Climatic Change (2020) 162:1065–1079
https://doi.org/10.1007/s10584-020-02851-x

Traditional livelihoods under a changing climate: herder perceptions of climate change and its consequences in South Gobi, Mongolia

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Received: 26 May 2019 / Accepted: 26 August 2020 / Published online: 12 September 2020

Abstract
Climate change is affecting virtually all environments in the world today. The Central Asian mountains, where livestock herding is the main source of livelihood, are among the environments predicted to be most affected. In this paper, we use meteorological records and herder perceptions to improve the understanding of climate change and examine how different climate change scenarios will affect herder livelihoods in the Tost-Tosonbumba Nature Reserve of southern Mongolia. Herders with generation-long herding experience perceived that there had been changes in all eight meteorological variables examined in this study between 1995 and 2015, including winter temperature, summer temperature, summer precipitation, frequency of intense rain, frequency of drizzle rain, wind speed, number of windy days, and snow cover. Herder perceptions and meteorological data showed the same patterns for 3 of the 8 variables at $\alpha = 0.05$ and for 5 of the 8 variables at $\alpha = 0.10$. Herders also predicted that all 9 climate change scenarios presented would have negative impacts on their practices and livelihoods. Our work suggests that herder perceptions of climate change can provide important information on changes in the climate and insights on factors that put their livelihoods at risk.

Keywords Herder perception · Future practice · Impacts · Risk · Climate variables · Rangeland

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1 Introduction

There is strong evidence that the world's climate is changing (Stocker et al. 2013; Trenberth 2012). Studies report increasing temperatures, changes in patterns of precipitation, and a rise in the frequency of extreme climatic events across the globe (IPCC 2013; Trenberth 2011; UNEP 2018). However, in many parts of the world, it is unclear how humans will respond to these changes (Oliver-Smith 2012). This lack of knowledge hampers the development of locally relevant adaptations to climate change (Marin 2010).

In Central Asia, changes in climate are expected to have major impacts on the environment and the rangelands that people rely on for their livelihood (Angerer et al. 2008; Kjellstrom et al. 2009; Thornton et al. 2009). In Mongolia, the annual mean temperature is estimated to have increased by 2 °C since 1963 (Dagvadorj et al. 2014) and precipitation patterns have changed from gentle to heavy rains (Vandandorj et al. 2017). These changes have been shown to affect plant communities through changes in nutrient cycling and availability (Khishigbayar et al. 2015). Such shifts are also likely to have major impacts on economies and livelihoods given that one-third of the GDP in Mongolia comes from agriculture and livestock husbandry (Mahul and Skees 2007). A significant source of income in Mongolia is livestock herding, which depends on productive rangelands that in turn depend on favorable climatic conditions (Batjargal and Enkhjargal 2013). Another challenge for the grasslands of Mongolia is the increase in grazing pressure from a dramatic rise in livestock numbers which, together with climate change, impacts grassland quality (Hilker et al. 2014). Some studies suggest that over 70% of the Mongolian steppe is degraded (UNEP 2002).

Local perceptions of climate change are increasingly recognized as a valuable source of information to increase our understanding of environmental change (Green et al. 2010; Thornton and Scheer 2012; Bennett 2016). Marin (2010) found that local perceptions provided complementary information on climate change. Perceptions may provide important information about climate change at the local scale that may not be apparent in meteorological data and thus form an important complement to meteorological data (Marin 2010).

Considering the importance of local knowledge and perceptions of climate change, our objectives were to (1) improve the understanding of climate change in the context of local herder perceptions and (2) examine the views of herders in terms of their future practices and livelihoods under different climate change scenarios.

2 Method and study area

This study was conducted in the Tost *bag* (*bag* = the smallest administrative unit of Mongolia) in the South Gobi Province of southern Mongolia (43° N, 100° E) in 2016 and 2017. The entire Tost *bag* was designated as a local protected area in 2010 by the local government and as a nature reserve in 2016 by the Government of Mongolia. It forms a part of the south-eastern Gobi-Altai landscape and is mountainous with dry grassland steppes, with elevation ranging from 1450 to 2550 m. The area is dominated by grasses, mostly *Stipa* spp., and small shrubs and herbs such as *Caragana leucophloea, Allium polyrhizum, Ajania* spp., and *Artemisia* spp. (Fernandez-Gimenez and Swift 2003).

