DRIVERS OF DAURIAN PIKA (*OCHOTONA DAURICA*) OCCUPANCY AND ABUNDANCE IN THE DARHAD VALLEY, MONGOLIA

A Thesis

Presented to

The Faculty of the Environmental Science Program

The Colorado College

In Partial Fulfillment of the Requirements for the Degree

Bachelor of Arts in Environmental Science

By

Gila Goodwin

April 2023

Dr. Charlotte Gabrielsen

Assistant Professor of Environmental Science, Colorado College

Chris Smith

Lecturer I, University of Nevada, Reno at Lake Tahoe

TABLE OF CONTENTS

ABSTRACT

The Daurian pika (*Ochotona daurica)* is a burrowing, steppe-dwelling species native to the central Asian steppe and is a keystone species in many grassland ecosystems. Their presence has been shown to increase plant productivity, increase species biodiversity, and aid in the aeration and recycling of soils in the vicinity of burrow systems. Grassland ecosystems are threatened globally by the impacts of a changing climate, livestock overstocking, and agricultural production, all of which have the potential to negatively impact Daurian pika populations. This research examines Daurian pika occupancy and abundance throughout the Darhad Valley in relation to environmental factors associated with ideal Daurian pika habitat. Eighty-five plots were established across the Darhad Valley, Mongolia in which grass height, forb cover, grazing intensity, soil composition, weather, and geographical location were analyzed in relation to Daurian pika occupancy and abundance. It was found that Daurian pika occupancy and abundance was unequally distributed across the Darhad Valley, with large regional extirpations occurring across the valley according to region. Thus, we determined that region was the most important predictor of Daurian pika occupancy and abundance, informed by regional variation in soil moisture mediated by soil type, precipitation, and temperature. Furthermore, we found that Daurian pika are susceptible to flooding events, created by the combination of soil type, geographic location, land use, oscillations between sub-zero and above-freezing temperatures during the early spring, and precipitation events in adjacent montane regions which have the potential to result in the melting of snowpack and subsequent flooding throughout the low elevation valley floor. Variables previously correlated with pika survival in 2019 were found to have limited importance in determining distribution patterns amidst stochastic events. A changing climate, in combination with habitat degradation and increased grazing pressures, has

the potential to contribute to long-term declines in Daurian pika populations which would have cascading detrimental effects on biodiversity levels, soil quality, and ecological resiliency of steppe ecosystems. Thus, understanding which variables might help buffer local extinctions is critical to support ecological resiliency throughout the Darhad Valley and similar Mongolian steppe ecosystems, particularly in light of a changing climate.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my greatest appreciation to my advisors Dr. Charlotte Gabrielsen, Chris Smith, and Dr. Badamgarav Dovchin for their invaluable mentorship, advise, and support throughout this project. They have guided me through the scientific world and have fostered my creativity, critical thinking, and love for science that I will carry with me for the rest of my life. I will be eternally grateful for their encouragement, enthusiasm, time, and passion towards research, education, and mentorship.

I would also like to thank those involved with the GIS Lab and the Environmental Program at Colorado College, particularly Matt Cooney and Josh Birndorf, and my advisor Eric Perramond for their support and advice throughout this project. My appreciation also extends to all those involved in data collection, including the Summer 2022 Mongolia Round River Conservation cohort, Battogtokh Tumur, Batzaya Erdenebat, Chinbolt Byambjaw, and Bog Tserenjargal. Their enthusiasm in exhausting field conditions and encouragement throughout the research process were integral to this project. Turmursukh Jahlr, Director of Ulaan Taiga Strictly Protected Areas Administration, and the rangers and natural resources staff of the Ulaan Taiga Strictly Protected Areas were central in introducing us to the region and making our field work possible.

Furthermore, I would like to thank Round River Conservation Studies and the Ulaan Taiga Strictly Protected Area for their generous support of this study. Finally, I would like to extend my gratitude to my parents, friends, roommates, and wonderful humans who have supported and cared for me during this time. This project would not have been possible without their encouragement and support!

INTRODUCTION

Grasslands are one of the major ecosystems worldwide and are recognized globally for their high biodiversity. However, grassland ecosystems are highly vulnerable to climatic and anthropogenic change. In some regions, ecosystem engineers play a disproportionately large role is sustaining grassland ecosystems. Ecosystem engineers modify their habitat according to resource availability, ultimately influencing plant and animal community composition and diversity (Jones et al., 1994;Wright & Jones, 2006). Ecosystem engineers alter the availability of resources to other species on multiple spatial and temporal scales by actively modifying, maintaining, and creating habitats (Jones et al., 1994; Wright and Jones, 2006). Specifically, in the temperate steppe ecosystem of Central Asia, pika and other small mammals have been shown to alter biodiversity levels throughout their habitat as they augment soil composition, support grassland health, and act as major prey base for raptors and other common predators (Smith and Foggin, 1999). Within the Darhad Valley of northern Mongolia (Figure 1), three species of pika exist, including the Alpine/Altai pika (*Ochotona alpine)*, Northern/Siberian pika *(Ochotona hyperborea)*, and the Daurian pika *(Ochotona daurica)*, which is the focus of this study (Lissovsky, 2014).

The Daurian pika (*Ochotona daurica)* is a burrowing, semi-desert, steppe-dwelling species that is native to areas of Russia, China, and Mongolia, and is known to fulfill a critical ecosystem role in maintaining steppe biodiversity and grassland health (Komonen, 2003; Smith et al., 1990). As an ecosystem engineer, Daurian pika have been shown to increase local primary plant productivity, increase plant species richness, and aid in the aeration and recycling of soils in the vicinity of burrow systems (Komonen, 2003; Smith et al., 1990; Jones et al., 1994; G. Wang et al., 1999). Given the variety of important ecosystem services that Daurian pika provide to the local ecosystem that they inhabit, they have been considered a keystone species in some areas, as their loss would have cascading detrimental effects on other species in the community (Smith and Foggin, 1999). Disturbance from their digging activity loosens and improves soil quality, and the accumulation of their excrement creates rich microhabitats surrounding burrow systems with high levels of nitrogen, calcium, and phosphorous in comparison to nearby areas without burrows (Smith and Foggin, 1999; Chapman & Flux, n.d.). Areas inhabited by pikas have also been shown to have a greater biomass of roots, taller plants, and increased density of plant cover near burrow systems (Smith and Foggin, 1999). In fact, certain steppe shrubs of the pea family (including *Caragana bungei* and *Caragana leucopheloea)* are only found in proximity to Daurian pika burrows (Travina et al., 2000). Furthermore, Daurian pika serve as a primary prey base for numerous predator species that occupy the Mongolian steppe, especially during the winter, as Daurian pika are one of few non- hibernating prey species (Smith et al., 1990; Singleton et al., 2003). For example, Daurian pika may comprise the majority of the diet of the steppe eagle (*Auquila nipalensis),* eagle owl (*Bubo bubo)*, saker falcon (*Falco chernug)*, and upland buzzard (*Buteo hemilasius)* (Smith et al., 1990). Larger predators such as wolves (*Canis lupus)*, brown bears (*Ursus arctos),* and snow leopards (*Panthera uncia)* may also depend on Daurian pika as a secondary food source when larger prey are unavailable. Accordingly, Daurian pika abundance influences overall biodiversity levels across steppe habitats (Smith and Foggin, 1999).

