of climate change on human-wildlife-ecosystem interactions in the Trans-Himalaya region of Nepal

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Abstract The Trans-Himalaya region boasts an immense biodiversity which includes several threatened species and supports the livelihood of local human populations. Our aim in this study was to evaluate the impact of recent climate change on the biodiversity and human inhabitants of the upper Mustang region of the Trans-Himalaya, Nepal. We found that the average annual temperature in the upper Mustang region has increased by 0.13 °C per year over the last 23 years; a higher annual temperature increase than experienced in other parts of Himalaya. A predictive model suggested that the mean annual temperature will double by 2161 to reach 20 °C in the upper Mustang region. The combined effects of increased temperature and diminished snowfall have resulted in a reduction in the area of land suitable for agriculture. Most seriously affected are Samjung village (at 4,100 m altitude) and Dhey village (at 3,800 m) in upper Mustang, where villagers have been forced to relocate to an area with better water availability. Concurrent with the recent change in climate, there have been substantial changes in vegetation communities. Between 1979 and 2009, grasslands and forests in the Mustang district have diminished by 11 and 42 %, respectively, with the tree line having shifted towards higher elevation. Further, grasses and many shrub species are no longer found in abundance at higher elevations and consequently blue sheep (*Pseduois nayaur*) move to forage at lower elevations where they encounter and raid human crops. The movement of blue sheep attracts snow leopard (*Panthera uncia*) from their higher-elevation habitats to lower sites, where they encounter and depredate livestock. Increased crop raiding by blue sheep and depredations of livestock by snow leopard have impacted adversely on the livelihoods of local people.

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1 Introduction

The United Nations Intergovernmental Panel on Climate Change reported that the increasing concentration of carbon dioxide in the atmosphere has caused a rise in global temperature, and projected a further increase in global mean temperatures of between 1.4 and 5.8 °C by the year 2100 (IPCC 2001; Locky and Mackey 2009). High altitude, cold deserts, such as the Trans-Himalayan region, are among the most vulnerable of all ecosystems to these climatic changes (Christensen and Heilmann-Clausen 2009; Xu et al. 2009; Dong et al. 2009; Sharma and Tsering 2009; Aryal et al. 2012a, b). Furthermore, the high altitude, harsh climatic conditions, and low productivity of these regions make the human inhabitants vulnerable to changes that reduce the effectiveness of the cultural adaptations that have enabled them to persist in these marginal habitats. However, while there are many studies of climate change that focus on community and individual perceptions (Berkes 1999; Cruikshank 2001; Nuttall 2001; Riedlinger and Berkes 2001; Fox 2002; Bagchi et al. 2004), there is a lack of information specifically related to these high-altitude ecosystems and their human inhabitants.

The Trans-Himalaya region of Nepal extends from the Gorkha district to the border in the northwestern part of country. With a cold and arid climate, the region supports an assemblage of large Pleistocene herbivores including the blue sheep (*Pseudois nayaur*) and its iconic principal predator, the snow leopard (*Panthera uncia*), together with other endangered prey and their predators (Xu et al. 2009; Schaller 1998; Oli et al. 1993; Namgail 2009; Aryal et al. 2010, 2012c). Additionally, the region hosts a range of human societies whose main source of income is livestock farming and agriculture. The changes in climatic patterns, and resultant increases in anthropogenic pressures, have impacted on these Himalaya ecosystems in Nepal and their human inhabitants (Beniston 2003; Comiso 2003; Chetri and Gurung 2004; Cruz et al. 2007; Bates et al. 2008; Xu et al. 2009; Dong et al. 2009; Sharma and Tsering 2009; Ma et al. 2009).

Particularly vulnerable are areas such as the Mustang region, which have low precipitation and consequently rely on runoff from snow cover as the main source of water (Aryal et al. 2012a, b). The low precipitation is associated with distinctive patterns of vegetation cover, and cultural practices that are suited to dry conditions and are vulnerable to climate change. For example, the main occupation of this region, livestock farming, is dependent on adequate grass cover, while the mud houses, which are effective in a dry climate, are vulnerable to increases in rainfall. Furthermore, the region provides unique habitat for threatened species such as the snow leopard, brown bear (*Ursus arctos*), wolf (*Canis lupus*), musk deer (*Moschus* spp.), wild ass (*Equus kiang*), and Tibetan argali (*Ovis ammon hodgsoni*; Aryal et al. 2012a, b, c). Climatic changes that destabilize such systems pose serious challenges for their management, including the difficult task of balancing the interests of wildlife biodiversity and resource use by local human populations (Comiso 2003; Mishra et al. 2004; Namgail et al. 2007; Sharma and Tsering 2009).

Our aim in this study is contribute to the understanding of the impacts of climate change on human–wildlife–ecosystem interactions in Nepal's highest altitude human settlements (>3,800 m) in the Mustang district of the Trans-Himalaya.

