PLOS CLIMATE

RESEARCH ARTICLE

Understanding the impact of climate change and resilience among highlanders in northern parts of Bhutan: A case study in Gasa district

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OPEN ACCESS

Citation: Dorji T, Yangzom D, Norbu N, Rinchen S, Dorjee J, Tenzin T (2023) Understanding the impact of climate change and resilience among highlanders in northern parts of Bhutan: A case study in Gasa district. PLOS Clim 2(4): e0000079. https://doi.org/10.1371/journal.pclm.0000079

Editor: Anamika Barua, Indian Institute of Technology Guwahati, INDIA

Received: March 25, 2022

Accepted: March 3, 2023

Published: April 6, 2023

Peer Review History: PLOS recognizes the benefits of transparency in the peer review process; therefore, we enable the publication of all of the content of peer review and author responses alongside final, published articles. The editorial history of this article is available here: https://doi.org/10.1371/journal.pclm.0000079

Data Availability Statement: Data in supplement information.

Funding: The research funding was supported by the Royal Government of Bhutan, District

Abstract

Mountainous regions are affected the most by climate change across the world. The livelihood of highlanders primarily depends on livestock farming and natural resources. In Bhutan, yak farming and sale of *Cordyceps sinensis* (caterpillar fungus)remain the main source of income for most highlanders. We conducted a study to understand the impact of climate change on the community livelihoods in Bhutan. A cross-sectional survey was conducted and interviewed 132 household heads, two focus group discussions of 20 respondents (10 in each group), and key informant interviews (n = 5) in two highland communities (i.e., Laya and Lunana) of Gasa district in northern Bhutan between August 2019 and February 2020. The study revealed that the caterpillar fungus (78.8%) is the major source of income for highland communities which overtook the yak farming practices since its legalization in 2004. More than 80% of households have abandoned yak farming due to its poor economic return because of the decreased utility of yak for meat purposes and other socio-cultural related practices. The majority of the respondents (91%) expressed concern that climate change is posing a threat to the growth and subsequent harvest of caterpillar fungus. The highland people reported emergence of insects/vectors in their community and mosquitoes were the most frequently reported (85%) insect. A small proportion of respondents (1.5%) were concerned about the grazing habitat of the yaks due to the change in the botanical composition of the rangeland. Given that there is a decrease in caterpillar fungus, which is the main source of income for highland communities, this study calls for a climate-resilient community-based economic opportunity for the sustainable livelihood of highland communities. Furthermore, we recommend a detailed study of the negative impacts due to climate change on freshwater resources, the distribution of vectors and vector-borne diseases, and rangeland ecology in the highland.

Administration Gasa, District Livestock Sector as part of research work in sheep reviving activities and highland development plan; Capital budget FY: 2019-2020 OBC 52.06 to the first author(TD). The funders has no role in this study design, data collection and analysis, decision to prepare manuscript and publish.

Competing interests: The authors have declared that no competing interests exist.

Introduction

Climate change is affecting the livelihood of people living in the mountainous region of the world, mostly in the high and medium-latitude mountains of Asia, North America, and Europe and the mid-latitude mountains of Asia [1]. By 2055, across the mountain region, the average warming temperature is predicted to disproportionately increase by approximately 2.1˚C to 3.2˚C, depending on the emissions scenario [2]. Since 1570, the average temperature of the earth has increased by 1˚C (1.8˚F), or the near-surface air temperature increased by 0.09 ± 0.01˚C/a from 1982–2011, and the rate of warming is increasing every year [3]. The record from the Department of Hydrology and Metrology Services, Bhutan (DHMS), shows that the average temperature of the northern parts of Bhutan has slightly increased over 10 years from 2010–2020, which is congruent with the data maintained mainly for the Himalayan range of the Hindu Kush (an increase from 0.077˚C to 0.176˚C per decade) [4].

Of the 1050 million people in the mountain region, 35% live in rural areas [5], mostly in the Asia-Pacific region. The brunt of climate change includes the melting of glaciers, erratic rainfall in the valleys, flash floods, emergence and re-emergence of infectious diseases, and drying of freshwater resources. These changes pose threats to food and nutrition security and make highland communities vulnerable to natural disasters [6–8]. Changes in weather and climate patterns, such as late snowfall and melting of glaciers in the mountain, have resulted in the drying up of water resources, thereby impacting agricultural production and posing threats to the livelihood of highlanders. In addition, due to the longer warm seasons, unlike in the past, there are notable changes observed in the botanical composition of the rangeland. Furthermore, warmer seasons have favoured the disease-carrying vectors to thrive, and therefore, an increase in the incidence of an emerging infectious disease remains a concern [9–13].

Mountain communities depend primarily on natural resources and livestock farming for their livelihood [14,15]. In the Himalayan communities in India, Nepal, China, and Bhutan, in addition to other natural resources, *Cordyceps sinensis* English name caterpillar fungus, called *Yartsa Guenboob* in Bhutan, forms one of the main sources of income [16–18]. The caterpillar fungus is a unique fungus/mushroom described to have many health benefits [19]. Until recent years, the trend of harvesting caterpillar fungus has been declining, causing pressure among the communities that earn income from the sale of the fungus [20]. The growth of caterpillar fungi, both in terms of quality and quantity, is described to be dependent on the temperature and amount of snowfall in addition to other anthropogenic factors, such as soil management during the harvest period [21,22].