Traditionally, herders moved at least four times a year for seasonal pasture rotation (Schmidt 2006; Joly et al. 2013). However, herders move less frequently today with the majority moving two times per year (Bedunah and Schmidt 2004; Mijiddorj et al. 2018). The primary livelihood in Tost *bag* is livestock herding (Mijiddorj et al. 2018), and cashmere is the primary income source (Sheehy et al. 2010). In 2016, there were approximately 88 semi-nomadic herder families living in the Tost *bag* (Local statistic information 2016). According to the local statistical information from 2016, Tost *bag* herders kept 56,229 heads of livestock of which 50,201 were goats, 3461 sheep, 1499 camels, 900 horses, and 168 cattle, with 80 to 1200 heads of livestock per family (Local statistic information 2016).

2.1 Meteorological data

We obtained meteorological data of Gurvantes *soum* (*soum* = district and the second smallest administrative unit in Mongolia) located ca. 40 km east of the Tost *bag* for 1995 to 2015 from the National Meteorology Agency and the Environmental Monitoring Center in Ulaanbaatar, Mongolia. Specifically, we were provided with data on mean monthly temperature, mean monthly precipitation, frequency of intense rain events (defined by > 7.6 mm rain per hour), frequency of drizzle rain events (defined by < 2.5 mm per hour), mean monthly wind speed, and number of windy days per year (defined by average daily wind speed over > 15 m/s). We converted these variables to mean temperature in winter (December–February), mean temperature in summer (July–August), mean precipitation in summer (July–August), frequency of intense rain events, frequency of drizzle rain events, monthly mean wind speed, and number of windy days per year. Frequency of intense rain and drizzle rains was reported by number of events per year. In addition, we extracted snow cover data from MODIS (Terra Snow Cover 5 Min L2 Swath 500m, version 6). We then calculated the maximum percentage of snow cover for each year for the Gurvantes *soum* as our measure of snow cover.

We examined trends in all 8 meteorological variables: winter and summer temperature, summer precipitation, frequency of intense rains, frequency of drizzle rains, wind speed and number of windy days from 1995 to 2015, and snow cover data between 2001 and 2015 using Mann-Kendall tests (Hirsch and Slack 1984; Yue et al. 2002). The Mann-Kendall test is a non-parametric test for monotonic trends in time-series data (Hirsch and Slack 1984) and the tau-value is a measure of the ordinal association between two variables. Low tau-values (0) show a low association between two variables whereas high tau-values (1) show high association. All analyses were performed in the software R (R Core Team 2013).

2.2 Herder interviews

Semi-structured household interviews were held with 32 herders (21 men and 11 women) in the Tost *bag* in September and October in 2016, representing 36% of the total households. Using local government population data, we identified 48 herder families that had stayed in the region for more than 20 years. Nine of these families were excluded because of very advanced age of the potential respondents. Five interviews could not be completed and we were not able to locate two families. The remaining 32 households all agreed to be interviewed.

Before proceeding with the interview, we explained the aims of the research to the interviewees and informed them that they did not have to answer all or any questions and that they could stop the interview at any time. All herders approached consented to be interviewed by both oral and written consent. All interviewees answered all the questions. Interviewee names were kept confidential. We carried out three interviews per day on average, and each interview generally lasted 2–3 h.

The interview included discussions on their lifestyle and perception of weather and pasture conditions during the period from 1995 to 2015. We covered three main topics: (1) general characteristics of interviewees including age, type and total number of livestock owned, family size, and how long they had been herding in the study area; (2) perceptions of changes in 8 climatic variables from 1995 to 2015 (winter temperature, summer temperature, summer precipitation, frequency of intense rain events, frequency of drizzle rain events, monthly mean wind speed, number of windy days, and snow cover) and additional 6 variables relating to climate and pasture conditions (length of winter and summer, areas of rain coverage, dry period, pasture quality, pasture yield/biomass, plant composition); (3) how local environmental, economic, and social changes were affecting the rangelands, livestock health (disease trends and outbreaks), and livestock yields (such as cashmere, wool, meat, and dairy products).

For each question, we reminded the interviewees to focus on changes from 1995 to 2015. We did not use the term "climate change" during our interview. Instead, we expressed the questions in relation to "environmental change" to avoid limiting their responses to potential changes in temperature only.