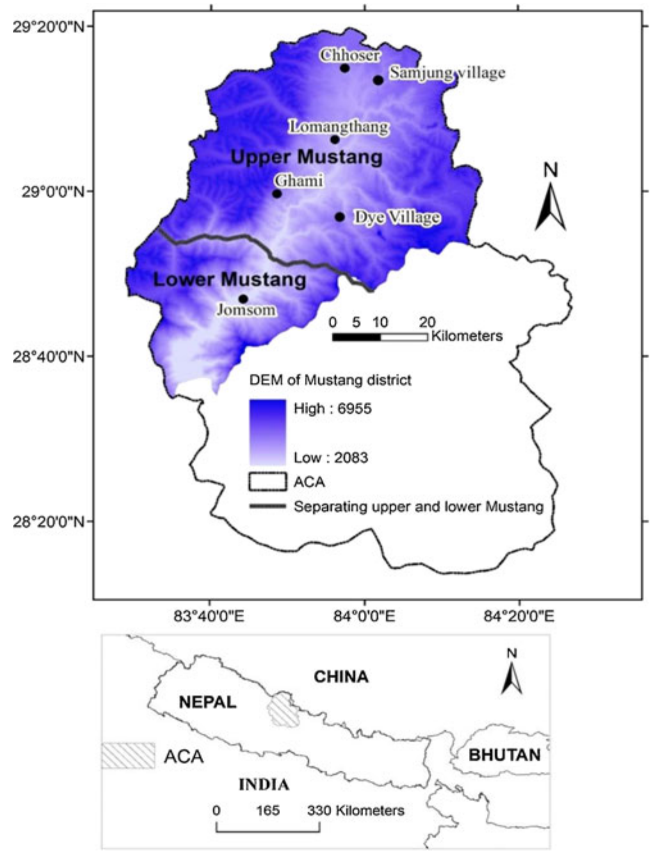

Fig. 1 Map of the Annapurna Conservation Area (ACA), with the study area (upper and lower Mustang) highlighted using the digital elevation model (DEM). Villages are also shown

2 Methods and materials

2.1 Study area

This study was conducted in the Mustang district of Nepal (Fig. 1). The district is divided into two regions; lower Mustang and upper Mustang (Fig. 1). The field survey was undertaken in all the Village Development Committees (VDCs) of upper Mustang, this region being the main focus of the study. However, changes in land cover were estimated for both the upper and lower Mustang regions, and field-based questionnaire surveys were conducted both in upper Mustang (all regions) and parts of lower Mustang (Chhuksang, Jomosm, and Muktinath area; Fig. 1).

The upper Mustang region adjoins Tibet (China), and covers an area of approximately 2,500 km^2, with an estimated human population of 7,902 (Government of Nepal 2010) and includes seven VDCs. This region is remote, having no public transportation and no motor vehicle roads connecting it to the wider area, with horses and donkeys used for transportation. The upper Mustang region has a cold desert climate, with most of the area being covered by snow which provides the main water source for irrigation and drinking (Chetri and Gurung 2004; Government of Nepal 2010; Aryal et al. 2012a, b). The region and its associated mountains are the main source of the largest river in Nepal, the Kali Gandaki River (Chetri and Gurung 2004; Government of Nepal 2010; Aryal et al. 2012a, b, c).

The lower Mustang region covers approximately 1,035 km^2 and consists of six VDCs with a human population greater than 10,000 people (Aryal et al. 2012a, b; Chetri and Gurung 2004; Government of Nepal 2010; Fig. 1). The district lies at altitudes between 2,000 and 7,000 m and encompasses prime habitat for diverse flora and fauna communities. (Bhattarai et al. 2010; Government of Nepal 2010; Aryal et al. 2012a, b).

2.2 Modeling of current and future climate change through the analysis of temperature and rainfall data from 1987 to 2009

Temperature and rainfall data (1987–2009) for the Lomangthang, Chhoser, and Ghami VDCs in upper Mustang

(Fig. 1) were obtained from the Department of Meteorology, Government of Nepal. In the local region, temperature and precipitation are measured daily and then converted to mean monthly temperature and precipitation; from these data, annual and monthly means were calculated. The stations are situated in the grasslands of the three VDCs and approximately 1 km from villages and settlements. The Ghami station is situated approximately 30 km south of the Chhoser station and 20 km south of the Lomangthang station and about 30 km north of Jomsom in the lower Mustang region (Fig. 1). Monthly temperature and precipitation data from the three stations were combined and means were calculated separately then combined based on seasons and years. Thereafter, the grouped means for each month, each season (spring, summer, autumn, and winter) and each year were used for further analysis of data. In order to determine whether there were any significant changes in the temperature and rainfall from 1987 to 2009, an ANOVA test was used with season and year as factors.

Future rainfall and temperature were projected by extrapolating from the best-fit model of past temperature and rainfall data. Different models were tested (equations 1–7) using a regression curve estimation procedure in SPSS version 16.1, and the best-fit model was used to predict future rainfall and temperature.

$$\text{Linear}: y = a + bx \tag{1}$$

[where *x* is year and *y* is rainfall or temperature]

$$\text{Logarithmic}: y = \log_b(x) \tag{2}$$

$$\text{Inverse}: y = a + b/x \tag{3}$$

$$\text{Quadratic}: y = ax^2 + bx + c \tag{4}$$

$$\text{Cubic}: y = ax^3 + bx^2 + cx + d \tag{5}$$

$$\text{Power}: y = a \times x^b \tag{6}$$

$$\text{Exponential}: y = ae^{bX} \tag{7}$$

The best-fit models of temperature and rainfall were selected based on: (a) adjusted coefficient of determination (R^2adj), (b) homogeneity of the residuals, (c) root mean squared error, and (d) variance inflation factor (Montgomery et al. 2006).

2.3 Local inhabitants' perceptions of climate

Participatory rural appraisal (PRA) tools were used to gather basic information on people's perceptions of climate change in the study region. The main aim of the questionnaire was to assess the people's perceptions of the impact of climate change on their livelihood, the wildlife, and the rangelands. PRA tools such as timeline trends, social and resource maps, and questionnaire surveys were used to determine the impact of climate change at local levels. The questionnaire format was developed to use with the local people of the Ghami, Surkhang, Lomangthang, Charang, Chhunup, and Chhoser VDCs of upper Mustang and the Chhuksang, Muktinath, and Jomsom area of lower Mustang. The questions comprised both "yes/no" questions and open questions (see Table 1 for details).

In total, 221 people were interviewed (84 during November and December 2009 and 80 during February 2010 in the upper Mustang region and 57 people were interviewed in April–June 2011 in the lower Mustang region). We selected only interviewees that were 40 years or older (age was asked prior to the interview), and thus had longer experience of the past history of climate and local ecology. Many of the interviewees were herders of the upper Mustang and lower Mustang regions.