The record from the Department of Agriculture and Marketing Cooperative (DAMC) of Bhutan suggests that there has been a decline in the quantity of harvest over the years. For instance, a total of 8,988 kg was exported in 2007 as opposed to only 540.25 kg in 2011. However, the revenue has increased many-fold from USD 6000/kg in 2008 to USD 24000/kg in 2012, with the highest increase in 2017 being USD 37000/kg caterpillar fungus. The prices of the first-class caterpillar fungus are traded at the worth of Nu.2.71 million (USD 0.38 million). In 2017, the highest price in the auction was fetched in Bumthang district, and one household would have harvested more than 2 kg if the situation was the same as in the past decades [23]. In contrast, the price was not as high as it is today, and declining quantity has increased the market price. Very recently, *Cordyceps sinensis* was listed in the ICUN red list 2019 as a vulnerable species [24]. On the other hand, there are threats to the economy and industry involved in natural fungi due to breakthroughs in the artificial cultivation of similar caterpillar fungi on a large scale, which ultimately will affect the livelihood of communities depending on this fungus [25].

The yak (*Bos grunniens*) is considered a lifeline for mountain communities of the Himalayas. They are raised at altitudes between 3,000 and 5000 meters above sea level. The

productivity of yaks is expected to decrease if the average environmental temperature rises above 13˚C due to adaptive mechanisms of the body through accelerating respiration and heart rate to cope with heat stress in yaks [26]. In Bhutan, the number of households owning yaks has decreased by more than 80% for various reasons, including the legalization of caterpillar fungus collection and sale since 2004 [16].

It is a natural phenomenon for the community to come up with solutions to problems [27]. In response to climate change, highland communities adopt other means of earning income, such as developing tourism-related activities in addition to their traditional knowledge and natural coping in adaptation [27,28]. However, the viability of a tourism-related business in the highland is driven by the presence of roads, electricity, and other modern amenities [29].

Bhutan is a small Himalayan kingdom located between India and China. It is predominantly a mountainous country with diverse topography with altitudes ranging from 100 meters above sea level (masl) in the south to 7,500 meters above sea level (masl) in the north [30]. Administratively, Bhutan consists of 20 districts *(Dzongkhag)* and 205 subdistricts *(Geog)*. Of the 20 districts, some commuinities of 11 (55%) districts rear yaks, of 205 subdistricts in the country, 29 (14%) subdistricts are actual highland communities, and 17 subdistricts are dependent on caterpillar fungus. Bhutan is similar to any other mountain people of the Himalayas, and the highlanders of Bhutan extensively depend on yak farming and natural resources, particularly caterpillar fungus, for their livelihood [31].

The major income for the people of Laya and Lunana in Gasa district in northern Bhutan is derived from the sale of caterpillar fungus and yak products [16,32]. However, the statements were different before 2004. Until the legalization of caterpillar fungus harvest and marketing in 2004, the main sources of income among the community of Laya and Lunana were the sale of yak and yak products such as meat, butter, and cheese [16,33]. There are limited data available about the impacts of climate change on the mountain communities in Bhutan. The absence of scientific knowledge can result in poor planning and implementation of any projects aimed at highland community development. Integration of climate change resilient income-generation activities acceptable by the highland community has become necessary.

The main objective of this preliminary survey is to understand the reality of climate change and its impact as well as the adaptations to cope with the impacts in two highland communities (Laya and Lunana) of the Gasa district in northern Bhutan.

Materials and methods

Study site

The study was conducted in Gasa district's two subdistricts (Laya and Lunana) (Fig 1). By territory, Gasa is the largest among the 20 districts in Bhutan; however, it has the lowest human population and human settlement [31].

Laya is located approximately two days walk (43 km) from Gasa, the district headquarters. Out of 216 households in Laya, 64 owned yaks. Laya has five *chiwogs* (a cluster of villages) with a human population of 1075 [31].

Lunana is 10 days walking distance (127 km) from Gasa headquarters and needs to cross 3–4 mountains with an altitude above 5000 masl. These mountains are accessible only for a few months (early June-October), while they remain cut off for the rest of the months due to heavy snowfall. However, emergency services are provided through helicopter services. Of the total 194 households in Lunana, 120 own yaks with a human population of 699 in 5 chiwogs [31].

The average annual temperature for Laya is 12˚C, recording 21˚C in July and -11˚C in January for the last decade. Similarly, for Lunana, the average annual temperature is 10˚C, with a