2.3 Group discussion

We held one group discussion with 10 herders from Tost-Tosonbumba Nature Reserve (8 men and 2 women) in June 2017. All participants were over 55 years old and had herded livestock in the study area for at least 20 years. Discussion focused on how future herding practices are likely to change in relation to perceived and predicted environmental changes. We presented the herders with a set of 9 scenarios, 4 of which were based on predicted scenarios from literature (Sato et al. 2007; Angerer et al. 2008, and Goulden et al. 2016) and 5 scenarios were based on the herder perceptions of climate change that emerged from the individual interviews. The group discussed how they would respond to the different scenarios and the likely impact on their herding practices and livelihoods. Scenarios included events such as drought and *dzud* where *dzud* was defined as livestock mass mortality caused by starvation or exposure related to extreme winter events such as extremely low temperatures or deep snow (Morinaga et al. 2003; Fernandez-Gimenez et al. 2012; Rao et al. 2015) predicted to increase in frequency and intensity with climate change (Houghton et al. 2001; Mayer 2015).

In our study, each scenario was scored as having (+ 2) large positive effect on their pastoral practices and livelihoods, (+ 1) positive effect on their pastoral practices and livelihoods, (0) no effect on their pastoral practices and livelihoods, (− 1) negative effect on their pastoral practices and livelihoods, and (− 2) large negative effect on their pastoral practices and livelihoods. Participants were asked to identify key events and changes that had affected the community most and asked to rank the impacts of these events based on their experiences.

3 Results

3.1 Trends in meteorological data from 1995 to 2015

The mean annual temperature in Gurvantes over the period 1995–2015 was 5.4 °C (SE = 0.13). The coldest month was January with a mean temperature of − 13.2 °C (SE = 0.63). The mean winter temperature (December–February) was − 10.8 °C (SE = 0.39). There was no evidence of change in the mean winter temperature in 1995 to 2015 (Fig. 1, tau = − 0.105, P =

0.526). The mean winter temperature did fluctuate from year to year, with the lowest winter temperature of − 15.5 °C (SE = 1.1) occurring in 2005 and the warmest winter temperature of − 9.1 °C (SE = 30) occurring in 2007 (Fig. 1a). The mean summer (June–August) temperature from 1995 to 2015 was 20.6 °C (SE = 0.23). There was no evidence of an increasing or decreasing trend in mean summer temperatures between 1995 and 2015 (tau = 0.056, P = 0.735). The mean summer temperature varied somewhat between years with the warmest summer temperature recorded in 2002 (+ 22.5 °C, SE = 0.75) and the lowest summer temperature recorded in 2003 (+ 19.4 °C, SE = 0.56) (Fig. 1b).

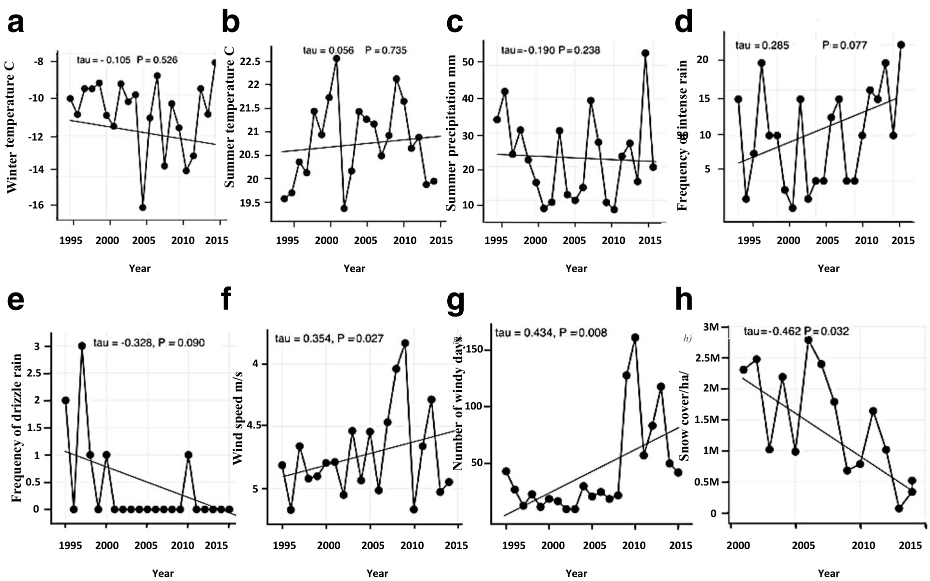

Fig. 1 Meteorological data in 1995 to 2015. **a** Mean winter temperature. **b** Summer temperature. **c** Summer precipitation. **d** Frequency of intense rain. **e** Frequency of drizzle rain. **f** Wind speed. **g** Number of windy days. **h** Snow cover index