Ten group discussions with herders and local non-government organizations, such as Annapurna Conservation Area Project, the youth club, and Conservation Area Management Committee, were conducted to produce a perceived timeline and history of climate change and its impact on local livelihoods, wildlife, and ecosystems. Additionally, a 1-day workshop was organized to gain an understanding of the perceptions of climate change and its impact on local livelihoods, the populations of blue sheep, snow leopards, and the rangelands.

2.4 Assessment of land cover changes between 1979 and 2009

Landsat Multi Spectral Scanner (MSS) images of 07 July 1979 and Landsat Enhanced Thematic Mapper Plus (ETM+) images of 09 November 2009 were used to assess the extent of land cover change over the past 30 years. The images, which are available free of cost (USGS 2011), were downloaded from United States Geological Survey Earth Explorer portal (USGS 2011). The image processing software "ERDAS Imagine 9.2" was used to preprocess and classify the acquired images to different land cover classes.

Geometric correction was carried out in both images to correct the errors in relative position of pixels induced by sensor viewing geometry and terrain variations. To identify the extent of land cover change accurately, it was important

Table 1 Responses in interview of 221 respondents on the impacts of climate change on the Trans-Himalayan ecosystem and its associated landscapes

Variable of climate change and questions asked to local people (n=221)	Response of local people
Changing of climate	100 % yes
How have you internalized the impact of climate change?	Less land in production (33 %); changes in lifestyle (7 %); increase in health problems/disease (2 %); uncertainty about the weather (47 %); increased drought (11 %)
How have climate change related factors influenced wildlife/ blue sheep/snow leopards and their capacity to adapt?	Decrease in grass production (65 %); habitat destruction (9 %); moving down of snow leopards and blue sheep as an adaptation strategy (26 %)
Do you think the knowledge of elders would be useful in decreasing the peoples' vulnerability?	Yes (91 %); no (2 %); do not know (7 %)
Do you think our communities need to be made aware of the long term effects of climate change and gain knowledge of how to reduce the negative impacts?	Yes (96 %); do not know (4 %)
Is the composition of shrubs/grass/tree shifting towards higher elevation?	Yes (87 %); no (3 %); do not know (10 %). *Caragana* spp. shifting towards high altitude and distributing rapidly in rangeland in upper Mustang region. *Betula utilis*, *Abies* spp. and conifer species shifting up in lower Mustang region.
Is there any traditional knowledge for assessing and addressing current and future climate risks to the community?	No (91 %); yes (3 %); do not know (6 %)
Have you gained knowledge through formal/informal education on climate change?	No (97 %); yes (1 %); do not know (2 %)
Have you participated in awareness raising training/workshop/ programs on climate change?	No (98 %); yes (2 %)
Have you observed climatic uncertainties?	Yes (95 %); no (5 %)
Have you observed an increase in temperature?	Yes (100 %) and hotter and drier areas; unusual changes; increases in both maximum and minimum temperatures
Have you observed changes in rainfall/snowfall?	Yes (100 %), changes in soil moisture, reduced water sources, drier rivers, and drier farmland, reduced grass production in grassland; Dhey and Samjung village local people demanded that their villages be shifted to areas with available water.

to make the images from 1979 and 2009 match each other so that they are comparable (Agapiou et al. 2011; Bhandari et al. 2012). This was done using a topographic map of 1:50,000 scale to identify the uniformly distributed ground control points. A subpixel level positional accuracy was obtained for all satellite images during the process. The MSS image was resampled to 30 m pixel size for comparability with ETM+ pixel size.

Unsupervised classification was used for the classification of images. The procedure employs a computer algorithm that locates naturally occurring concentrations of features vectors from a heterogeneous sample of pixels and classifies them to the closest cluster. The iterative process continues until the difference between the cluster mean of each iteration becomes small. Five different clusters were produced by unsupervised classification in each case at the first step. The five clusters were finally merged to produce a land cover map with three different classes (forest, barren land, and grassland which also included shrub land; Fig. 2). The process was assisted by the field GPS points collected during the field trips and the knowledge of the area. Out of a total of 689 GPS points collected during the different field trips, 424 were collected in 2009. A total of 124 of those points collected in 2009 were used as ground truth data to produce the 2009 land cover map, whereas the remaining 300 points were used to check its accuracy. Overall map accuracy was estimated for the 2009 land cover map by matching those points with the satellite image of 2009 and similar accuracy was assumed for the 1976 map. The land cover maps were finally used to examine the land cover change over the period using ArcGIS (version 9.3, ESRI Inc., Redlands, CA, USA) software.

In addition to the examination of land cover change over the assessment period, the spatial pattern of tree line area of the lower Mustang region (Nammu area) was visited and the tree distribution pattern investigated by direct observation. The observation was undertaken with local herders who are familiar with the areas. New growth trees were analyzed and previous and current tree lines based on local herders' experience were also recorded for analysis.

The changed patterns of land coverage were correlated with temperature and rainfall in the study area. Additionally, anthropogenic pressures (human population and grazing pressure/collection of forest products) may impact the patterns of ground cover, and we also included an index of this in the analysis. Since population levels in the study region

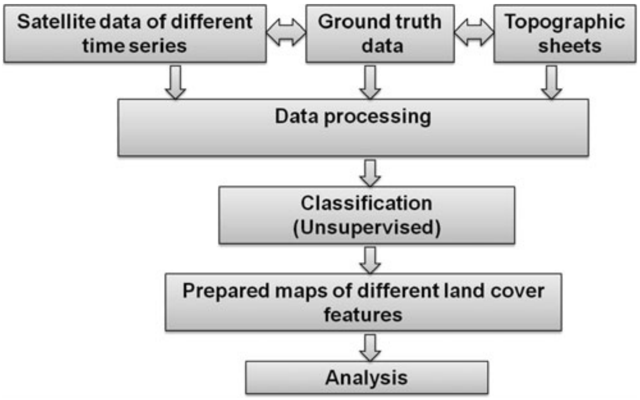

Fig. 2 Flowchart summarizing the procedure used to analyze ground cover change between 1979 and 2009

have increased between the 1980s and 2010 (Government of Nepal 2010), a we ranked the anthropogenic factors as 1 for the 1980s, 2 for the 1990s, and 3 for the 2000s to include in the analysis. Pearson correlation was used to determine the relationships among the variables, namely anthropogenic factors, temperature, rainfall, and land cover change. SPSS 16.1 was used for the analysis (SPSS 2007).