In Mongolia, Daurian pika habitat predominately corresponds with regions utilized by nomadic pastoralists to graze sheep, goats, cattle, yak, horses, and camel – activities that have been found to affect regional ecosystem-level dynamics. The Darhad Valley experiences harsh winters and is home to around 15,000 people, dispersed across small towns and nomadic settlements which allows nomadic herders to move camps multiple times a year to maintain healthily grazed pastures and seek shelter from harsh westerly winds (Moore et al. 2017; Nandintsetseg et al., 2007). The interaction between grazing pressure and Daurian pika population levels is of unique importance to Mongolian environmental conservation interests, the management of communal grazing land, and local herders who depend on grassland vitality. Overall, the social relationship of Mongolian peoples to pika is complex, ranging from a belief that pika are a pest species causing detriment to domesticated livestock and the Mongolian steppe to respect and reverence. Historically, the presence of pika has been met with concern largely owing to the belief that pika compete with domesticated livestock for forage. The perception of pikas as pests led to a variety of extermination programs throughout Asia, specifically in China and the Soviet Union prior to World War II (Smith and Foggin, 1999). Mongolia was not immune to such programs which had lasting, far-reaching consequences on areas exposed to poisoning (Smith et al., 1990). On the other hand, many Mongolians have high regard for pikas as they are considered to occupy a role that is beyond that of being strictly ecological. For example, local herders utilize observations of pika hay-piling behavior to predict winter weather intensity and value pikas as an indicator of grassland health (personal communication, 2022). During hard winters, livestock will often consume pika hay piles if food sources are scarce which garners pika much respect from local herders. Although Daurian pika elicit varied social perceptions, they provide a range of ecosystem services that are critical to grassland health (Smith and Foggin, 1999), and at least locally, their presence usually elicits positive responses and respect among herders (personal communication, 2022).

Mongolia maintains the world’s largest contiguous area of common grazing (126 million ha) which provides significant opportunities for collective management, delivers noteworthy ecological benefits, and grants an avenue through which the "needs of humans can be integrated in the application of conservation" (Seddon et al., 2014; Reading et al., 2006). That said, communal land management in Mongolia has experienced many challenges, the most recent being the transition to a free-market capitalist system that privatized herds in 1991 (Reading et al., 2006). This political shift led to substantial increases in the number of herders and livestock, resulting in overstocking and subsequent steppe degradation (Reading et al., 2006). Despite their importance to Mongolian steppe ecology, little research has been conducted on Daurian pika in relation to grassland ecology and their interaction with nomadic pastoralism. From the limited studies that exist, pika populations have been found to decline substantially in heavily grazed areas with limited grass cover due to limited forage availability or increased vulnerability to predation (Komonen et al., 2003); Heny et al., 2019). Further degradation due to increased numbers of herders and livestock is predicted to continue without conservation measures to mitigate the impacts of overstocking, climate change, and resource extraction, all of which in turn will undoubtedly have consequences on the health of Daurian pika populations.

Given the harsh winter weather patterns observed throughout Daurian pika's range, the species has developed several behavioral and physiological adaptations that support survival (Weiner and Górecki, 1981). Daurian pika exhibit interesting combinations of metabolic characteristics that are shared by desert animals. Given the cold climate of Mongolia, they express traits associated with arctic and alpine environments (Weiner and Górecki, 1981). Due to the unique climate that they inhabit, Daurian pika exhibit an increased basal metabolic rate, a relatively low critical temperature, and a broad thermoneutral zone which supports their survival in harsh conditions with relatively minimal precipitation and cold temperatures (Weiner and Górecki, 1981). In a lab setting, Daurian pika's range of optimal survival during winter months was found to be -10 to 17 °C, but were able to tolerate temperatures as low as -45 °C for up to six hours (Borisova et al., 2020). In addition to being well adapted to the Mongolian steppe, Daurian pikas significantly expand the range of temperatures in which they can survive and reproduce by creating burrow systems (Borisova et al., 2020).

Although well-adapted to cold temperatures, the highest natural mortality of Daurian pika occurs throughout the winter. Excluding instances related to catastrophic disturbances such as extreme weather events, high winter mortality rates may result from insufficient forage availability, thin snowpacks, low temperatures, and the formation of hard crusts within the snowpack (Borisova et al., 2020). Thin snowpacks do not provide adequate insulation for Daurian pika when temperatures exceed the species' survivable temperature range. Although a deeper snowpack provides insulation, the ability for the species to move under the snow decreases, and burrows are subject to flooding as the snow melts. While Daurian pika are subject to large population fluctuations through high winter mortality, they are also known to have high rates of reproduction, being able to give birth to up to five litters over the course of one summer, especially during wet summers when vegetation biomass is high (personal communication, 2022; Smith & Foggin, 1999; Zhang et al., 2003). The high fertility rates and behavioral adaptations to cold weather conditions observed in Daurian pika populations support high reproduction rates despite extreme conditions — a characteristic of the species which is critical for continued population growth throughout Mongolia. That said, climate scientists have anticipated that due to their physiological adaptations to cold, Daurian pika will be particularly sensitive to climate change which is predicted to lower the suitability of their current habitats, as well as increase the risk of habitat fragmentation (Borisova et al., 2020). Furthermore, the Darhad Valley is on the southernmost edge of the Siberian permafrost where it has been predicted that some of the most rapid shifts associated with climate change are likely to occur (IPCC, 2022).

Objectives

This study seeks to (1) assess how livestock grazing intensity, vegetation cover and height, soil composition, weather, and topographical variables affect Daurian pika occupancy and density across the Darhad Valley and (2) assess the ecological benefits associated with Daurian pika by characterizing soil composition in the vicinity of active burrow systems. Starting in the fall of 2019, Round River Conservation Studies and the Ulaan Taiga Strictly Protected Area Administration began data collection on Daurian pika populations throughout the Darhad valley, examining pika occupancy, abundance, and a variety of topographical, soil, and grazing intensity variables in relation to pika burrow systems. Continuing with the methods established in 2019, this study seeks to provide insights that can be used to inform the Ulaan Taiga Strictly Protected Area Administration and the local community on grazing management decisions in relation to Daurian pika populations.

METHODS

Study Area

This study was conducted across the grazed steppe of the Darhad Valley located in the Hovsgol province of Northern Mongolia (Figure 1). The Darhad Valley is surrounded by the Ulaan Taiga and Horidol Saridag mountains and contribute to the Shishged Watershed. This region is home to the Horidol Saridag Strictly Protected Area, the Ulaan Taiga Strictly Protected Area, and Tengis Shishged National Park. The annual migration of nomadic herders and their livestock results in differing levels of grazing pressures across the landscape, with areas along traditional migration routes experiencing heavy grazing intensity during the fall. Conditions in the northern regions of the valley (Tsagaannuur), however, force residents to leave earlier in the season to avoid the harsh conditions of winter, thus resulting in lower grazing pressures (B. Dovchin 2022, *personal communication*). This region of northern Mongolia has an extreme continental climate with warm, wet summers, and extremely cold, dry winters with an annual mean temperature of -6.9 ºC (+/- 9.5 ºC) between 1975 and 2005 (National Agency for Meteorology, 2016). Temperatures below -40 ºC are common during the winter months, with a mean January temperature of -32.3 ºC (National Agency for Meteorology, 2016) The majority of precipitation is received during the summer months, with 71% of moisture falling as rain between the months of June and August (Moore et al., 2017). With elevations ranging from 1,500-m to 2,500-m, the region has four major altitudinal vegetation zones including the steppe, transitional upland forest, Siberian larch forest, and alpine zone (Moore et al., 2017).

We surveyed points across the Darhad valley in three distinct regions near the towns of Ulaan Uul, Renchinlhumbe, and Tsagaannuur (Figure 1) that vary in topography, soil type, grazing pressures, and weather patterns. In the field, we observed patterns throughout the three regions, each with distinct grazing regimes, climates, and potential barriers to Daurian pika movement. For the purposes of this study, the Renchinlhumbe region was defined as the area near the Renchinlhumbe Soum Center, bounded on the north by the Arsai river and to the west by the Shishged river. This area is a major migration corridor in the fall for nomadic herders using the Horidol-Saridag migration route, and is thus associated with higher grazing intensity than other regions of the Darhad Valley. The Tsagaanuur region extends over the northern edge of Tsagaanuur Lake and is bounded on the southeast by the Sharga river, and on the southwest by a constriction of forested mountains near the southern edge of the Tsagaanuur Lake. This region is the coldest and herders traditionally migrate from this area in the early fall season. The southern region, Ulaan Uul, is bounded on all sides by mountains, on the east by the Shishged river, and on the west by the Hüg river. Most herders migrate out of this area along dispersed routes in the fall, although a few families remain in scattered winter camps throughout the Ulaan Uul region. This area has small, forested mountainous areas in a matrix of well-connected grasslands.