The mean precipitation in summer (June–August) was 67.5 mm (SE = 7.69) per year. There was no evidence of an increasing or decreasing trend in mean rainfall in summer between 1995 and 2015 (tau = − 0.19, P = 0.238). There was, however, a big difference between the largest amount of summer rainfall in summer in 2014 (161 mm) and the smallest amount of summer rainfall in 2001 (22.9 mm) (Fig. 1c). There was a trend for an increase in the frequency of intense rains between 1995 and 2015 although this was significant only at $\alpha = 0.10$ (tau = 0.285, P = 0.077). A total of 196 intense rain events occurred between 1995 and 2015 with a mean of 9.3 (SE = 1.08) intense rains per year. Similarly, there was a trend for a decrease in the frequency of drizzle rains between 1995 and 2015 although this was also significant only at $\alpha = 0.10$ (tau = − 0.328, P = 0.090). Drizzle and gentle rains occurred only 8 times between 1995 and 2015 (Fig. 1e) and with a mean of 1.3 (SE = 0.21).

The mean annual wind speed increased over the period 1995–2015 (tau = 0.354, P = 0.027*). Furthermore, the mean annual wind speed fluctuated little from year to year with the minimum mean wind speed of 3.8 m/s (SE = 0.24) occurring in 1997 and the maximum mean annual wind speed of 5.2 m/s (SE = 0.29) occurring in 2010. In 1995, 1998, and 1999, the maximum wind speed reached 34 m/s, which was the strongest wind recorded during the study period (Fig. 1f). The number of windy days also increased between 1995 and 2015 (tau = 0.434, P = 0.008*; Fig. 1g). The year 2010 recorded the maximum number of windy days (n = 160). The mean snow cover index decreased between 2001 and 2015 (tau = − 0.462, P = 0.033*). The lowest snow cover index (2.5%) occurred in 2013 and the highest snow cover index (99.5%) occurred in 2006 (Fig. 1h).

3.2 Herder characteristics

All interviewed herders (n = 32) reported that they had lived in the area their entire lives and considered themselves permanent residents of the area. The age ranges of the interviewees who participated in the household interviews were 45 to 78 years old (mean = 57.6; SD = 10.5). The main livelihood source of all interviewees was livestock production. The mean livestock holding was 320 heads (SE = 58) per household. The overall livestock holdings consisted of 88% goats (n = 6743), 8% sheep (n = 627), 2% camels (n = 162), and 2% horses (n = 151). All interviewees reported that they received information about climate-related matters through the local television channel. In terms of education, the majority of interviewees (n = 30, 94%) graduated 4th grade and the remaining finished 8th grade (n = 2, 6%).

3.3 Herder perceptions of climatic variables

Herders generally agreed that there had been an overall change in all 8 climatic variables from 1995 to 2015. Most of the herders (93.7%, n = 30) thought that the winters were getting warmer and 78.0% (n = 25) reported that the summers were getting colder with some fluctuations. Similarly, 93.8% (n = 30) of the herders reported that the length of both the winter and the summer had decreased, with increase in the durations of spring and fall (Table 1). Some herders (n = 16, 50%) also reported that winter temperatures were now more variable and, for example, that extremely cold days would occur more frequently. One interviewee (age 68 years) said, "Nowadays, we are experiencing such awkward seasonal shifts. Earlier we used to have signs (light frost in the morning) to move to wintering camp. Now there are no such signs to move and prepare for winter. Winter temperature drop is not gradual as it was before. There are lots of fluctuations. I feel that the spring is prolonged with harsh windy days continuing for a long time. I did not feel summer warmth.