3 Results

3.1 Temperature trends

The mean annual temperature in upper Mustang ranged from 5.7 °C in 1987 to 9.2 °C in 2009, showing a mean annual temperature increase of 0.13 °C per year. Over all years between 1987 and 2009, the mean annual maximum and minimum temperatures were 13.92 and −0.07 °C, respectively (Fig. 3). The best-fit temperature change regression model (linear) suggested that at the current rate of change, the mean annual temperature will double by 2161, reaching 20 °C. Seven different models were tested to predict the temperature change scenario of the upper Mustang with the model of best fit being temperature=−261.98+0.13x (F=35, p<0.0001, R^2=0.76; Figs. 3 and 4).

3.2 Seasonal maximum and minimum temperature trends

The mean maximum temperatures for the different seasons were 8.9 °C (winter), 16.9 °C (spring), 19.3 °C (summer), and 13.9 °C (autumn; Fig. 5). The mean minimum temperatures for the different seasons were −7.2 °C (winter), 2.5 °C (spring), 9.3 °C (summer), and 0.57 °C (autumn) (Fig. 6). Spring and summer are the main time for plant growth but both the maximum and minimum mean temperatures in these seasons increased between 1987 and 2009, and these increases were positively correlated (r_s=0.49, p<0.86; Figs. 5 and 6).

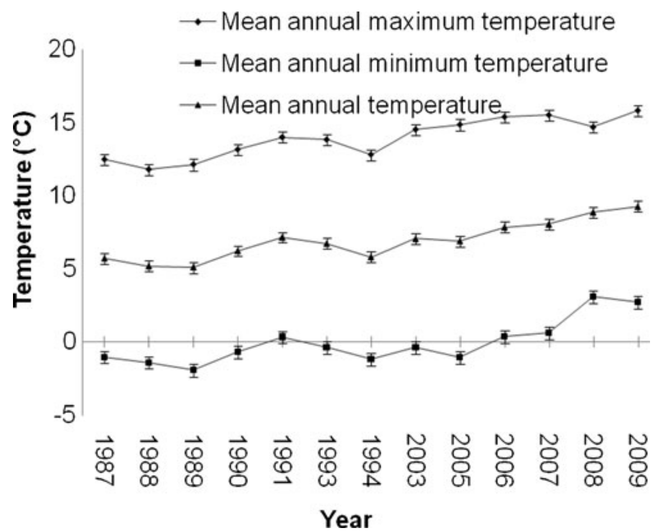

Fig. 3 Temperature trends between 1987 and 2009 in upper Mustang (mean±SE)

3.3 Precipitation trends

The amount of rainfall in upper Mustang increased abruptly in 1999, and has remained higher up to 2009 than experienced in any year between 1987 and 1998 (Fig. 8). Combined with higher temperatures, this increased rainfall has also contributed to significant snow melt. Respondents in the survey also note that snow cover has diminished over recent years. This is significant, because snow continues to

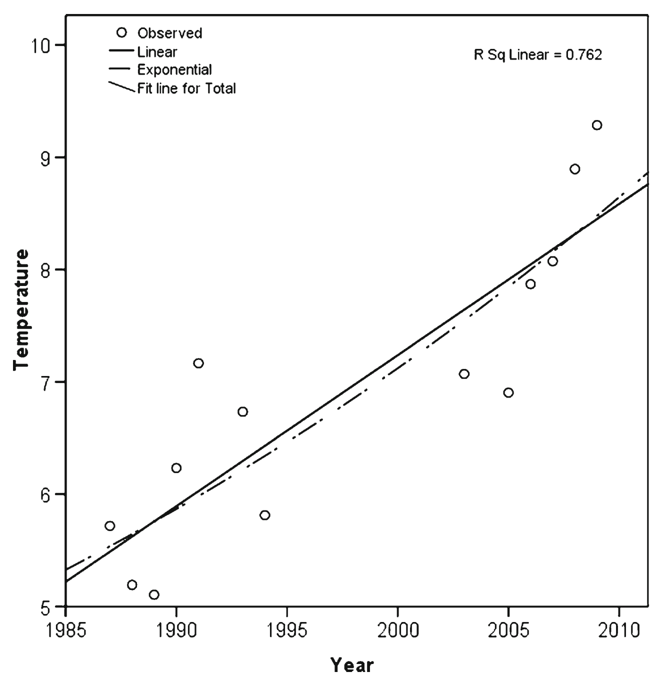

Fig. 4 Best fit (linear) model to predict mean annual temperature (in degree Celcius) in the region (Y=−261.98+0.13x; F=35, p<0.0001, R^2=0.76) (*solid line*). Also shown is the second best fitted model (exponential, *broken line*)

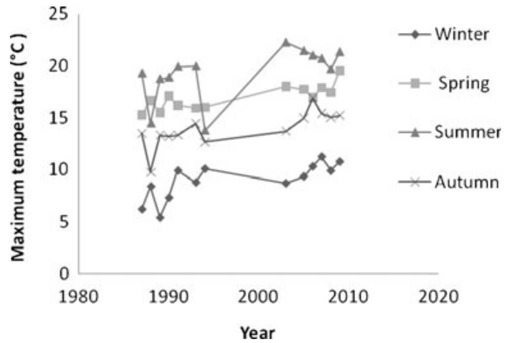

Fig. 5 Seasonal mean maximum temperature trends. Winter mean ±SE=8.9±0.48, spring mean±SE=16.9±0.3, summer mean±SE= 19.4±0.7, autumn mean±SE=13.9±0.48

be the source of river water and drinking water in the region. The best fit model for rainfall prediction was $-1{,}070.25+0.541x$ (F=6.3, P=0.02, R^2=0.53, x years; Figs. 7 and 8).