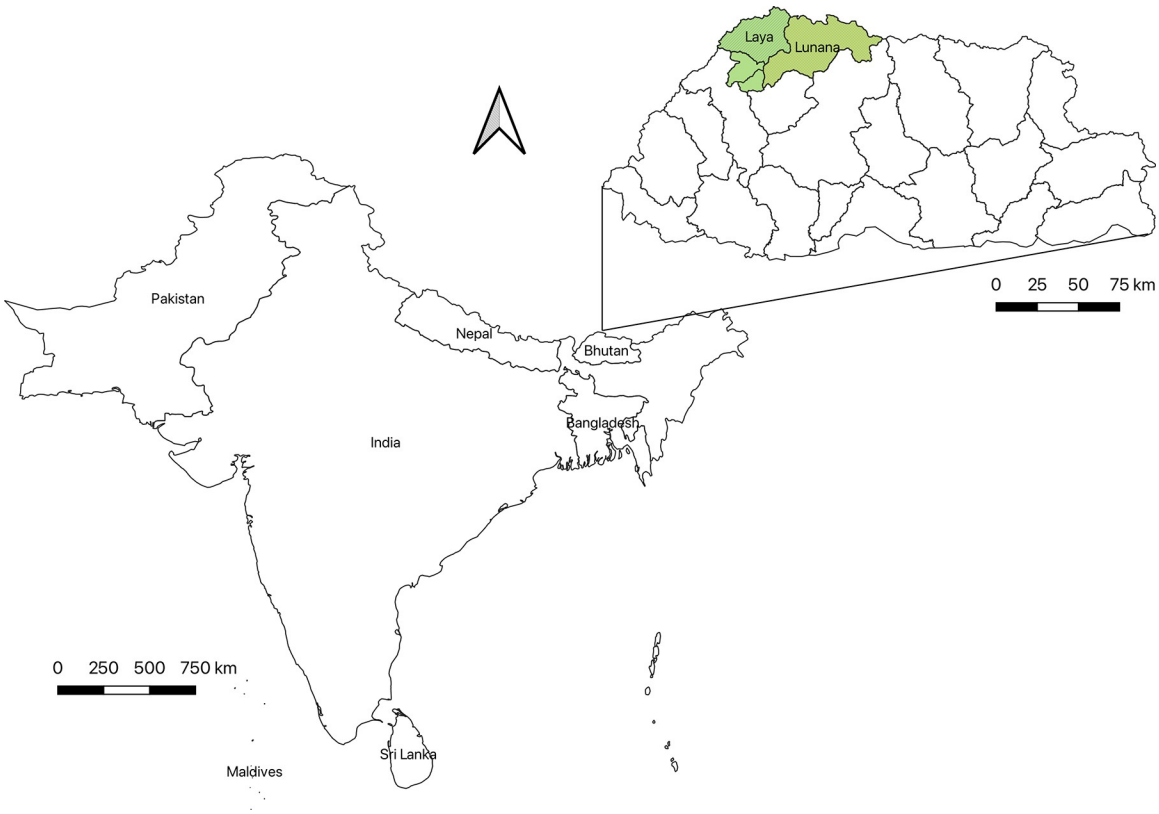

Fig 1. Map of Bhutan showing the study areas (Laya and Lunana *geogs* in Gasa district). This map was prepared using QGIS Development Team (2020) October, QGIS Version 3.16 LTR (Hannover) Geographic Information System, Open-Source Geospatial Foundation Project (http://qgis.osgeo.org) and was not taken from another source.

https://doi.org/10.1371/journal.pclm.0000079.g001

maximum of 20˚C in summer and -12˚C in winter for the last decade. Lunana is the most remote settlement in Bhutan [34].

Both study sites have minimal modern amenities except that they are connected to the communication network. The government schools, basic health unit, livestock and agriculture extension, forest park services, and office of the local government administration are established at the sub-district. The human settlements in these two sub-districts are located above 3500 masl. The yak herds are located between 3500–5100 masl, with a maximum of 4–5 herds at each site. Most of the herders migrate from one grazing pasture to another, mainly identified as their summer and winter grazing herds. Horses and yaks are used as a means of transport by communities [35].

Study design and data collection

Sample size. There are 410 officially registered households (hh) in the two study sites, 216 in Laya and 194 in Lunana [24]. The sample size of 67 and 65 household heads from the Laya and Lunana sub-district respectively, was calculated using the formula $n = \frac{Z^2 p(1-p)}{c^2}$, where Z (95% level of confidence) = 1.96, p = estimated baseline proportion of household heads who were presumed to have adequate knowledge of climate change and its impacts = 0.5, and e = margin of error = 0.10. We assumed that 50% of people know about climate change and its impact. The study was designed to have two phases of data collection: a survey with the head of households using a questionnaire survey followed by a Focused Group Discussion (FGD) and Key Informants' (KI) interview. The questionnaire was developed with a combination of

both closed and open-ended questions and divided into six sections: respondents' demographic characteristics, climate change and impacts, a threat to sources of income due to climate change, the emergence of new insects/vectors due to climate change, rangeland ecosystem changes because of climate change, and potential adaptability practices by the community. The questionnaire was piloted among five farmers from Laya and then modified accordingly to improve clarity. A checklist of questions was prepared during key informant interviews and FGDs to obtain triangulated data through in-depth interviews and discussions in addition to the survey data S1 Text **Understating the impact of climate change and the resilience of highlanders in north Bhutan: a case study under Gasa district**.

In the first phase, the field survey was conducted by visiting the households of all the chiwogs in the geogs and by visiting herd to herd by the trained livestock extension officers of Gasa district. A minimum of 10 households was selected from each chiwog from both communities. The snowball sampling method was applied in each chiwog where the selected household provided information to visit the next household. One adult person (>18 years of age) from each selected household was interviewed face-to-face. The study targeted household heads or adult members of the family, who usually reside in a household throughout the year, as the main respondents because they will have better experiences with their community. Verbal consent was obtained from the respondents before the interview. The interview was organized in the local language *Dzongkha* but translated and recorded in English since the questionnaire was developed in English. Each selected adult respondent was informed about the objectives of the study, and all individuals agreed to participate in the survey.

In the second phase, focus group discussions and key informant interviews were organized in each study area to explore the understanding and experience of climate change, the implications, and future adaptability practices for their sustainable livelihoods. The participants (n = 20), 10 from each study for the focus group discussion, included two subdistrict leaders (*Gup* and *Mangmi*), five village headmen (*Tshogpa*), and three farmers who have been dependent on yak farming for several years. The names of three farmers were identified and suggested by the local leaders who have knowledge about the community. The free-listing exercise by individual participants, mapping and ranking in group methods using a whiteboard, and chart papers were applied during focus group discussion.