Table 1 Herder perceptions of changes in eight climatic variables from 1995 to 2015 in Tost-Tosonbumba Nature Reserve, Gurvantes Soum, South Gobi, Mongolia

Climatic variables	Increased %	Decreased %	No change %	Do not know %	No trend but high fluctuations %
Winter temperature	93.8	0.0	3.1	3.1	0.0
Summer temperature	9.4	78.1	3.1	3.1	6.3
Summer precipitation	3.1	87.5	0.0	3.1	6.3
Frequency of intense rains	84.4	0.0	12.5	3.1	0.0
Frequency of drizzle rains	0.0	84.4	12.5	3.1	0.0
Wind speed	78.1	9.4	6.3	6.3	0.0
Number of windy days	78.1	9.4	6.3	6.3	0.0
Snow cover	3.1	78.1	3.1	0.0	15.6

Total number of households: $n = 32$

Suddenly, very unpleasant hot days appear. All seasonal routines are distorted and it is hard to predict the weather" (Tost-Tosonbumba Nature Reserve herder, 68 years old).

Summer precipitation ($n = 28$, 87.5%) and snow cover ($n = 25$, 78.1%) were reported to have decreased, which herder believed that it leads to decreased soil moisture and shrinking river beds. On the other hand, 78.1% ($n = 27$) of the interviewees suggested that the intensity of rains had increased and the frequency of drizzle rains had decreased. Similarly, 78.1% (25) of the interviewees reported that the number of windy days had increased and that the winds had become stronger, especially during the dry period in spring (Table 1). Herders suggested that there was strong evidence of changes in more than eight climatic variables. A comparison of herder perceptions and meteorological data is provided in (Table 2).

3.4 Herder perceptions of climatic and pasture conditions

Most (93.8%) herders reported that winters were starting later and more abruptly, whereas summer temperatures were generally cooler with prolonged windy days along with a few extremely hot days. The herders reported a change in the timing of moving to their wintering camps. They reported (99% of respondents) that it used have be early winter cold signs for moving to winter camps such as mild

Table 2 Comparison of patterns of change in eight climate variables based on herder perceptions and meteorological data from 1995 to 2015 (except for snow cover where the comparison of patterns of change was made from 2001 to 2015 due to availability of data)

Variables	Local knowledge	Meteorological data	Slope	Measurement
Winter temperatures	Declining (93.7%)	No change ($P = 0.526$)	− 0.105	Degree Celsius
Summer temperatures	Declining (78.1%)	No change ($P = 0.753$)	0.056	Degree Celsius
Summer rainfall	Declining (87.5%)	No change ($P = 0.238$)	− 0.190	Millimeter
Frequency of intense rains	Increasing (78.1%)	Trend for increase ($P = 0.077$)	0.285	Number of occurrence
Frequency of drizzle rains	Declining (78.1%)	Trend for decline ($P = 0.090$)	− 0.328	Number of occurrence
Wind speed	Increasing (79.2%)	Increasing ($P = 0.027$*)	0.354	Meter/second
Windy days	Increasing (78.1%)	Increasing ($P = 0.008$*)	0.434	Number of occurrence
Snow cover	Declining (78.1%)	Declining ($P = 0.032$*)	− 0.462	Percent coverage

Total number of households: $n = 32$

frost in the morning and evening. Now, there is no sign while it was warmer; sudden abrupt cold appears.

Thirty respondents (93.8%) reported that the areas receiving rainfall in Tost-Tosonbumba Nature Reserve had decreased. The patchy rains forced them to converge in the few areas receiving rainfall, leading to grazing conflicts among herders. Twenty-nine herders (90.6%) reported that the prevalence of prolonged dry periods, relatively less rain, and increase in the number of windy days had caused a reduction in grass cover and production over the years (Table 3). A majority of herders (90%) reported a decrease in water resources, intensified further by human activities such as mining and development in the area. In addition, thirty herders (93.8%) reported that due to shift in the onset of spring rains and an increase in the intensity of rains, pasture quality decreased, and soil properties and fertility declined. Eighteen (56.3%) herders reported that heavy, intense rains decreased rangeland plant diversity, whereas 13 (40.6%) reported a shift in abundance of plant forms with a decline in palatable herbaceous species and increase in unpalatable species.

Twenty-five (78%) interviewees expressed that the decline in summer temperature may negatively influence vegetation growth. A 52-year-old interviewee said "Summer is crucial time for livestock to graze more to fatten up. Dull summers makes conditions worse by delaying grass growth and growth of the grass not being completed."