3.4 Seasonally based rainfall trends

The mean maximum rainfall for the different seasons was 26.8 mm (winter), 14.18 mm (spring), 66.23 mm (summer), and 14.68 mm (autumn) with the most marked change occurring in summer (Fig. 9).

3.5 Impacts of climate change on prey, predators, and local livelihoods

Table 1 shows a summary of the responses of local people to the questionnaire. Although predators (including snow leopards, brown bears, lynx, wolves, and foxes) have historically preyed upon livestock in the area, local interviews from 2009 suggest that depredations are increasing. Local people state that the culprits for a majority of these losses were snow leopards. They believe that grasses and shrubs are no longer found in abundance at high elevation due to climate change, and therefore blue sheep are foraging on these foods at lower elevations, where they also raid agricultural crops. Ninety-three percent of respondents stated that some plants, including the Graminae family, were becoming dryer and dying before reaching maturity and seed production, and no longer available

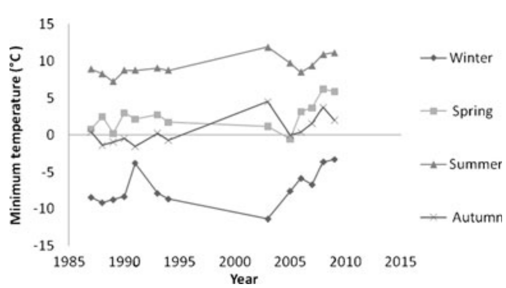

Fig. 6 Seasonal minimum temperature trends. Winter mean±SE=−7.2± 0.7, spring mean±SE=2.5±0.6, summer mean±SE=9.2±0.4, autumn mean±SE=0.58±0.5

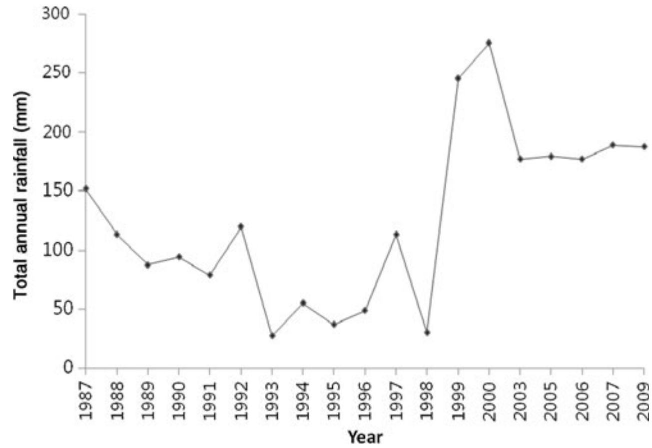

Fig. 7 Rainfall trends in upper Mustang in the period 1987–2009 (mean±SE, <125±17.3)

in each season. The respondents stated that a consequence of this is that blue sheep (the main prey source for snow leopards) are feeding at lower elevations (<3,800 m) than they did traditionally, and frequently come to agriculture land. Additionally, the people noted that the movement of blue sheep draws snow leopards down from their high elevation (>4,500 m) habitats, and this has resulted in an increase in the number of livestock depredations and human–snow leopard conflicts. The local people believed that there was no alternative to the retaliatory killing of snow leopards in order to reduce future livestock losses.

Local people have changed their farming periods due to increases in the mean seasonal temperature and changes in

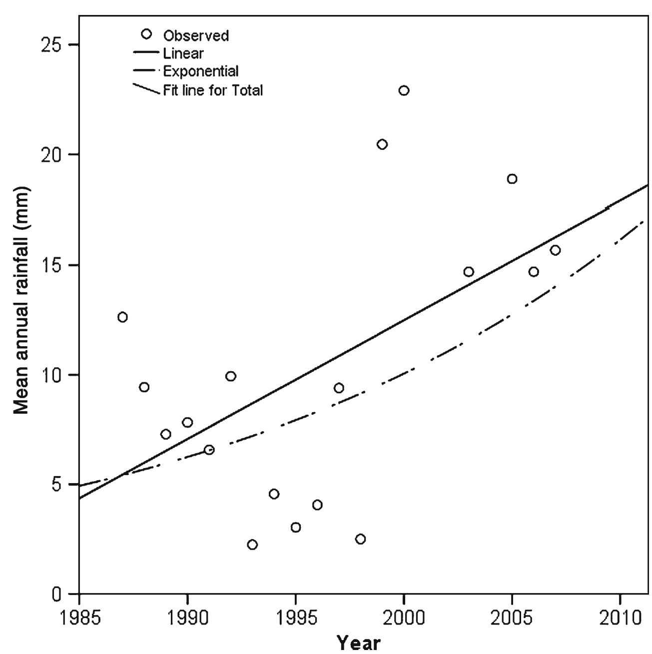

Fig. 8 Best fit (linear) model to predict rainfall in the Mustang region (Y=−1070.25+0.541x; F=6.3, p=0.02, R^2=0.53, x years; *solid line*). Also shown is the second best fitted model (exponential, *broken line*)