Sampling design

In 2019, Round River Conservation Studies and the Ulaan Taiga Strictly Protected Area Administration selected plots across the steppe of the Darhad Valley to monitor Daurian pika occupancy and abundance. To do so, 160 randomly generated points were generated across the steppe of the Darhad Valley using a GRTS (generalized random tessellation stratified) program. Randomly generated points that fell within waterbodies or forested areas were eliminated, resulting in 117 remaining points for sampling. Of these points, a total of 85 points were sampled in Fall 2019. During the summer of 2022, Round River Conservation Studies returned to these same 85 randomly generated plots and at each survey point, two 50-m transects were placed perpendicular to one another in North-South and East-West directions, as this approximates the spatial scale of an average pika home range (M. Wang et al., 2000).

Daurian pika occupancy and abundance

To establish a metric of current Daurian pika occupancy, we examined relationships between active pika burrows and the presence of fresh scat in the vicinity of burrow systems. We surveyed Daurian pika burrows at each plot within the four quadrants designated by the two perpendicular 50-m transects. We inspected each burrow for the presence of scat and characterized each as either fresh or old according to color and texture. We also noted the presence of ground squirrel ("GS") and vole scat. Fresh scat, indicated by it being "externally green," found at or near the mouth of an open burrow indicates active Daurian pika presence and acts as an index to determine their occupancy and abundance (Wang et al., 2006). To quantify abundance ("PF"), we totaled the number of active pika burrows within a plot and designated the site as "inactive" (indicated by zero active pika burrows) or "active" (designated by one or more active pika burrows) ("PP").

Relationship between fresh scat and Daurian pika occupancy

To establish an index of Daurian pika density and abundance, we followed similar methods to those developed by Wang et al. (2006) whereby we filled pika burrows within a plot with dirt in the evening and counted the number of reopened burrows the following morning. The renewal of entrances indicates whether burrow entrances are active or abandoned and can serve as a reliable index for population levels within a plot (Wang et al., 2006). In 2019, Round River Conservation Studies established ten 10x10-m active pika burrow plots and determined that a positive correlation existed between the presence of fresh Daurian pika scat and the number of re-opened burrows ($r^2 = 0.9822$). In the summer of 2022, we established twenty new 10x10-m plots that we assumed to be active and monitored them for pika activity. Before closing Daurian pika burrows with soil at dusk, we observed scat in the latrines and classified it as "externally green," "internally green" (brownish on outside but bright green inside, indicating intermediate age), or "old" (brown internally and often dried hard). We then cleared the pika latrines of scat, filled the burrow entrances with soil, and checked the latrines the following morning for the presence of fresh, externally green scat.

We continued to investigate the correlation between scat and reopened burrows by examining if a relationship exists between reopened burrows and the presence of internally green excrement, characteristic of older scat. Of the nine plots that contained only internally green scat at the entrance of burrows, no burrows were re-opened the following morning, thus concluding that only externally green scat signified active pika occupancy. As a result of this study, we decided to only examine "externally green" and "old" scat at plot locations as an index for pika occupancy.

Explanatory variables

Vegetation & Grazing Intensity

We measured vegetation coverage and height data along each 50-m transect at 1-m intervals. At each interval, we recorded the height of the tallest grass, forb, and shrub in contact with the meter stick, as well as contact with lichen or solid rock at the base of the meter stick. We assessed livestock grazing intensity at each plot by measuring each of the following metrics at 1-m intervals along each 50-m transect, which were oriented in North-South and East-West directions: (1) grass and forb height ("GrassHt," ForbHt"); (2) the presence of livestock scat ("Scat"); (3) grazing intensity indicator species ("Overgraz"); and (4) bare ground ("BareGrnd"). We recorded the presence or absence of livestock scat within 10-cm of the base of the meter stick as "sheep/goat," "horse," and/or "cow/yak" scat. The presence or absence of livestock scat served as an indicator of grazing pressure, as well as a metric to determine the composition of livestock species present at each plot. The livestock species composition was important to note, as different livestock species may produce different grazing patterns and effects on the landscape. We recorded plant species known to be indicators of grazing pressure if they touched the meter stick at each 1-m interval along the transect. These indicator species included: Stipa (*Stipa baicalensis*), Artemisia (*Artemisia sp.*), and Cinquefoil species (*Potentilla sp.)*. The quantities of these plants offer an alternative proxy for overgrazing as their presence often indicates overgrazing. We also recorded the presence of bare ground, which we defined as a 75% or greater absence of vegetation within a 1.5-cm diameter circle under the meter stick. In addition to characterizing grazing intensity using the four metrics described above, a visual assessment of the grazing pressure ("GrazPres") was also collected at each plot center, and recorded as "low," "medium," or "high" by Dr. B. Dovchin who grew up herding in Western Mongolia and completed her Masters and PhD on soil quality and grazing within the Darhad Valley.

Soil Composition

We recorded metrics of soil composition from soil samples at each plot, including: pH ("pH"), phosphorous ("P"), nitrogen ("N"), potassium ("K"), and soil moisture levels ("SoilMoist"). We measured soil moisture at a depth of 5-10 cm within the A horizon using a soil moisture probe at the center of each plot. Surveyed areas experienced light rain during our study, however, we concluded that it did not infiltrate to the depth of our measurements. Soil nutrient levels were examined using the Luster Leaf 1665 Professional Soil Kit (LaMotte Inc). We found that it was difficult to accurately classify N and K using the soil composition kit: therefore, these metrics were excluded from our analyses. If the plot was classified as being active based on the presence of fresh Daurian pika scat, we conducted a second soil test at the mouth of the active burrow ("On-burrow") to determine if soil characteristics immediately surrounding burrows differed from that of the soil measurements taken at the plot center ("Off-burrow").

Normalized Differential Vegetation Index

We derived Normalized Differential Vegetation Index (NDVI) across each of the 85 plots to examine productivity in relation to occupancy patterns across the Darhad Valley. We downloaded Landsat 8-9 OLI/TIRS (Landsat Collection 2 Level-2 collection) imagery through USGS Earth Explorer. The majority of plot sites were encompassed by two Landsat scenes (Path136 Row024 and Path136 Row025) collected on July 8, 2022 (during the data sampling period, when most vegetation has greened-up but before grasses have reached their peak heights); however, nine plots were excluded from the analysis due to extensive cloud cover. We created a single raster dataset from the two Landsat scenes using the ArcGIS Pro "Mosaic to New Raster" tool and obtained NDVI values using the ArcGIS Pro "Band Arithmetic function" under the predefined NDVI algorithm. The default equation for NDVI is equal to ((IR – R)/(IR +R)), utilizing pixel values from the infrared band (IR) and pixel values from the red band (R), which in Landsat 8-9 corresponds to bands 5 and 4, respectively. A single NDVI value was extracted at the coordinates of the center of each plot given that our plot transects were similar in size to the 30-m spatial resolution of the Landsat data. NDVI values were exported to Excel and later analyzed in R.

Weather

We obtained daily weather data from the Mongolian National Agency for Meteorology and Environmental Monitoring (NAMEM) for the town centers of Renchinlhumbe, Ulaan Uul, and Tsagaannuur to examine average air temperature ("AvgAirTemp"), maximum air temperature (“MaxAirTemp”), minimum air temperature (“MinAirTemp”), daily precipitation (“Precip”; the Snow-Water Equivalent during winter;), and snow height (“SnowHt”). These variables were analyzed by region, specifically looking events that could cause high pika mortality, including: high precipitation events in summer (May-September), low winter (October-April) minimum temperatures, and instances of significant snow melt in Spring (March-April). To further examine weather variability, we utilized quantiles for time periods to illuminate the variation in the data, specifically in relation to minimum air temperature, precipitation, and snow height.