The majority of herders ($n = 27$, 84.4%) suggested that pasture yield/biomass was diminishing due to insufficient rains (amount and rain pattern) with intense prolonged wind. A 65-year-old interviewee reported "We regularly monitor the weather because pasture is directly dependent on the onset of rain, and its amount and distribution patterns. If rains occur at the right time, in the right amount, and are properly distributed, our pastures are rich enough to sustain any number of livestock. But in the recent few decades everything has changed in reverse ways."

Both the individual interviews (78.1%) and the group discussion suggested that strong reductions in the snow cover had strong negative impacts on livelihoods as snow was an important source of water for herder families and livestock in winter.

3.5 Herder responses to future climate change scenarios

In a group discussion, the herders suggested that 6 of the 9 climate change scenarios presented to them would have strong negative impacts on pastures and their livelihoods (Table 4). The scenarios related to changes in the onset and pattern of rain and extreme climatic events (*dzud* and drought) were expected to have the strongest impact. During the discussions, the word *dzud* was frequently used. The *Soum* and *Bag* governors reported that after *dzud* and drought events, many herders

Table 3 Herder perceptions to changes of six variables related to climate and pasture conditions from 1995 to 2015

Climatic variables	Increased %	Decreased %	No change %	Do not know %	No trend but high fluctuations %
Length of winter and summer	0.0	*93.8*	3.1	3.1	0.0
Areas of rain coverage	0.0	*93.8*	0.0	3.1	3.1
Length of dry period	*90.6*	0.0	0.0	3.1	6.3
Pasture quality	0.0	*93.8*	3.1	0.0	3.1
Pasture yield/biomass	0.0	*84.4*	3.1	3.1	9.4
Plants composition	0.0	*56.3*	0.0	3.1	40.6

Total number of households: $n = 32$

Table 4 Herder responses to how they predicted that nine different climate change scenarios would impact their practices and livelihoods

Number	Scenarios	Scores	Herder practices	Impact on herding condition and livelihood
1	Increase in rain intensity (Sato et al. 2007)	− 2	Delayed movement to summer camp	Increased competition and conflict for access to summer pastures, reduced yield of meat and lower price
2	Change in pasture composition (Angerer et al. 2008)	− 2	Changes pasture and campsite	More time spend searching for good pastures, increased competition for pasture use
3	Less rain in summer (Goulden et al. 2016 and herder perception)	− 2	Increased movement in search of better pasture	Reduced livestock yields and health, increased pasture competition
4	Increase in dzud and droughts (IPCC 2007; Houghton et al. 2001; Mayer 2015)	− 2	Change to more weather resilient breeds	Reduced income as the cashmere of weather resilient breeds may sell at lower price
			Finding alternative jobs, may stop herding	Alternative jobs often less predictable and lower paid.
5	Delay in the onset of rains (herder perception)	− 2	Delayed cashmere harvest (combing)	Reduced cashmere quality and income
6	Increase in winter temperature fluctuations (herder perception)	− 1	Changed herd composition, keep animal barren for better survival through the winter	Reduced dairy production
7	Reduction in summer temperature (herder perception)	− 1	Cold temperature negatively affects pasture quality. Need to graze larger areas. Cannot milk livestock two times a day.	Reduced quality and yield of livestock, reduced milk yield
8	Reduction in snow cover (herder perception)	− 2	Seek alternative winter camps for reliable for water source	Increased competition for water sources
9	Increase in intensity and number of windy days (herder perception)	− 1	Increased duration of time in camp, less time for livestock to graze, increased need to purchase fodder	Increased cost of fodder, reduced livestock quality and yield.

*Scenario scores represent the following: (+ 2) large positive effect, (+ 1) positive effect, (0) no effect, (− 1) negative effect, (− 2) large negative effect tended to give up livestock herding and move to the *soum* center, which, in turn, resulted in increasing rural poverty and urban unemployment. Our interviewees also reported ($n = 11$, 32.3%) that if the frequency of *dzud* and drought increased, they would seek other jobs and move to urban areas (Table 4).

The most common response in 5 of the 9 scenarios was an expected increase in herder movement, leading to increased pasture competition. The most commonly expected impact on herder livelihoods in 5 of the 9 scenarios was the reduction in the yield and condition of livestock products such as cashmere. Based on the scenario of irregular rainfall patterns, herders reported they would increasingly cluster in smaller areas to graze livestock, which in turn would result in competition for pastures.