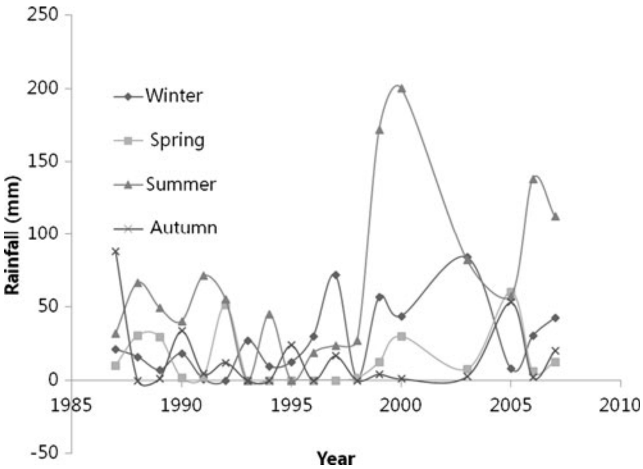

Fig. 9 Seasonal rainfall in upper Mustang from 1987 to 2009. Winter mean±SE=26.8±5.8, spring mean±SE=14.2±4.4, summer mean±SE=66.23±13.3, autumn mean±SE, 14.7±5.5

precipitation. Most respondents agreed that they are cultivating their crops 1 or 2 months later compared to previous years. Further perceptions of the local people on the level of impact on local livelihoods, associated ecosystems, blue sheep, and snow leopards are given below in Tables 1, 2, and 3.

3.6 Demands of the local people of Samjung and Dhey villages

In the upper Mustang region, the mountain snow and peaks have changed because of the unseasonal melting of snow packs and glaciers that rely on freshwater runoff from high mountains. Rising temperatures and reduced snowfall have created a problem in the upper Mustang region as snow melts earlier and faster in the spring. This has shifted the timing and distribution of runoff in the different areas and led to a lack of water resources in spring, summer, and autumn. These changes have affected the availability of freshwater for natural systems and human uses, such as agriculture, and has also impacted on natural rangelands. Two serious examples of these effects are Samjung village (at an altitude of 4,100 m) of Chhoser VDC, and Dhey village (at altitude 3800 m) of Surkhang VDC, upper Mustang (Fig. 10). The villagers wanted to shift their whole village.

3.7 Land cover changes and tree line shifts in Mustang district

Land cover changes were detected and estimated by using remote sensing satellite data of the Mustang district of Nepal, as described in the "Methods and materials" section. In this way, an overall map accuracy of 88.6 % was achieved, and a similar accuracy was assumed for the 1979 map as a similar procedure was used. Forest and grass land had decreased by 42 and 11 %, respectively, and barren lands had increased by 58 % (Table 3; Fig. 11). Grass and forest lands had decreased drastically in the region. These changes may have been a result of an increase in human population and demand for forest products in the local market. The barren land has increased greatly as consequence of climate change (increasing temperatures and a decrease in snowfall) and overgrazing in the region. Our study indicated that the tree line was shifting to a higher elevation in the Nammu area and its surrounding valley in the lower Mustang region (Fig. 12).

The results showed that rainfall and temperature correlated significantly with changes in land cover in the region

Table 2 Overall impact of climate change based on four parameters. Source: Interview with local people (n=221). Data are the percentages of the 221 respondents that agreed with the statement

Rangelands (%)	Livelihood (%)	Blue sheep (%)	Snow leopard (%)
Reduction in water sources (18)	Reduction in food and drier farmland (9)	Reduction in numbers (38)	Reduction in numbers and low sighting (41)
Reduction in grasses (33)	Reduction in livestock (4)	Crop raiding (16)	Increase in livestock depredations due to decrease in natural prey (24)
Drier (12)	Health problems with new diseases (3)	Movement downwards towards farmlands (14)	Approaching the villages (13)
Reduction in snowfall (27)	Reduction in drinking water and fewer irrigation channels (36)	Sightings near villages (4)	Change in use of habitat and change in predation behaviors to kill domestic livestock then natural prey (22)
Move towards desertification (10)	Changes in agricultural crop cultivation time (27)	Reduction in grazing land (20)	
	Increase in wind speed	Change in habitats use (8)	
	Economic crisis (7)		
	Water seepage and damage to traditional houses (14)		

Table 3 Land cover changes between 1979 and 2009 in Mustang District

Land cover	Area in 1979 (km^2)	Area in 2010 (km^2)	Trend km^2 (+, increase; −, decrease)	Trend % (+, increase; −, decrease)	Linear regression equation for change in area between 1979 and 2009
Barren land	774.25	1,229.71	+455.46	+58.78	Barren land (y)=455.46x (years)+318.79; R^2=0.92
Forest land	415.42	238.08	−177.34	−42.64	Forest land (y)=−177.34x (years)+592.76; R^2=0.89
Grassland	2,374.71	2,096.98	−277.73	−11.66	Grass land (y)=−277.73x (years)+2,652.4; R^2=0.83

(Appendix). However, there are other factors that might have influenced the land cover changes, namely anthropogenic pressure on forests for timber and fuel wood, and on grassland from grazing. Although we did not measure these directly, we used the increase in human population size in the region across successive decades as a proxy, scored as 1 (1980s), 2 (1990s), and 3 (2000s). It was concluded that all three variables (anthropogenic pressure, temperature, and rainfall) likely contributed to changes in land cover in the Mustang district of Nepal (Appendix).