Local Knowledge

We heavily relied on communication and local knowledge from herders in the Darhad Valley throughout this study, specifically regarding weather observations and Daurian pika activity between 2019 and 2022. General descriptions of historical weather patterns and factors influencing Daurian pika populations were provided by Dr. B. Dovchin and Tumursukh Jahlr, Director of the Ulaan Taiga Strictly Protected Areas Administration and discussions with park rangers and local herders Battogtokh Tumur and Batzaya Erdenebat contributed to a more robust understanding of the human-pika relationship, and how locals perceive their presence in relation to cultural traditions, nomadic herding, and weather forecasting.

Statistical analyses

We used the software programs R and Microsoft Excel to determine which variables (n=20; Table 6) provided the best explanation for pika occupancy and abundance across the eighty-five plots surveyed throughout the three regions of the Darhad Valley in 2022. To test if historically higher pika population levels buffered the effect of stochastic events, we also included the 2019 Daurian pika abundance data as an explanatory variable. We used Akaike Information Criterion (AIC) scores (Burnham & Anderson, 2002) to compare hypotheses related to pika occupancy and abundance. Because of the large number of variables, we first selected variables that had a reasonable amount of predictive power. We created a model set with single explanatory variables and kept variables that had >1% AIC weight. These predictive variables were then combined in additive models to find their best combination. We then model-averaged the slope of each variable and evaluated their significance based on 95% confidence intervals that did not overlap zero. We used the R package *lme4* to apply generalized linear models (run as a logistic regression) to our occupancy data, and with a zero-inflated distribution for the abundance analyses due to the large number of zeros (indicating "unoccupied" sites) in our dataset. Additional analyses of relationships between Daurian pika occupancy and grass and forb height were conducted to examine any correlations between Daurian pika occupancy and forage competition with domesticated livestock. Plots located in highly grazed summer camp locations were removed from these analyses to account for the impacts of domesticated livestock grazing on grass and forb biomass. To understand which variables might influence ground cover, soil quality indicators and grazing intensity metrics were examined in relation to the presence or absence of bare ground.

Differences in regional occupancy and environmental variables

General Daurian pika occupancy trends were examined by comparing the percent of plots that exhibited active presence of Daurian pika between 2019 and 2022 across the study site and three distinct regions, using confidence intervals to assess statistical significance. Further analyses investigating the reasons behind extirpation or colonization patterns of individual pika plots were examined according to geographical location, Daurian pika abundance in 2019, soil moisture, grazing pressure, grass height, forb height, and percent forb cover. Plots were organized according to region, and differences in vegetation, grazing intensity, and soil characteristics were analyzed according to statistical significance. An assessment of regional variation in Daurian pika abundance was completed to analyze any spatial distribution patterns associated with Daurian pika population patterns. Additionally, differences in regional weather data were examined according to statistical significance.

Differences in environmental variables according to extirpation and colonization events between 2019 and 2022

To examine if certain environmental variables buffered extirpation events at distinct Daurian pika plots, we organized plots by their occupancy change between 2019 and 2022 according to if they experienced “no change” (signifying that active plots in 2019 remained active in 2022, and inactive plots in 2019 remained inactive in 2022), were “extirpated” (signifying active plots in 2019 that became inactive in 2022) or were “colonized” (signifying inactive plots in 2019 that became active in 2022). Environmental variables of vegetation, grazing intensity, and soil characteristics were examined across the three groups according to 95% confidence intervals to determine statistical significance.

Relationship between pika occupancy and soil composition

To examine the influence of Daurian pika presence on local soil quality, we compared soil data collected at active burrow sites (“On-burrow”) to general plot soil data (“Off-burrow”) sampled at the center point of the plot. Additional examination of the impact of Daurian pika presence on soil quality at burrow sites was analyzed by performing a paired two-sample t-Test to ascertain if there was a statistically significant difference between the soil quality adjacent to active burrows versus non-burrow sites.

RESULTS

Daurian pika population trends

Of the 85 plots surveyed, a total of nineteen plots (22%) were occupied by Daurian pika which signifies a 57% decline in occupancy rates since 2019 (Figure 2). A total of thirty plot extirpations occurred during this time with only five additional plot colonizations. Additionally, Daurian pika abundance decreased substantially, with burrow numbers declining by 70% from 2019 to 2022 (Figure 2), as seen by a substantial decline in the average number of active burrows per pika plot (Figure 3).

Generalized linear model of Daurian pika occupancy

Our analyses suggest that pika occupancy varies strongly by region, with no statistically significant correlation with grazing pressure, grass height, forb height, percent ground cover, lichen, livestock scat, or overgrazing indicator species. However, we observed a strong correlation between the presence or absence of Daurian pika in 2019 and plot abundance in 2022. According to AIC scores generated in R, we found that together, geographical region and bare ground best explained the distribution of pika observed in 2022 (Table 1). With an AIC weight of 0.93, this model provided the most robust explanation for abundance patterns across the Darhad Valley (Table 2). This is of particular importance to this study given that Darhad Valley weather data was not included in this model, given that it is a discrete variable with only three collection sites. The modeled averaged confidence intervals for region did not overlap 0, thus indicating their significant influence on pika abundance in 2022 (Table 2).

Generalized linear model of Daurian pika abundance

Based on AIC scores generated in R associated with a generalized linear model describing Daurian pika abundance, region in combination with bare ground best explained the distribution patterns of pika abundance throughout the Darhad Valley, as the model averaged confidence interval did not overlap zero (Table 2). We could not analyze colonization patterns because our sample size of colonized plots (n=5) was too small.

Correlation between fresh scat and Daurian pika occupancy

As described earlier, we examined the relationship between Daurian pika scat presence and recent burrow activity to determine occupancy status of plots. Our results confirm conclusions made by Round River Conservation Studies in 2019: fresh pika scat found outside of a burrow in the evening is strongly correlated with the burrow being excavated the following morning ($y = 0.72x$, $r^2 = 0.8293$ with intercept fixed at 0; 2022 analysis produced a relatively similar slope of $y = 0.82x$). All burrows revisited with green color inside the scat were confirmed to be unoccupied by lack of fresh excavations the following morning.

Regional analyses

We found a strong trend between occupancy of Daurian pika in 2022 and region, suggesting that their distribution within Tsagaannuur, Renchinlhumbe, and Ulaan Uul strongly impacts their abundance and occupancy (Figure 6). The majority of plot extirpations occurred in the Renchinlhumbe region, demonstrating a likely regional extirpation of Daurian pika (Figure

3). We therefore performed a number of further analyses to investigate what other factors varied regionally, to aid in our explanation of why pika populations varied regionally.

2022 Daurian pika occupancy and abundance

We found that Daurian pika occupancy ("PP") was significantly higher in Tsagaannuur (*M*=54.17% occupied, *SD*=20.36%) than either Renchinlhumbe (*M*=0% occupied, *SD*=0%) or Ulaan Uul (*M*=15.15% occupied, *SD*=12.42%). From our analysis of regional differences in abundance levels of Daurian pika, we observed that pika abundance in Tsagaannuur (*M*=14.58 active burrows/plot, *SD*=10.35) was significantly higher than that in both Renchinlhumbe (*M*=0 active burrows/plot, *SD*=0) and Ulaan Uul. No significant differences were observed when comparing 2019 pika abundances ("Pika2019") across regions.

Vegetation

We found that grass height ("GrassHt") and forb height ("ForbHt") were significantly different across regions; Renchinlhumbe and Ulaan Uul had higher average grass height and forb cover than Tsagaannuur (Figures 9 & 10; Table 12).

Our analysis of regional differences in percent grass cover ("GrassCov") demonstrated that Ulaan Uul had a significantly greater percentage of grass cover than either Renchinlhumbe or Tsagaannuur. Furthermore, Tsagaannuur had significantly lower grass cover than either Renchinlhumbe or Ulaan Uul (Figure 7b; Table 12).

Lastly, percent forb cover ("ForbCov") varied significantly across regions; Tsagaannuur had significantly less forb cover than either Renchinlhumbe or Ulaan Uul. Percent forb cover was similar between Renchinlhumbe and Ulaan Uul (Figure 7e; Table 12).