The semi-structured interviews were conducted with (n = 5) key informants from two study sites. They were mostly elders and ex-local leaders because of their in-depth knowledge of topics such as the trend of yak farming in the community and challenges, information related to caterpillar fungus collection and non-wood forest products, and knowledge about rangeland ecology and vectors/insect distribution. Three key informants were females who had been engaged in yak farming since their childhood, and two male key informants were former *gups* (leaders of the sub-district). Video recording was also performed with some key informants (n = 2) to collect the information from those who agreed to record it. Two phases of the field study, questionnaire survey focus group discussions and key informant interviews, were carried out between August 2019 and February 2020.

Ethics. The study protocol was reviewed and received ethical approval by the Research and Extension Division (RED), Department of Livestock vide LRED-Protocol Form No 2, and administrative approval by the district administration, Gasa (Local Government) vide DAG/DLS/04/2019-2020/017 dated August 14, 2019.

Data management and analysis

The quantitative data obtained from the questionnaire survey were entered and managed within a Microsoft Excel database (Microsoft Excel, Redmond, USA) and were analysed in R

statistical software version 3.6.0 using the packages "base", "stats", "methods", "utils", and "graphics" [36]. We categorized the age of the respondents into 18–40, 41–60, and >61 years and gender as female and male for analysis S1 Data. Descriptive statistics were performed to calculate proportions, frequency, mean, median, standard deviation, range, and maximum values for categorical and continuous variables. The frequencies of the categorical variables between two sub-districts were compared using Pearson's chi-square test and Fisher's exact test based on the number of variables to be counted in the cells during approximation for correct statistical analysis. The S2 Data obtained were entered and analyzed using FLAME 1.2 software [37]. The free listing data of the emerging vectors/insects by the respondents were ranked and calculated as the Sutrop index. Sutrop index is a measurement based on the frequency of citations and the mean rank of citations from the total respondents [37]. The study areas were mapped by using QGIS version 3.16 Moreover, (http://qgis.osgeo.org).

Result

Sociodemographic characteristics

Out of 132 participants, there were more female respondents from Laya than Lunana. The age of the participants ranged from 18 to 80 years with a mean of 38.3 years. The position occupied by the head of household among the participants during the survey was different in the two highland communities, with higher percentages of mothers in Laya and fathers in Lunana. The distribution of the respondents' occupations was similar in both sub-districts, with more than 90% being farmers. The majority of the respondents did not have formal education in either community of Laya or Lunana. The rest of the participants had either primary/high school/monastic education, and none of the respondents had a university degree during the time of our survey. On average, 4.4 people were living in the households, and 97% of the respondents had spent their entire life within their community. Only a few respondents returned to their community either as retired military or ex-monks. The minimum number of years that the respondents lived in the community was three. There were significant differences in the possession of television (TV) between the two sub-districts of Laya and Lunana; however, (16%) of the respondents in Laya owned a vehicle compared to only (8%) in Lunana at the time survey (Table 1).

Socioeconomic activities in two communities and their impacts due to climate change

The major sources of income were from the sale of caterpillar fungus for both communities followed by yak and yak products, transportation services of horses, agriculture, non-wood forest products, and tourism (Table 2). Surprisingly, the respondents from Lunana have mentioned that they have no income from the sale of yak and yak products, horse and transportation and non-wood forest products. Correspondingly, the respondents from Laya reported no income earned from tourism and business (Table 2). There was a significant difference ($P < 0.05$) between the list of income sources between Laya and Lunana. From the group discussion, it was revealed that the people of Laya operate different activities, such as the collection and sale of incense materials (40%), porter and pony services for the tourist (30%), conducting trekking and selling of yak and yak products (30%) and caterpillar fungus collection to earn income. However, a key informant from Lunana mentioned that "*these activities are not favourable to Lunana and the major reason is due to limited accessibility of road connectivity and high transportation cost unlike other highland communities*". The dependency on the collection of caterpillar fungus is still a major economic activity (90%) when compared to other economic activities (10%).

Table 1. Sociodemographic characteristics of respondents in the two study sites—Laya and Lunana.

Variable/categories	Laya n (%)	Lunana n (%)	Chi-square or Fisher's exact test
Gender			0.001
Male	31 (46)	48 (74)	
Female	36 (54)	17 (26)	
Age (years)			<0.03
18–40	42 (63)	38 (58)	
41–60	16(24)	25(39)	
>61	9 (13)	2(3)	
Qualification			0.01 (Fisher's exact test)
No schooling	45 (67)	55 (85)	
Non-Formal Education	2 (3)	4 (6)	
Primary school (< = 6)	10 (15)	3 (5)	
Lower secondary school (< = 8)	5 (7)	0(0)	
Higher secondary school (< = 12)	2 (3)	0(0)	
Monastic education	3 (5)	3(4)	
Occupation			0.522 (Fisher's exact test)
Farmer	64(95.5)	62 (95)	
Civil servant/corporate employee	2 (3)	1 (2)	
Military	1 (1.5)	0 (0)	
Student	0 (9)	0 (0)	
Monk/*Gomchen*/Nun	0 (6)	0 (0)	
Business/Contractor	0 (0)	2 (3)	
Household positions			<0.001
Father	21 (31)	49 (75.5)	
Mother	28 (42)	9 (14)	
Sons/Daughter	17 (25.5)	6 (9)	
In-laws	1 (1.5)	1 (1.5)	
Number of years lived in the village			0.002
1–5	2 (3)	1 (1.5)	
6–18	0 (0)	3 (5)	
19–50	52 (78)	60 (92)	
>51	13 (19)	1 (1.5)	
Own television (TV)			0.01
Yes	49(73)	58(89)	
No	18(27)	7(11)	
Own vehicle			0.13
Yes	11(16)	5 (8)	
No	56(84)	59 (92)	