4 Discussion

4.1 Rainfall and temperature trends and impacts

The upper Mustang region has a cold desert climate, with an average total annual rainfall as low as the desert area of India (<50 mm; Hofer and Messerli 2006). However, the current level of temperature change and the reduction in snowfall (with snow melting very fast) has been inducing the process of desertification. The rapid melting of snow and increase in temperature have caused several negative impacts, with less river water remaining in the upper part of the region, lower ground water discharge, less grass production, changes in agricultural production, and a changing ecosystem. Observations of local villagers suggest that this has had a direct impact on the wild prey and predators in the region, especially on blue sheep and snow leopards. Respondents noted that these animals have moved down to lower elevations and are interacting more with local people. Climate change has already been documented in the Himalaya (Beniston 2003; Cruz et al. 2007; Bates et al. 2008; Ma et al. 2009; Parmesan 2006). Most of the communities and herders interviewed in our study felt that there is an increasing shortage of grasses available in the pasture. The pressure upon grazing lands is increasing while the regeneration of the palatable grass species has decreased sharply. The local herders expressed the view that the scarcity of grasses in the pasture lands is the major threat confronting the rearing of livestock. When asked about the reason for the decreasing availability of grass in the grazing land, most respondents suggested that the long drought period and lack of snowfall over the past 5 years was the major reason for the low regeneration of the natural grasslands. This has been further aggravated by an increase in the pressure put on the grasslands by local livestock, as well as by the livestock brought in by traders for commercial purposes. Generally, temperatures decrease rapidly with an increase in elevation, so the Trans-Himalayan habitat provides cool escape routes for those species that cannot tolerate high temperatures. However, species that already exist at the highest level of mountains or at the summit regions are likely to find it very difficult to survive with the increasing temperature in upper Mustang. There has been a reduction in grasslands, as well as other threats to the survival of species. Local respondents from the upper Mustang region noted that the existing range of *Caragana* species is shifting upwards towards higher elevations and overlapping with the existing grasslands because these plants survive in high

Fig. 10 Samjung village (*top*) and the villagers welcoming the researchers (*bottom*). The villagers requested that the researchers take steps to shift their village to an area with a good supply of available water. Villagers have also reported the situation to concerned government and nongovernment organizations

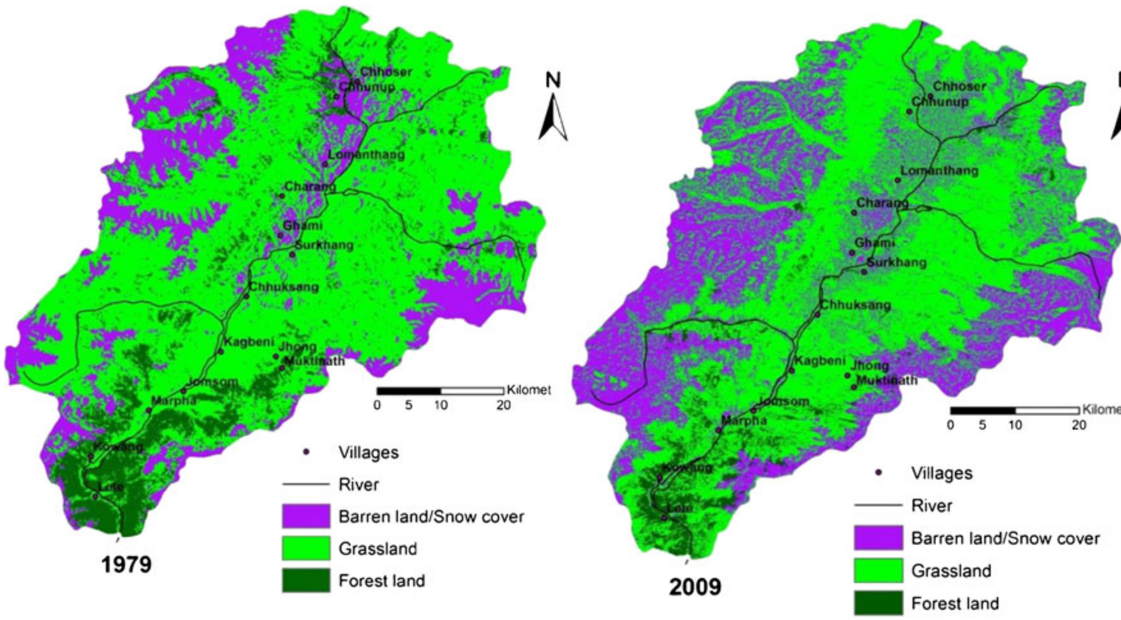

Fig. 11 Land cover changes in the Mustang district between1979 to 2009

temperatures. Thus, the shifting of some grass species towards high elevations has occurred in the region as well, and there are also some grass species that have not adapted or migrated to higher or lower ranges than their historical distribution range. These include *Caragana* spp., *Kobressia* spp., *Androsace* spp., *Anaphalis* spp., *Saussurea nepalensis*, and *Saxifraga* spp. This may lead to a reduction or even loss in the abundance of such species in the upper Mustang region of Nepal. Our study suggests that changes in the climate of the upper Mustang have led to a change in species abundance (an increase in those adapted and a decrease in those that cannot adapt to a changing climate). Such changes in the composition of grass species in the rangeland of the upper Mustang have directly impacted on free-ranging herbivore species and livestock. This has induced a change in the behaviors of animals and livestock, which ultimately impacts on the livelihoods of the people living in upper Mustang.

Global climate change occurs more rapidly with increasing elevation (about 1 °C per 160 m) than with latitude (Chaudhary and Bawa 2011; Pounds et al. 2006), and there is no doubt that the Himalaya region is experiencing a rapid increase in temperature (Chaudhary et al. 2011; Shrestha et al. 2012). Consequently, the Trans-Himalaya zone is expected to experience rapid changes in its ecosystem which will have a large impact on mammals and vegetation resources. Altitudinal changes in the distributions of species are becoming well-documented as species

Fig. 12 Shift of tree line towards a higher elevation in the Nammu area of the lower Mustang region, Nepal

shift their ranges upward to avoid warmer conditions (Pounds et al. 2006).