Grazing pressure

No statistically significant differences were found between the three regions in relation to grazing pressure according to the presence of scat ("Scat"), overgrazing indicator species ("Overgraz"), bare ground ("Baregrd"), or the qualitative description of grazing pressure by Dr. Dovchin ("Grazpres"). Similarly, there were no differences in 2022 grass height or forb cover observed between summer and winter pastures.

Soil characteristics

Soil moisture content ("SoilMoist") across Tsagaanuur, Renchinlhumbe, and Ulaan Uul varied significantly; average soil moisture content in Tsagaanuur was significantly lower than Renchinlhumbe, and Ulaan Uul (Figure 7d; Table 13). While soil moisture content was similar between Renchinlhumbe and Ulaan Uul, Renchinlhumbe had the highest soil moisture content of the three regions in the Darhad Valley (Table 13).

Soil chemistry analyses revealed that Renchinlhumbe soils were more basic ("pH") than either Tsagaannuur or Ulaan Uul (Figure 7f; Table 13). Ulaan Uul had significantly lower levels of phosphorous ("P") compared to Renchinlhumbe. Furthermore, Renchinlhumbe demonstrated marginally statistically significant higher levels of phosphorous compared to Tsagaannuur (Figure 7g; Table 13).

Normalized Differential Vegetation Index, 2022

Analysis revealed that Tsagaannuur has lower NDVI values (“NDVI2022”) compared to both Renchinlhumbe and Ulaan Uul, both of which had similar values (Figure 9; Table 13).

Regional analysis overview

According to a regional analysis of explanatory variables it was found that compared to the other two regions, Tsagaannuur has a lower soil moisture content, lower grass and forb height, lower percent forb and grass cover, higher 2022 pika abundance levels, higher 2022 occupancy levels, and lower NDVI values. Similarly, Renchinlhumbe has the highest soil moisture levels, more basic soil, and greater levels of soil phosphorous. Analysis also revealed that Ulaan Uul has a greater percentage of grass cover and lower levels of soil phosphorous compared to the other two regions. Overall, Daurian pika occupancy rates in 2022 are clearly unevenly distributed according to region which suggests that regional variations between Tsagaannuur, Renchinlhumbe, and Ulaan Uul are of critical importance to Daurian pika occupancy and abundance.

Regional weather analyses

Temperature

Analysis of daily minimum temperature data of winter months between 1/1/2019 and 11/30/2022 revealed that Renchinlhumbe experienced statistically significant colder temperatures (M=-11.7 ºC, SD=0.83) than Ulaan Uul (M=-9.3 ºC, SD=0.79) and Tsagaannuur (M=-9.0 ºC, SD=0.71). During this same period, Renchinlhumbe experienced sixty-nine cold weather events that we defined as -40 ºC or below, a temperature at which pika can survive for up to a duration of six hours. Ulaan Uul experienced thirty-three of these events throughout the same time period, and Tsagaannuur experienced none. Due to limited data at certain weather stations, trends could not be distinguished for winter minimum air temperatures. No temperatures below -45 ºC were observed (see Appendix B). Thus, extreme winter temperatures are unlikely to cause the extirpation event observed.

Precipitation

Total yearly (January-December) precipitation levels also varied by region and year. In 2019, Ulaan Uul had statistically significant greater levels of precipitation than Tsagaannuur and Renchinlhumbe, both of which experienced similar total precipitation levels (Table 14). In 2020, Renchinlhumbe had statistically significantly greater levels of precipitation than Tsagaannuur and Ulaan Uul. Similarly in 2021, Ulaan Uul had statistically significant greater levels of precipitation than both Renchinlhumbe and Tsagaannuur (Table 14). In 2022, including the months of January through October, Tsagaannuur received statistically significant greater levels of precipitation than Renchinlhumbe and Ulaan Uul. It is also important to note that in 2022, Renchinlhumbe had statistically significant lower levels of precipitation than both Ulaan Uul and Tsagaannuur (Table 14; see Appendix B).

Analysis of large precipitation events across the three regions during the summer months of May – September revealed a three-day event starting 8/24/2020 that resulted in 40-mm of precipitation at the Renchinlhumbe weather station. An additional 26-mm event in Renchinlhumbe occurred on 7/13/2020. Ulaan Uul received 26-mm on 6/13/2019. Similarly, Ulaan Uul and Tsagaannuur received 35-mm of precipitation on 8/17/2021. No additional large precipitation events of interest were observed. Close examination of precipitation patterns across the three regions revealed that Renchinlhumbe tends to receive a greater number of large individual precipitation events in comparison to Ulaan Uul and Tsagaannuur where precipitation is typically received in smaller quantities more frequently (see Appendix B).

Snow Cover

Analysis of weather data according to region between 2018 and 2022 during the winter months of September – April demonstrated that in 2018 Ulaan Uul had statistically significant higher levels of snow cover than Renchinlhumbe (Table 8; Table 15). In 2021 Renchinlhumbe had statistically significant higher levels of snow cover than Ulaan Uul (Table 9; Table 15) and marginally statistically significant higher levels of snow cover than Tsagaannuur (Table 10; Table 15). On average, Renchinlhumbe experiences the highest levels of snow cover throughout the valley (see Appendix B).

Analysis of significant snow melt events revealed that 25-cm of snowpack melted in Ulaan Uul during mid-May of 2019, as well as 18-cm of melt on 10/26/2019, and 26-cm of melt on 4/28/2021. Additionally, we observed that 27-cm of snowpack in Renchinlhumbe melted in six days starting 4/9/2022. Very few large melting events were observed in Tsagaannuur, however, a 24-cm melt occurred on 5/1/2021. No additional large snow melt events greater than 25-cm were observed (see Appendix B).

Weather variability – quantiles

No significant variability was found between Renchinlhumbe, Tsagaannuur, and Ulaan Uul through quantile analysis of precipitation levels and snow cover height. That said, Renchinlhumbe tended to experience colder temperatures and higher levels of snow cover between the months of December through February (see Appendix A).

Weather trends Summary

Observational analysis of trends in temperature, precipitation, and snow height illuminated that the Darhad Valley experienced a particularly harsh 2019-2020 winter. In the Renchinlhumbe region this was followed by abnormally early above-freezing temperatures during the spring of 2020 with subsequent sub-zero freezing events, multiple rainfall events, and large oscillations between sub-zero and above-freezing temperatures (see Appendix B).

Soil Composition

Differences in average pH levels between active burrow soil samples and plot soil samples ("pH") were found to be marginally significantly higher near active burrows (Table 3). Similarly, phosphorus levels ("P") were significantly higher in the vicinity of active burrows (Table 4) and soil moisture was significantly (Table 5). Nitrogen and potassium levels were inaccurate due to challenges associated with reading the tests and thus not analyzed.

Plot-level changes in vegetation and soil composition between 2019 and 2022

To examine trends in vegetation and soil composition, we investigated whether several important grazing variables were similar within plots between 2019 and 2022. For each variable, we created a scatter plot with values from each pika plot in 2019 (x-axis) and 2022 (y-axis), and then performed a linear regression on each variable. All variables showed significant correlation coefficients between the years, suggesting that these characteristics remained relatively similar at each site between 2019 and 2022, despite being measured in different seasons. Slopes are in the direction expected, showing soils becoming drier and grass and forb height/cover increasing during the summer growing season (July 2022) into the fall (September 2019).

DISCUSSION

Daurian pika populations are undeniably experiencing significant declines in occupancy and abundance across the Darhad Valley on a regional scale. Spatial patterns associated with Daurian pika abundance in three distinct regions provide the most rigorous model to predict their abundance and distribution, specifically in relation to regional variation within the Darhad Valley and abundance patterns observed in 2019. Interestingly, variables once important in determining Daurian pika abundance were found to have little correlation with the population's distribution in 2022. The insignificance of grazing pressure, grass height, forb height, percent ground cover, lichen, livestock scat presence, and overgrazing indicator species suggests that a stochastic event resulted in large declines in population levels between 2019 and 2022, regardless of plot vegetation and soil conditions. That said, significant patterns associated with spatial distribution of pika occupancy suggests that regional variation between Renchinlhumbe, Tsagaannuur, and Ulaan Uul drove the localized extirpation events observed.