https://doi.org/10.1371/journal.pclm.0000079.t001

The former local leader (gup) explained that "*yak farming was the main source of income before the introduction of cordyceps into the international market. The income from yak farming is from the sale of yak meat, butter, and Chugo (the hard-dried casein). Since the late 1900s and early 2000s, increased awareness of the people about the sinful act to kill yak for meat purposes has resulted in declined practices of killing yaks for meat and consequently demotivated the community on the value of yak farming*". In contrast, a woman key informant from Laya mentioned that "*as per the tradition, yak herding responsibilities falls on the women. This is one of the reasons that in the past, women would marry two husbands: one to look after household business to cater*

Table 2. List of income sources and list that are highly impacted by climate change as mentioned by two highland communities of Gasa District.

Variables/categories	Laya n (%)	Lunana (n)%	Fisher's exact test
Sources of income			<0.001
Cordyceps sale	40(60)	64(98)	
Yak and yak products sale	18(27)	0(0)	
Horses and transportation (porter/pony business)	2(3.5)	0(0)	
Tourism	0(0)	1(2)	
Agriculture	2(3.5)	0(0)	
Others (Nonwood forest products sale)	4(6)	0(0)	
List of income sources being affected by climate change			0.004
Cordyceps sale	56(83.5)	64(98)	
Yak and yak products sale	8(12)	0(0)	
Horses and transportation (porter/pony business)	0(0)	0(0)	
Tourism	0(0)	0(0)	
Agriculture	2(3)	1(2)	
Others (Non-wood forest products sale)	1(1.5)	0(0)	

https://doi.org/10.1371/journal.pclm.0000079.t002

to the ration and one to be involved in yak farming. The present youths (girls) do not like yak farming, nor would they like to marry two husbands. This decline in traditional practices has contributed to decreasing the number of yak herders to less than 20%, unlike in the past, when most households owned yaks. I have two husbands, and they are brothers. The elder husband looks after the household income, and the younger husband assists in yak farming. I remain in the herd areas and rarely visit the village, as I have approximately more than 100 yaks to look after".

A gup from Lunana explained that "*yak was also used for transportation purposes and the trend is now declining because of an increasing number of horses which was not in the past. Except during migration of herds, yak is not used for transportation purposes*". He claimed that in the future, yaks can be a showcase for tourists only rather than a source of livelihood for the people.

The majority of the respondents have pointed out that their income is being affected by climate change; however, there are significant differences between Laya and Lunana over this statement (P = 0.004). The caterpillar fungus business is considered the most affected in both communities (83.5% Laya and 98% Lunana) due to climate change, followed by yak and yak products (12% Laya), agriculture (3% Laya and 2% Lunana), and non-wood forest products (1.5% Laya) (Table 2). The income of the communities affected by the caterpillar business was higher in Lunana than in Laya. The key informant participants stated that the income of the community are affected by climate change due to the low yield of caterpillar fungus collected from the mountains. "*As a result, some household has already started leaving the highland community and started settling in other districts looking for better income opportunities and comfortable life*" stated former Laya Gup. The focus group discussion and key informant interview revealed that ever since the legalization of caterpillar fungus, the people of Lunana were largely dependent on the caterpillar fungus business, unlike Layaps, whose source of livelihood is now being diversified on other activities.

Climate change and impacts observed by the highland communities

One of the aims of the survey was to understand the experience of climate change as well as their adaptation approaches. A question was asked to understand whether the community has

Table 3. Agreement on climate changes and impacts observed.

Variables/categories	Laya n (%)	Lunana (n)%	Chi-square test
Have noticed temperature changes			0.5
Yes	61(91)	61(94)	
No	6(9)	4(6)	
Temperature changes towards			0.4
Colder months	3(4)	5(8)	
Warmer months	64(96)	60(92)	
Have experience temperature changes and negative impacts			0.009
Observed	63(94)	51(78)	
Not observed	4(6)	14(22)	

https://doi.org/10.1371/journal.pclm.0000079.t003

experienced a change in temperature over the years in their settlement. The majority of the respondents (91% from Laya and 94% from Lunana) agreed that temperature changes have occurred in their communities. Among the respondents, 96% from Laya and 92% from Lunana mentioned that it has become warmer than before. More than 75% of the survey respondents (94% Laya and 78% Lunana) reported the negative impact of temperature changes (Table 3, Fig 2).

Because of the changing environmental temperature caused by climate change, the respondents observed several negative impacts at the community level. Among them, melting glaciers or snow was the highest, followed by erratic rainfall, decreasing amounts of precipitation, and changes in grass species in the mountain rangeland (Fig 2).