4 Discussion

Monitoring and understanding the impacts of climate change is increasingly important as virtually all environments in the world are affected by it (Walther et al. 2002). In this study, we found that herders perceived significant changes in the local weather patterns during the last 20 years. Herders also thought that all climate change scenarios presented would have negative impacts on their practices and livelihoods.

4.1 Herder perceptions of climate change

Herders in our study perceived that the climate in their region has changed considerably in the last 20 years. This was supported by the meteorological data showing the same patterns for 3 of 8 variables (increasing wind speed, increasing number of windy days, and decreasing snow cover) at $\alpha = 0.05$ and for an additional 2 variables (increase in intense rains and decrease in drizzle rains) at $\alpha = 0.10$. The overall correlation between herder perceptions and the meteorological data was thus high. Local peoples' perceptions are being increasingly recognized as a valuable source of information on climate change (Green et al. 2010; Thornton and Scheer 2012; Bennett 2016). One explanation for the differences in herder perceptions and the meteorological data that we recorded might be that the herders are more likely to monitor variables linked closely to their livelihoods (Marin 2010; Goulden et al. 2016; Galloway-McLean 2017). Moreover, pasture quality and livestock health are affected by abiotic variables, such as climate change, and biotic variables such as grazing pressure (Hilker et al. 2014). Livestock numbers in Mongolia have increased from about 25 million in the early 1990s to over 55 million in 2015 (Mongolian Statistical Information Service 2020). Similarly, the number of livestock in the Tost bag increased from 36,000 in 1995 to 61,000 heads in 2015 (Local Statistic Information 2016). It is thus possible that some of the changes that herders attributed to climate change may also be influenced by the increasing livestock numbers (Hilker et al. 2014).

Both the meteorological data and the herder perceptions suggested that the snow cover in Tost Mountains has decreased, wind speed and number of windy days have increased, the frequency of intense rains has increased, and drizzle rains have decreased during the last two decades. Decreasing snow cover has been reported in other parts of Central Asia such as the Tibetan Plateau where it appears to be driven more by limited snowfall than by increasing temperatures (Han et al. 2014; Wang et al. 2015). In Tost, water for livestock was valued as one of the most important ecosystem services (Murali 2019). Our study further supported this and snow was described as being particularly important for livestock drinking water at herder wintering camps. If there is no snow available, many families are not able to use their wintering campsite and must search for an alternative location.

Herders in our study also described snow as being very important for wild ungulate drinking water. For example, in the winter of 2014–2015, mass die-offs of ibex (*Capra sibirica*) were reported in Tost, likely because there was very little snow that year (personal observation), a phenomenon locally called black *dzud* (Begzsuren et al. 2004). The frequency of *dzud* and drought events are predicted to increase in particular areas of Mongolia, with black *dzud* predicted to occur more often in the Gobi region (Angerer et al. 2008). Droughts and *dzud* events are known to be a cause of serious hardship for local herders, forcing them to change their livelihood strategies and shift their main income sources (Rao et al. 2015).

An increase in wind speed and the number of windy days in Tost Mountains is similar to increasing winds and sand storms in other parts of southern Mongolia and the nearby province of Gansu in northern China (Yan et al. 2006; Marin 2010). Similarly, increasing wind speed and the number of windy days are reported in other parts of the world like Northwestern Europe (Yan et al. 2006). Increasing winds and number of windy days dry out the soils and may thus reduce grassland quality and result in desertification (Natsagdorj et al. 2003). Herders in our study suggested that dryness (water diminishing) and strong, lengthy winds are further amplified by human-induced changes such as open cast mining and large-scale development. As reported in other studies, these factors together with excessive livestock grazing are likely contributing to the regions' desertification and change in vegetation cover (Wu et al. 2009; Xu et al. 2013).

Other studies in Mongolia have shown an increased frequency of intense rain and decrease in drizzle rain (Goulden et al. 2016), seasonal temperature change (Marin 2010), and increasing dry and drought events (Galloway-McLean 2017). Changes in precipitation patterns and intensity would directly affect the soil moisture and the vegetation (Yamanaka et al. 2007). For example, there may be high runoff of water during intense rains and flash floods, and inadequate water absorption by the soil. This may have a negative effect on the rangelands even if the overall amount of annual rain remains the same. Changes and variation in rainfall patterns were described by the herders in our study with delays in rains leading to a low productivity of pastures. Such reductions of pasture quality, in turn, will result in a reduction of herder livelihoods in an area where livestock grazing is a crucial ecosystem service (Murali 2019). Moreover, irregular rain events were reported by the herders to result in increasing competition between neighboring families as they search for suitable areas to graze their livestock. Similar competition for rangelands as a result of variability in the rainfall has been reported in Zimbabwe and Eastern Africa (Scoones 1992; Hailegiorgis et al. 2010). Such changes in rain patterns and availability of forage may lead to amplified degradation of the rangelands (Galloway-McLean 2017).