Occupancy analyses

Overall, active plots demonstrated a lower level of percent forb cover, a greater percentage of bare ground, and lower soil moisture content compared to inactive plots. It is important to note that AIC models are evaluated according to the variables examined and has the potential to miss variables not included in analysis.

Regional analyses

Analysis of regional variability between Renchinlhumbe, Tsagaannuur, and Ulaan Uul provided multiple possible explanations for the regional extirpation event, in conjunction with local knowledge regarding historical weather data, nomadic herding routes, and Daurian pika population levels over the past ten years. We developed four hypotheses related to Daurian pika population declines in relation to regional variability: 1) lower grass height variation led to higher predation rates; 2) lower forage availability mediated by forb height and cover led to starvation of pika; 3) extreme winter temperatures resulted in the freezing of pika; and 4) variation in precipitation and soil moisture (mediated by soil type) resulted in excessive flooding during spring melting events.

Vegetation

Previous research has shown that a positive correlation exists between Daurian pika occupancy and grass height, likely due to increased cover from predators in areas with higher levels of grass biomass (Wang and Zhong, 2006). Additionally, forb cover has been shown to significantly impact winter survival rates of Daurian pika due to forage availability levels (Wangand Zhong, 2006). Both of these variables were examined according to region; however, against expectations, forb cover and grass height were not found to be lower in the Renchinlhumbe region when compared to Ulaan Uul or Tsagaannuur, suggesting they were not the primary cause of Daurian pika population declines.

Grazing intensity

As previously noted, the Darhad Valley is populated by nomadic herders and their livestock which contributes significantly to local environmental conditions according to migration patterns and herding practices. Winter herder migrations happen well after vegetation measurements were taken (personal communication, 2022), potentially altering the conditions of regions through late season grazing which we were unable to detect. The Renchinlhumbe region is traditionally along a major winter migration corridor, where livestock grazing pressure throughout the fall season has the potential to result in disproportionately lower levels of forage availability over the winter, most likely leading to higher rates of Daurian pika mortality (Borisova et al., 2020). The Tsagaannuur region, which suffered no declines in Daurian pika occupancy levels between 2019 and 2022, experiences early fall migration due to a consistently early onset of cold winter weather (personal communication, 2022; Mongolian National Agency for Meteorology and Environmental Monitoring). This migration pattern results in lower livestock grazing pressure throughout the fall season and thus likely leaves greater levels of forage availability for Daurian pika throughout the winter. The Ulaan Uul region tends to have mid-season migration, with a few families remaining in the area throughout the winter season to utilize pastures that retain higher grass levels (personal communication, 2022). These grazing patterns may not normally influence pika survival rates, but in extreme conditions when winter food supplies may be more critical, their effects may be more pronounced. Given high mortality rates observed in Daurian pika over winter (Zhong et al., 2008; Borisova et al., 2020), this hypothesis has particularly high plausibility.

Soil characteristics

Regional soil moisture levels illustrated that the Renchinlhumbe region had significantly higher levels of soil moisture, which could indicate the potential for flooding in the area. Previous studies examining the relationship between soil moisture content and Daurian pika spatial distribution suggests that an inverse relationship exists between the occurrence of active Daurian pika and soil moisture content in late summer (Wang et al., 2002; G. Wang, Zhong, et al., 2003). That said, a study in Inner Mongolia found that increases in precipitation was positively correlated with increases in the growth rate of Daurian pika populations, and locations with lower soil moisture content demonstrated higher Daurian pika abundance (G. Wang & Zhong, 2006). Most likely attributed to increases in vegetation height associated with precipitation, soil moisture content could indirectly affect the spatial distribution of Daurian pika through altering vegetation regimes (Wang et al., 2002). The ideal amount of precipitation required for adequate vegetation growth for predation protection is unknown, as well as the upper limit of precipitation levels which might create uninhabitable conditions due to high soil moisture content. Thus, further studies are necessary to distinguish the role of soil moisture content in pika habitat selection, however, our study agrees with previous research that suggests Daurian pika select less moist environments (Wang et al., 2002).

Specific attention should be given to the Tsagaannuur region which experienced no plot extirpations despite having the lowest grass and forb height, lowest percent forb and grass cover, and lowest NDVI values in 2022. Most importantly, analysis revealed that Tsagaannuur had the lowest soil moisture content out of the three regions despite receiving the highest levels of precipitation throughout the summer of 2022 prior to sampling. This combination strongly suggests that variation in soil type throughout the Darhad Valley heavily impacts Daurian pika distribution and abundance given its linkage to soil moisture content which has been shown to influence habitat suitability (G. Wang, Zhou, et al., 2003) This hypothesis is further supported by Renchinlhumbe having the highest soil moisture levels throughout the region as well as the highest levels of plot extirpations in 2022. Given the high pika abundancy levels observed throughout the Tsagaannuur region in 2022, unfavorable vegetation conditions for pika survival appear to be of secondary importance to soil moisture content in relation to soil type and precipitation patterns. In other words, the favorable soil conditions in the Tsagaannuur region are of greater importance to Daurian pika habitat suitability than forage availability or protection from predators during stochastic events. That said, further research is required to determine the minimum levels of forage availability required to adequately support healthy pika populations.

Weather

Due to the importance of soil moisture content in determining habitat suitability, we analyzed weather data to examine large flooding events, either from precipitation or snow melt, which may have contributed to the regional extirpations observed in the Renchinlhumbe region. We found evidence of pika mortality by flooding in the Renchinlhumbe region, specifically due to the region's geography, soil type, land use, and unique weather conditions during the spring of 2020. The Renchinlhumbe region is known for having soil with low porosity given its geographic location as an ecotone between montane regions and the low elevation steppe with nearby mountains that contain rich soils (personal communication, 2022). This is further supported by data measurements which shows the region having the highest soil moisture content throughout the Darhad Valley, despite low precipitation levels when measurements were taken (Figure 7d). Furthermore, during the spring of 2020, the Renchinlhumbe region experienced a series of precipitation events in conjunction with temperature oscillations between sub-zero and above freezing temperatures, resulting in significant melting of snow in the adjacent montane regions which likely led to substantial flooding in the low elevation steppe. It is important to note that precipitation as rain has the potential to result in melting (especially during the spring), further contributing to flooding potential. Soils are also still frozen only a few inches underground during this time, meaning that floods happen quickly, as water cannot penetrate the soil. Furthermore, spring precipitation as rain in the nearby montane regions may result in flooding of the valley bottom, even in the absence of precipitation at the weather stations located throughout the steppe. Thus, we hypothesize that early precipitation as rain in the adjacent montane regions resulted in flooding of the low elevation Renchinlhumbe region, and its subsequent freezing and melting led to inhospitable conditions for Daurian pika which ultimately led to their extirpation (see Appendix B, spring 2020 precipitation and temperature data).

Furthermore, as the lowest point in the valley, local knowledge has indicated that the Renchinlhumbe region experienced a harsh winter in 2019-2020, followed by a significant melting and subsequent flooding event during the early spring, that then froze forming cold, icy soil, potentially uninhabitable by Daurian pika populations (personal communication, 2022). As described above, this local knowledge agrees with weather data that illuminates a harsh 2019-2020 winter in the Renchinlhumbe region, early spring melting of snow, and subsequent precipitation and sub-zero temperatures that likely led to a flooding event resulting in Daurian pika mortality. It is important to note that local rangers living on the steppe recall two other large valley-wide pika extirpations in 2000 and 2010 which were both preceded by harsh winter conditions (personal communication, Battogtog Tumur 2022).