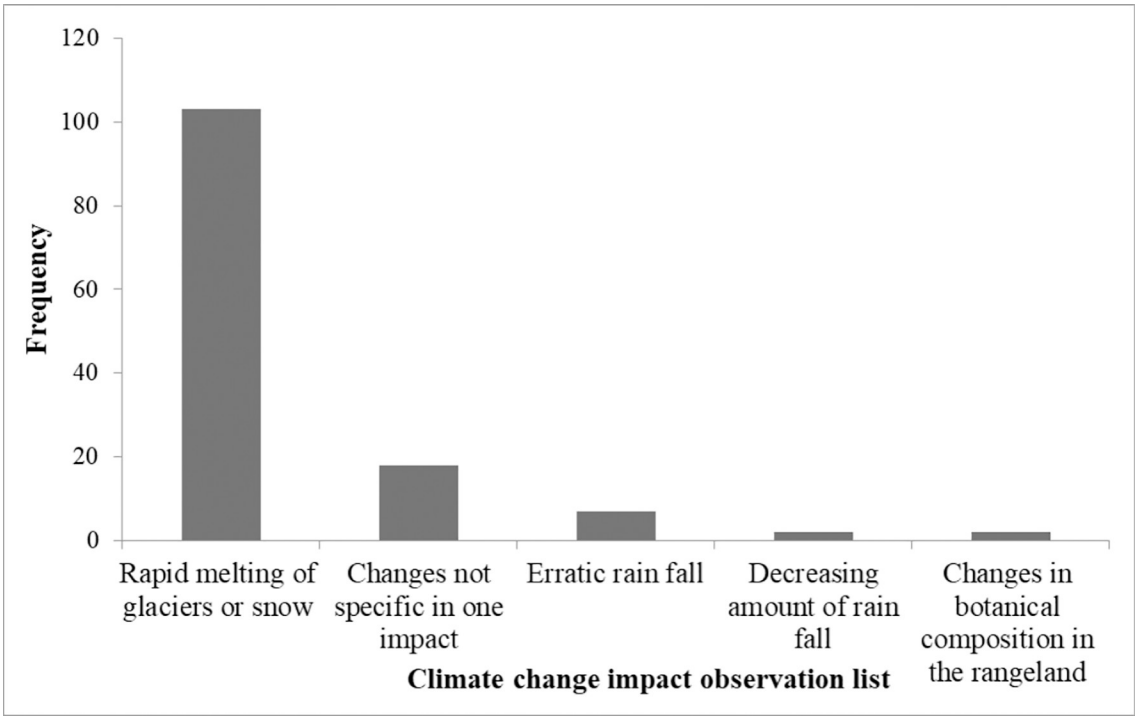

Fig 2. Choices of economic activities listed by the farmers to sustain their livelihood in the face of climate change.

https://doi.org/10.1371/journal.pclm.0000079.g002

Table 4. Agreement on the availability of new species of insects that bite humans and livestock that were not present in the past.

Variables/categories	Laya n (%)	Lunana (n)%	Chi-square test
Observed changes in the botanical composition of rangeland			<0.05
Yes	46 (69)	9 (14)	
No	21 (31)	56 (86)	
Observed emergences of insects/vectors that bite human			<0.001
Yes	48(72)	21(32)	
No	19(28)	44(68)	
Observed emergence of insects/vectors that bite livestock/animals			<0.001
Yes	45(67)	11(17)	
No	22(33)	54(83)	

https://doi.org/10.1371/journal.pclm.0000079.t004

Change in rangeland botanical species composition and the emergence of diseases observed due to climate changes by highland communities

The respondents mentioned that changes in rangeland ecosystems resulted in the growth of new species of grasses that were never observed before in their highlands (Table 4). From the group discussion, they mentioned that "*grasses that normally grow in warmer places can be seen growing in their pastureland. "The growth of Cordyceps sinensis (Yartsa Guenboob) is declining yearly*". The community people are worried about the gradual decline in the quantity and quality of caterpillar fungus harvest, which may result in a loss of income among the mountain people. Some members during the group discussion mentioned that "*income earned from Yartsa Guenboob in 2019 was less than Nu. One Hundred Thousand (USD 1300) because most of the fungus has decayed even before the actual harvest season (May-June) affected the quality*". In contrast, they believed, "*Yartsa Guenboob would fetch better price because of the unchanging demand by the consumers*". Some participants even expressed that *"the Yartsa Guenboob may become like any precious product in the market that can fetch higher prices in the future*". There are also incidences of drying up of water resources that were used as water sources in the herds. Similarly, the community has also observed new species of insects that bite humans and livestock, and it is prevalent more in Laya than in Lunana (Table 4).

From the group discussion, it was explained that *Zendhom*, *Chapchey and Bup nap is* normally seen in the lower regions of the districts and was never found in their community. They believed that these insects emerged in their communities in early 2000" in Laya and from 2016–2017 in Lunana. The former gup of Laya pointed out the "*presence of mosquitoes even in the yak herds; the places like Tsharijathang* 3500 meters above sea level*) almost for more than 5 years*". During the group discussion, one of the checklists was to gather detailed information about the name of the vectors and vector-borne diseases prevailing in the two communities. The Mosquitos (*Zoendhom)* were the most frequently cited vector/insects mentioned, followed by biting flies *(Chapchey) and* Cabbage Worm *(Bup Nap)* (Table 5). The list of vector-borne

Table 5. Most common names of vectors/insects listed by interviewees in study areas (n = 20 participants). The original (Dzongkha) name given by the respondent, the corresponding putative name in English (based on taxonomical and translation), the frequency and average rank of citation, and the salience Sutrop Index (see text; (Pennec et al., 2014) [37].