Herders also perceived that winter temperatures had decreased, summer temperatures had increased, and that the rainfall in summer had decreased. Winters starting earlier and summers getting longer have been reported by local people in other Asian regions such as northeastern Siberia (Crate et al. 2008), and this phenomenon is referred to as seasonal shift (Duzheng et al. 2003; Burrows et al. 2011). Such unpredictable seasonal shifts make herders more challenging to move timely between one place to another. Changes in these factors were also reported to further promote pasture degradation.

Our study suggests that herder perceptions can provide important information on climate change, especially in terms of how the observed patterns negatively influence herder livelihoods. It should be recognized, however, that perceptions can be influenced more strongly by recent experiences (Deese and Kaufman 1957; Murdoch 1962). For example, perceptions may be shaped by timing of the interview in relation to major climatic events, such as *dzuds*. The last *dzud* in Mongolia took place in 2010 (Middleton et al. 2015) and may have influenced herder perceptions about climate change events. In this study, the meteorological variables were compiled as annual and seasonal means, which may lead to a loss of finer details (Marin 2010). Finally, fostering dialog with communities around their interpretation of meteorological data and climatic events is important to strengthen the understanding of the local settings and possible impacts on their livelihoods.

4.2 Herder responses to future climate change scenarios

The herders in our study predicted that all climate change scenarios presented would have negative impacts on their practices and livelihoods. Negative impacts of climate change on herder practices and livelihoods are already observed in some parts of Mongolia (Mayer 2015; Tachiiri et al. 2017; Mijiddorj et al. 2019). For example, herders in our study said that a delayed onset of spring rains has resulted in a delay in the time when they can comb their goats for cashmere, which in turn affects the quality and the price of the product (Krumm and Kharas 2004). Since cashmere is the main source of livelihood for herders in the South Gobi (Lecraw et al. 2005), herders generally give strong emphasis on factors affecting cashmere-related matters (Morris-Trainor 2019). The potential impacts of climate change on herder livelihoods are further exemplified by even relatively small changes and variations in meteorological patterns that can have relatively large impacts on animals and their performance (Elton 1924), which can become costly on herder livelihoods. In addition, a recent study reported that herders in the Tost Mountains would diversify their livelihoods with other sources such as illegal mining of gold and valued gemstones if *dzuds* and droughts were to occur more frequently (Mijiddorj et al. 2019). Herders also mentioned that they would move to more urbanized areas seeking alternative livelihoods or opportunities if the environment continued to change. A similar pattern has been seen in other areas too (Sternberg 2010; Erdenebileg 2018).

Understanding how communities respond to climate change is crucial as this provides a foundation for future mitigation measures (Flint and Luloff 2005). Our research can assist government agencies and decision-makers to prepare and adapt to climate change emergencies. Although we do not know the exact nature of future climate change scenarios, especially when considering the fact that the impacts will vary between regions (IPCC. Climate Change 2001; Boko et al. 2007), our research suggests that it will have strong negative impacts on herder practices and livelihoods in the Tost-Tosonbumba Nature Reserve and surrounding areas in southern Mongolia.

5 Conclusion

Herders in the Tost-Tosonbumba Nature Reserve perceived that there have been significant changes in the climate in their region during the last 20 years, and they expected that future climate change scenarios would have dramatic impacts on their practices and livelihoods. The perceptions of local people regarding the changing climate, and on the impacts of climate change on their livelihoods, can provide important information for management and governance at the local level (Manandhar et al. 2015). Local predictions of future responses to different climate change scenarios may also help to develop sustainable and adaptive interventions that will be received better by local people.

Acknowledgments The authors gratefully acknowledge the Tost herders for their time, kindness, and cooperation in this study.

Funding This study is supported by the Wildlife Conservation Network "Sydney Byers Scholarship" and Partnership Funding by Foundation Segre managed by Whitley Fund for Nature.

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