Additional variations in weather patterns across the Darhad Valley have the potential to affect Daurian pika populations on a regional scale, specifically in relation to snow precipitation levels which are known to impact pika survival rates (Borisova et al. 2020). Minimal snow cover has been shown to correlate with low below-ground temperatures which have the potential to result in pika mortality if sustained for long durations (Borisova et al., 2020). Previous research has shown that Daurian pika are able to withstand -45 ºC temperatures for up to six hours after which their survival rate begins to decline (Borisova et al., 2020). That said, weather data in the winter and spring of 2019 illuminated that the Darhad Valley experienced multiple cold weather events less than -40ºC which resulted in no impact on occupancy and abundance levels examined during the summer of 2019 when plots were originally sampled by Round River Conservation Studies. Thus, we conclude that extreme cold weather events do not have significant consequences on Daurian pika mortality.

Additionally, significant levels of highly saturated, dense snow have the potential to decrease oxygen availability below-ground, resulting in suffocation of burrowing mammals (Borisova et al. 2020). That said, we found no evidence of snow cover conditions which might influence Daurian pika survival and thus conclude that regional variation in winter precipitation patterns do not explain the unequal spatial distribution of Daurian pika declines across the Darhad Valley and the significant extirpation event observed in the Renchinlhumbe region. That said, the Renchinlhumbe region experiences a significantly greater number of extreme winter weather events below -38 ºC than the rest of the valley, which might contribute to unfavorable environmental conditions if combined with low forage availability, high soil moisture content, or temperature variations resulting in regional flooding events and subsequent refreezing. It is important to note that soil type plays a large role in determining soil permeability which has the potential to obscure flooding intensity amid differing local soil conditions (Elhakim, 2016). While significant, additional analysis of flooding potential in conjunction with soil type data is required to develop a more comprehensive understanding of the Renchinlhumbe extirpation.

Soil composition

In agreement with previous research (Smith and Foggin, 1999), Daurian pika activity in the Darhad Valley was shown to be associated with increased pH, phosphorous, and soil moisture levels, most likely due to increased soil disturbance and defecation in these areas. Daurian pika are known to play a critical role in the ecology and biodiversity of the Mongolian steppe, specifically in relation to plant biodiversity, species richness, and soil composition (Komonen, 2003; Smith et al., 1990). Benefits associated with burrow system activity include the creation of rich microhabitats that support increased plant biomass, increased diversity of plant species, and dense root systems. Additional research is required to determine any correlations between burrow activity and nitrogen and potassium levels due to inaccuracies associated with the soil kit utilized in data collection. Regardless, Daurian pika play a prominent role in augmenting soil quality across the Mongolian steppe, creating rich microhabitats that are valuable in relation to plant biomass and species biodiversity.

CONCLUSION

Daurian pika abundance has experienced a dramatic decline since 2019, specifically associated with an extirpation of populations in the Renchinlhumbe region. Our data suggests that soil moisture content mediated by soil type and precipitation patterns predominately impacts Daurian pika distribution and abundance throughout the Darhad Valley, Mongolia during stochastic events. In 2022, Daurian pika populations were unequally distributed according to geographical location, which captures the diversity of soil type throughout the valley and suggests that soil moisture content plays a critical role in determining habitat suitability. We hypothesize that soil type, in conjunction with regional weather patterns and traditional livestock foraging patterns resulted in inhospitable environmental conditions for Daurian pika populations between 2019 and 2022 which had devastating effects on their distribution and abundance on a regional scale. Most importantly, we hypothesize that the Renchinlhumbe regional extirpation was a consequence of low soil permeability in combination with increased soil moisture content associated with high montane melting events, early spring above-freezing temperatures followed by subsequent freezing.

Furthermore, local herders utilize the Renchinlhumbe region in the fall months as seasonal pasture which may decrease forage availability throughout the winter. This is especially plausible given that our vegetation measurements were collected prior to this seasonal migration and thus did not capture any decrease in forage availability associated with domesticated livestock. It is important to note that although grazing pressure in the Renchinlhumbe region throughout the fall likely does not contribute to pika mortality under "normal" environmental conditions, harsh winter weather conditions and increased soil moisture content may contribute to unfavorable habitat conditions that cannot be buffered by adequate forage availability. This hypothesis is further supported by environmental conditions observed in the Tsagaannuur region where in 2022 Daurian pika abundance was highest and soil moisture content was lowest despite the area receiving the greatest amount of precipitation in 2022, indicating high soil porosity. Previously important variables such as grass height, forb cover, and grazing intensity did not buffer the population from local extirpation, suggesting that variables such as soil moisture content, nomadic herding routes, and weather patterns heavily affect Daurian pika population levels during extreme events. Furthermore, in 2022 the Tsagaannuur region did not demonstrate optimal vegetation conditions for Daurian pika habitat as established in 2019 by Round River Conservation Studies (Heny et al., 2019), suggesting that previously influential variables such as grass height and forb cover are of secondary importance to soil moisture content mediated by weather conditions and soil type.

Therefore, it is clear that in the midst of stochastic events, Daurian pika survival rates are not augmented by variables that traditionally support healthy populations. It is important to consider the interaction between soil conditions and vegetation growth, as these variables are highly interconnected and interact to impact Daurian pika habitat suitability. Additional research is required to gain a more robust understanding of the ideal balance between soil type, precipitation, and vegetation growth. As previously noted, adequate vegetation is critical for forage availability and predator protection which requires sufficient precipitation, however, high levels of precipitation pose the risk of high soil moisture content which this study found to be of greater importance than vegetation conditions in determining habitat suitability. Overall, we conclude that Daurian pika are susceptible to flooding events which have the potential to result in high mortality rates and subsequent extirpation. It is important to holistically analyze this threat by examining soil type, mineral composition of nearby montane regions, historic and present land use, geographic location, precipitation patterns, and its interaction with temperature to create oscillations between freezing and melting events. Thus, further research is required to illuminate in greater detail the environmental conditions that result in Daurian pika mortality, specifically related to the magnitude of flooding events that have the potential to result in extirpation, in combination with local environmental conditions including topography, soil type, land use, temperature and precipitation, and geographic location.

Potential for future research includes assessing the impact of fall livestock grazing intensity in the Renchinlhumbe region, winter forage availability, and continued assessment of recolonization rates of extirpated plots. The regional extirpations observed in 2022 provide a unique opportunity to observe Daurian pika in the aftermath of a stochastic event and its impacts on general biodiversity levels throughout the Darhad Valley. Of particular interest is the recolonization timeline of Daurian pika and if environmental variables influence geographic recolonization patterns. Although local knowledge suggests Daurian pika have gone through other large extirpation events in the past, climate change predictions for the region suggest more frequent extreme weather events (IPCC, 2022; Gong et al., 2004). Local land stewards and the Ulaan Taiga Strictly Protected Area Administration will play critical roles in maintaining ecological integrity within the Darhad Valley and mitigating the potential for long-term declines in Daurian pika populations. Our research illustrated the importance of Daurian pika in maintaining rich soil composition, high levels of biodiversity, and general ecological health of the Mongolian steppe; their conservation is of utmost importance, especially in the midst of climate change where the frequency of stochastic events are likely to increase. Continued collaboration between local pastoralists, conservation administrations, and researchers will be of vital importance to support healthy grasslands, adequate winter forage availability, and ample protection from predators so as to bolster the resiliency of Daurian pika during the ongoing escalation of climate change.

Future Management Considerations

The environment, culture, and political organization of Mongolia structures human-environmental interactions and contributes significantly to how people participate in environmental conservation and communal rangeland management. Over one-third of

Mongolians engage in pastoralism, and roughly one-half of the country's population depends directly on the benefits associated with the pastoral economy (Fernandez-Gimenez, 2000). The ecological knowledge of Mongolian nomadic pastoralists is extensive, influencing pasture use norms, herding practices, and attitudes toward pasture privatization and management (Fernandez-Gimenez, 2000). Given that the majority of Daurian pika habitat overlaps with traditional pastures and nomadic herding routes, rangeland management is of specific importance to this study as it implicates future conservation of the species.