Original/Dzongkha Name	Taxonomic/English Name	Frequency	Average rank	Sutrop Index
Zoendhom	*Culicidae*	85.0%	1.000	0.850
Chapchey	Biting flies	70.0%	1.786	0.392
Bub Nap	Cabbage Worm	30.0%	2.833	0.106

https://doi.org/10.1371/journal.pclm.0000079.t005

diseases mentioned during the group discussion that would be transmitted by these vectors/insects was ***Tsepney*** (Malaria) (73%), followed by Dengue (27%). The key informant expressed that "I *knew the name of these vector-borne diseases while visiting subtropical places such as Phuntsholing and Gelephu in south Bhutan*". One of the key informants believed "*these species of insects must have hatched naturally due to increasing environmental temperature*", and some believed "*these vectors/insects are coming along with the commuters during summer and then adapted to survive in the highland communities*". I wondered "*how these insects can survive during cold winter and emerge in summer*?".

Community adaptability for sustainable livelihood in response to climate change among highland communities

The majority of the respondents in Laya (84%) and Lunana (98%) mentioned that caterpillar fungus will no longer be the main source of income in the future. In addition to *Yartsa Guenboob*, Layap mentioned that yak farming is at risk of declining due to climate change (11%). Given the choices for sustainable economic activities in the future to adapt to climate change, the adaptation activities were significantly different between the *geogs* (χ^2 = 228.59, df = 5, $P < 0.05$), although a majority of the people will venture yak farming as the main economic source in both communities (Fig 3). There are significant differences between male and female participants in approaching the sustainable adaptation of livelihood to mitigate the negative impacts of climate change ($\chi^{2\ =}$ 18.898, df = 5, p value = 0.002), where yaks and yak products remain the top priority. Male respondents are more likely to rear yaks (57%) than females (43%) in the future. However, the age, education level and occupation of the participants did not influence their choice of yaks and yak products as future income sources in response to climate change. During the focus key informant interview, a participant from Lunana expressed,

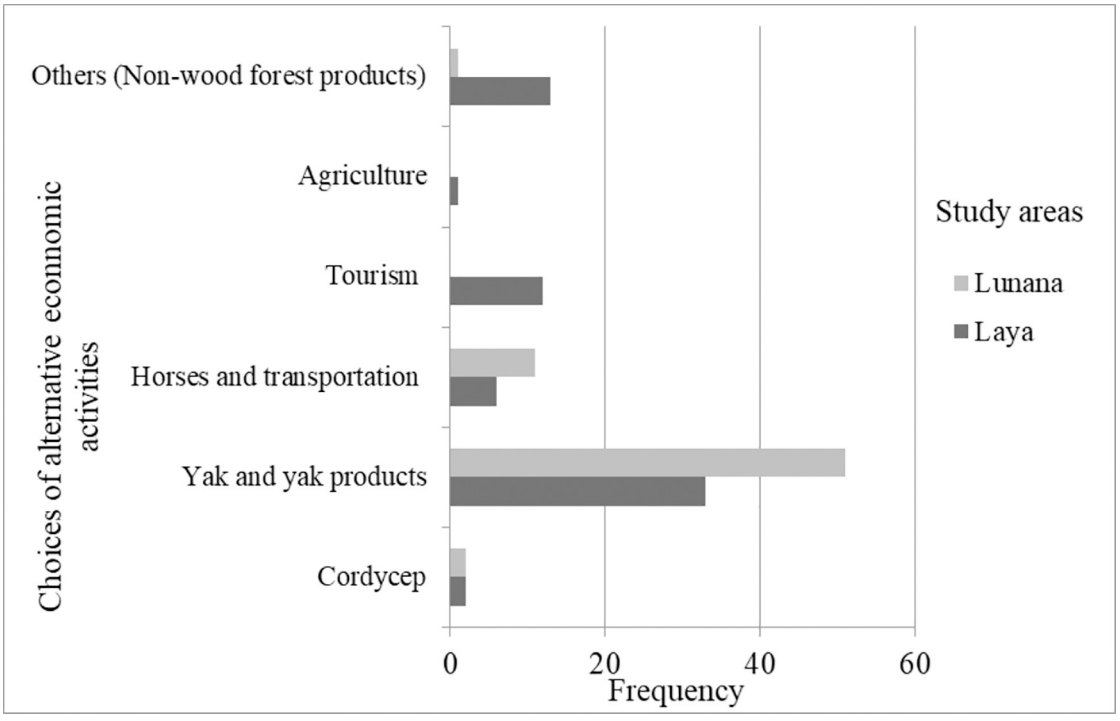

Fig 3.

https://doi.org/10.1371/journal.pclm.0000079.g003

"*I am not interested in taking up agricultural farming, tourism, and sales of nonwood forest products as alternative economic activities because of the distances from motorable roads and marketing challenges"*. The people of Laya are more likely to venture into tourism and nonwood forest products. The hope for caterpillar fungus dependences in the future was similar in both *geogs*. However, some expressed that the value of caterpillar fungus would remain high in the international market due to less harvest and high demand.

The chances of income diversity are higher in Laya than in Lunana, and both communities are looking for alternative economic ventures. The key informants from both communities mentioned that *"the collection of Yartsa Guenboob and legalization of business was not a historic practice until it was legalized in 2004"*. Before its legalization, livestock farming, mainly yaks, sheep, and horses, was only the main source of income, and very recently, the people of Laya have explored nonwood forest products in addition to caterpillar fungi such as *Pangpoe*, *Balusulu*, *Pudhi*, and other herbal herbs available in the mountain rangeland. One of the key informants from Laya claims that "*these were exported as raw materials for pharmaceutical productions or incense productions which are not common selling practices of Lunana people*". However, both the present and ex-local leaders mentioned that "*we do not have proper regulations in harvestings of these raw materials or the awareness and education of the rules are poorly disseminated by the concerned agencies resulting in decreasing of quantity drastically*".