Our findings also indicated that the increasing temperatures are significantly correlated with an increase in rainfall (r=0.6, p=0.028) in the upper Mustang region. The region has a style of traditional house constructed from special local mud, including a roof that is covered by thick (>20 cm) mud. These traditional houses, which are important to the cultural heritage of the area, are being damaged by the increased rainfall in upper Mustang, having a serious negative impact on local livelihoods. Local people have had to change their traditional forms of housing and build tin roofs to combat this problem and adapt to the current increasing levels of rainfall. The present increase in mean annual temperature of 0.13 °C in the upper Mustang region is considerably lower than the global annual temperature increase (0.7 °C; Locky and Mackey 2009). Nevertheless, the present study shows that the annual temperature increase in Trans-Himalaya (upper Mustang region) was higher than the recent Himalaya region (India and Nepal) temperature increase (0.06 °C per year in Nepal and 0.01–0.04 °C per year in India) (Sharma et al. 2009; Shrestha et al. 2012).

Overall current levels of change in temperature have impacted negatively on the local ecosystem, local livelihoods, wildlife (blue sheep and snow leopards) and livestock, and the relationships that exist between them (Table 2). Furthermore, such change could be forcing a shift in predator-prey relations. A similar scenario has been observed in the other regions of Greater Himalaya (Xu et al. 2009). Although change in climate is one of the major causes of changing impacts, there may be other factors arising from the human impacts or additional associated drivers of change which require further analysis.

4.2 Land cover changes

Forest land (<93 %) mostly lies in the lower Mustang region; very little remains in the upper Mustang region (Fig. 11). Forest areas have decreased because of an increase in population pressure, road access to the area, and an increase in tourism in the region. Lower Mustang forests were once the main source of timber production both for the lower and upper Mustang regions, and the high demand for timber production was one of the major causes of the decrease in forests in the lower Mustang region. Furthermore, the high demand for timber and fuel also led to the decline in forests in upper Mustang. Grasslands have generally decreased in the Mustang district as a result of increases in temperatures in the region, as well as the reduction in snowfall. Consequently, there is less moisture contained in the rangelands of the district. There has, additionally, been high pressure of livestock numbers on the rangelands of the district (Government of Nepal 2010; Paudel and Andersen 2010), which has also contributed to the decrease in grasslands.

Many studies have reported on the shifting of the tree line and vegetation (Xu et al. 2009; Dubey et al. 2003; Wilkes 2008); however, the Trans-Himalayan region presents a special scenario because of its complicated biogeography, site characteristics (cold desert) and anthropogenic influences. In the course of this study, we did not observe any shift in the tree line above the past existing range in the upper Mustang region; it appeared that most of the trees and forest had been destroyed for timber and fuel wood. However, changes in the forest landscape that may be attributed to anthropogenic changes and changing temperature and rainfall patterns in the Mustang district were noted. In lower Mustang, it was observed that the tree line had shifted towards a higher elevation above its existing range (observation of the younger *Betula utilis* and *Abies* spp. tree species (<10 years old; Fig. 12)). Similarly, other studies have also reported the shifting species distribution related to of climate change (Klanderud and Birks 2003; Menzel et al. 2006; Harsch et al. 2009). Moritz et al. (2008) reported that lower elevation species have expanded to higher elevations, and there have been changes in the community composition. However, in the Himalaya, especially in higher altitudes, species shifting towards a higher elevation are limited because of soil types, water resources, and other factors (Xu et al. 2009; Moritz et al. 2008). If such a process continues in the Trans-Himalaya, it is likely that some species will be driven to extinction. (Moritz et al. 2008; Wichmann et al. 2005).

5 Conclusions

In conclusion, the current level of climate change appears to be altering the Trans-Himalaya region ecosystems, wildlife, plants, and local livelihood. A strategy of adaptation and mitigation should be implemented at the local level to combat the current level of climate change. The strategy could include: plantations on private land and local areas, the use of solar energy for cooking and heating, the spread of native grass seeding around the area, the development of water holes in the areas where long distances need to be covered, the storage of rainfall water for agriculture, the construction of reservoirs for winter and times of water shortage, control of poaching, continued monitoring of the distribution and shift of trees, the encouragement of social, cultural and religious beliefs, and the involvement of local people in the implementation of any kind of program related to the study, adaptation, mitigation, and measurement of climate change. A national participatory community-based climate change program should be prepared and implemented at the local level. Some initiatives started at a local level might influence the global mission to reduce the effect of climate change on the environment and local livelihoods. The government should take these issues seriously, and studies and measures for adaptation and mitigation should be implemented at a national level.

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Appendix

Table 4 Pearson correlation test between temperatures, rainfall, anthropogenic pressure with land cover

		Years	Rainfall	Temperature	Forest	Barren land	Grass land
Rainfall	Pearson correlation	0.606[a]					
	Sig. (two-tailed)	0.028					
	N	13					
Temperature	Pearson correlation	0.917[b]	0.606[a]				
	Sig. (two-tailed)	0.000	0.028				
	N	13	13				
Forest	Pearson correlation	−1.000[b]	−0.606[a]	−0.917[b]			
	Sig. (two-tailed)	0.000	0.028	0.000			
	N	13	13	13			
Barren land	Pearson correlation	1.000[b]	0.606[a]	0.917[b]	−1.000[b]		
	Sig. (two-tailed)	0.000	0.028	0.000	0.000		
	N	13	13	13	13		
Grass land	Pearson correlation	−1.000[b]	−0.606[a]	−0.917[b]	1.000[b]	−1.000[b]	
	Sig. (two-tailed)	0.000	0.028	0.000	0.000	0.000	
	N	13	13	13	13	13	
Anthropogenic pressure	Pearson Correlation	0.939[b]	0.483	0.939[b]	−0.939[b]	0.939[b]	−0.939[b]
	Sig. (two-tailed)	0.000	0.094	0.000	0.000	0.000	0.000
	N	13	13	13	13	13	13

[a] Correlation is significant at the 0.05 level (two-tailed)

[b] Correlation is significant at the 0.01 level (two-tailed)

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