Discussion

Our study noted that community people across the mountains have been experiencing longer warmer monsoons, melting of glaciers, erratic rainfall, decreasing amounts of precipitation, and changes in snowfall patterns, which is in concordance with the findings in the Tibetan Plateau [38]. People who have resided in communities for more than 10 years are more likely to better understand the reality of climate change and impact observations.

From the study, it is understood that climate change can hurt people living in mountain regions in terms of affecting their livelihood through less income generation from the sale of caterpillar fungus, fewer households taking on yak farming and the likelihood of the emergence of infectious diseases, which were also described by similar research in other mountainous regions in the world [9,12]. In our study areas, ever since the legalization and commercialization of caterpillar fungus harvest and sale in 2004, most households' income has shifted from traditional yak herding practices to caterpillar fungus collection. Secondly, the number of household-rearing yak decreased due to the poor economic value of yak because of stopping the yak slaughter for meat purposes. Further, the decrease in yak farming by more than 80% of the households are associated with changing tradition and culture of women engaging in yak farming and youths not interested in yak farming. However, because of climate change or the possibility of excessive harvesting over the years, the quality and yield of caterpillar fungi have been decreasing, resulting in uncertainty in income generation among highland communities. These uncertainties of income generation of livelihood for the highland communities may opt the people to return the yak farming practices. Similar situations of declining yield and quality were reported in caterpillar fungus income-dependent communities in China, India, and Nepal [4,39]. Some researchers have warned that the income from the sale of caterpillar fungus might no longer be sustainable in the future [17,18,40]. Furthermore, the record from the Department of Agriculture and Marketing Cooperative (DAMC), the agency that maintains the record of caterpillar fungus harvest and marketing in Bhutan, also suggests a decline in the quantity of *Cordyceps sinensis* harvested and sold over the years from 8,988 kg in 2007 to 540.25 kg in 2011, indicating that the caterpillar fungus yield has decreased

over the years, although the demand and prices increase every year from USD 6000/kg in 2008 to USD 24000/kg in 2012, with the highest of USD 37000/kg in 2017 [41].

Second, from our study, we understand that people living across mountain regions have been observing changes in the botanical composition of rangelands that threaten the grazing pasture for yaks [42]. The yak, which is the lifeline for highland communities, is also decreasing in productivity due to climate change, which requires detailed scientific studies.

Furthermore, from this study, we documented that the communities of Laya and Lunana have observed the emergence of insects/vectors such as mosquitoes that would result in the spread and transmission of vector-borne diseases. The evidence of emerging vectors in the highland was described previously and covered in mainstream media news [43,44]. The study also attempted to document the possible exact year that mosquitoes could have intruded into these communities for the first time. The people noticed mosquitoes from 2004–2005 in Laya and from 2016–2017 in Lunana. However, our study did not cover in-depth classification and identification of mosquitoes. People in the community are aware of mosquito-related diseases such as malaria and dengue, which will help in future disease surveillance. This vector is considered a threat to them, and people believe that the emergence of such new insects could be due to longer warmer summers and erratic rainfall due to climate change and other anthropogenic factors. This study also observed the climate change impact such as drying up of water sources that were linked with glacier collections, which required a detailed study.

Nevertheless, the study also found that resilience and climate change adaptation strategies were adopted by the community [45–47]. For instance, the community has been engaging in exploring diverse economic activities, such as the collection and sale of non-wood forest products, but the Department of Park and Forest Services needs to provide adequate education and awareness on sustainable management and collection of non-wood forest products. Tourism, both local and international, is believed to benefit the people through porter/pony transportation charges, the sale of local products, and renting a house for the tourist as a farmhouse, among others [48]. Building a proper market linkage for their yak products would also boost the traditional yak farming system [32,49,50]. Among economic activities as a choice for future mitigation against climate change, yak and yak products remain the topmost priority, which will help the government initiative development plan for the 12th Five years (2018–2023) and likely beyond the project period. The male population from the community is more likely to take up yak farming as an adaptation to climate change, and the current education level and occupation may not influence the mitigation of sustainable climate change and livelihood activities.

Conclusion

Our study explored the impact of climate change on livelihood and situational adaptation in highland communities in Bhutan. The study shows the various impacts observed by highlanders due to climate change ranging from increasing environmental temperature, changes in the botanical composition of rangelands, and the emergence of new insects/vectors. These impacts due to climate change have led to a decrease in the quantity of caterpillar harvest among highlanders, which have become their main sources of income since its 2004 legalization. Nevertheless, situational adaptation and coping strategies among highland communities to sustain their livelihood have occurred through diversification of income generation and aiming to return to their age-old yak farming. This study calls for developing a sustainable yak and yak farming-related project and strategies to overcome these challenges through multisector engagement to keep the highland culture vibrant and alive.

Supporting information

S1 Text. Questionarrie.
(DOC)

S1 Data. Survey data.
(XLS)

S2 Data. Freelisting data.
(XLS)

Acknowledgments

We thank the yak herders of Laya and Lunana for participating in the data collection, livestock officials of Gasa Dzongkhag for data collection, Dzongkhag Livestock Sector, and Geog administration of Laya and Lunana for their administrative support during the conduct of the study.

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