Significant debate exists in relation to the benefits and detriments associated with communal resource management, explored by economic theories including the tragedy of the commons which refers to the propensity of community members to act in their own self-interest leading to the ultimate depletion of common resources (Hardin, 1968). That said, this theory has been undermined by empirical evidence (McCay & Acheson, 1987; Feeny et al., 1990) and competing theories have been developed in relation to how people engage in communal land management, for example social structures associated with Mongolian nomadic pastoralism. It has been found that a fundamental tenet of successful communal land management is the enhancement of social and economic structures that are rooted in reciprocity which allows for the development of a "flexible, mobile system of pastoral land use" (personal communication, 2022; Fernandez-Gimenez, 2000). For example, Mongolian herders engage in reciprocal hospitality in the midst of extreme weather events and economic instability associated with decreases in forage availability (personal communication, 2022). Extensive social customs motivate nomadic herders to conserve communal resources, and traditional ecological knowledge (TEK) supports sustainable stocking rates of livestock according to environmental, spatial, and temporal variability (personal communication, 2022). Furthermore, mobility associated with nomadism in

Mongolia allows for herders to engage in sustainable resource management and their herding strategies clearly articulate exceptional understanding of local environmental conditions (Fernandez-Gimenez, 2000). Increases in resiliency and adaptability associated with communal land use is expected to increase in importance as climate variability and the potential for devastating weather events increase. That said, limitations associated with communal land management in Mongolia include general trends towards decollectivization, livestock privatization, and the transition to a market economy, all of which undermine widely held norms associated with pasture use and disrupt century-long relationships with land management (Fernandez-Gimenez, 2000).

In relation to Daurian pika conservation, it is important to note that livestock grazing is associated with substantial benefits to soil quality, biodiversity, and biomass productivity (Retzer, 2007; Schuman et al., 1999). While the traditional pastoral system in Mongolia has been shown to enhance ecological health while supporting human communities through economic and social benefits (Schuman et al., 1999), 70% of Mongolian rangeland has been categorized as degraded (UNDP, 2012), most likely in association with increases in livestock stocking rates; Mongolia has experienced a 46% increase in domesticated livestock numbers within the last 20 years which is indicative of the shifting economic, social, and political structures that influence herding customs (Dovchin, 2014). Pastoral economies are slowly becoming threatened by fragmentation, climate change and climate variability, land use changes, sedentarization, and institutional changes, forcing Mongolians to explore adaptive management strategies (Galvin, 2009). As a "grassland's interdependent spatial units become disconnected," ecological resiliency and adaptability is harmed at the expense of pastoral economies and ecosystem health (Galvin, 2009). While most pastoral scholars agree that privatization is "counterproductive to sustainable land use in arid and semi-arid environments," a trend towards government-mandated privatization increases system rigidity and is predicted to further degrade the Mongolian steppe (Galvin, 2009). Special attention must be given to rangeland management in the coming decade amid large institutional changes that are shifting grazing regimes throughout the country and leading to behaviors that violate sustainable practices rooted in centuries-old traditional ecological knowledge (Fernandez-Gimenez, 2000). In relation to this study, the ecological consequences associated with land use changes will undeniably influence Daurian pika habitat quality and distribution (Borisova et al, 2020), especially in the midst of a changing climate.

REFERENCES

Borisova, N. G., Starkov, A. I., Popov, S. V., & Erbajeva, M. A. (2020). Spatial Assessment of the Climatic Niche of Daurian Pika. *Contemporary Problems of Ecology*, *13*, 469–483.

Burnham, K. P., & Anderson, D. R. (2002). *Model Selection and Inference: A Practical Information-Theoretic Approach* (2nd edition). Springer-Verlag.

Chapman, J. A., & Flux, J. E. C. (n.d.). *Rabbits, Hares and Pikas Status Survey and Action Plan*.

Dovchin, B. (2014). *USING HOLISTIC MANAGEMENT STEPS TOWARDS IMPROVING SOIL AND VEGETATION QUALITY AND FAMILY RESILIENCY IN MONGOLIA*. Montana State University .

Elhakim, A. F. (2016). Estimation of soil permeability. *Alexandria Engineering Journal*, *55*(3), 2631–2638. https://doi.org/https://doi.org/10.1016/j.aej.2016.07.034

Feeny, D., Berkes, F., McCay, B. J., & Acheson, J. M. (1990). The Tragedy of the Commons: Twenty-Two Years Later. *Human Ecology*, *18*(1), 1–19. http://www.jstor.org/stable/4602950

Fernandez-Gimenez, M. E. (2000). The role of Mongolian nomadic pastoralists' ecological knowledge in rangeland management. In *Ecological Applications* (Vol. 10, Issue 5, pp. 1318–1326). Ecological Society of America. https://doi.org/10.1890/1051-0761(2000)010[1318:TROMNP]2.0.CO;2

Galvin, K. A. (2009). Transitions: Pastoralists living with change. *Annual Review of Anthropology*, *38*, 185–198. https://doi.org/10.1146/annurev-anthro-091908-164442

Gong, D.-Y., Shi, P.-J., & Wang, J. A. (2004). Daily precipitation changes in the semi-arid region over northern China. *Journal of Arid Environments* , *59*(4), 771–784.

Hardin, G. (1968). The Tragedy of the Commons. *Science*, *162*(3859), 1243–1248. http://www.jstor.org/stable/1724745

Heny, S., Smith, C., & Dovchin, B. (2019). *Daurian pika distribution and abundance* .

IPCC. (2022). *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*.

Jones, C. G., Lawton, J. H., & Shachak, M. (1994). Organisms as Ecosystem Engineers. In *Source: Oikos* (Vol. 69, Issue 3). https://www.jstor.org/stable/3545850?seq=1&cid=pdf-

Komonen, M., Komonen, A., & Otgonsuren, A. (2003). Daurian pikas (Ochotona daurica) and grassland condition in eastern Mongolia. *Journal of Zoology*, *259*(3), 281–288. https://doi.org/10.1017/S0952836902003266

Lissovsky, A. A. (2014). Taxonomic revision of pikas Ochotona at the species level. *Mammalia*, *78*(2), 199–216. www.iucnredlist.org.

McCay, B., & Acheson, J. (1987). *The Question of the Commons: The Culture and Ecology of Communal Resources* (B. J. McCay & J. M. Acheson, Eds.). University of Arizona Press. https://doi.org/10.2307/j.ctv2fcct2z

Moore, P. E., Meyer, J. B., & Chow, L. S. (2017). *Natural Resource Inventory and Monitoring for Ulaan Taiga Specially Protected Areas-An Assessment of Needs and Opportunities in Northern Mongolia*.

Nandintsetseg, B., Greene, J. S., & Goulden, C. E. (2007). Trends in extreme daily precipitation and temperature near Lake Hövsgöl, Mongolia. *International Journal of Climatology*, *27*(3), 341–347. https://doi.org/10.1002/joc.1404

National Agency for Meteorology, H. and E. M. (2016). *Historical temperature and precipitation data, 1975–2015: Moron Branch, Moron, Khuvsgul aimag, Mongolia*. Www.Icc.Mn/Aimag/Khuvsgul/.

Reading, R., Bedunah, D., & Amgalanbaatar, S. (2006). Conserving Biodiversity on Mongolian Rangelands: Implications for Protected Area Development and Pastoral Uses. *Environmental Science* .

Retzer, V. (2007). Forage competition between livestock and Mongolian Pika (Ochotona pallasi) in Southern Mongolian mountain steppes. *Basic and Applied Ecology*, *8*(2), 147–157. https://doi.org/10.1016/j.baae.2006.05.002

Schuman, G. E., Reeder, J. D., Manley, J. T., Hart, R. H., & Manley, W. A. (1999). Impact of grazing management on the carbon and nitrogen balance of a mixed-grass rangeland. *Ecological Applications*, *9*(1), 65–71. https://doi.org/10.1890/1051-0761(1999)009[0065:IOGMOT]2.0.CO;2

Singleton, G. R., Hinds, L. A., Krebs, C. J., & Spratt, D. M. (2003). *Rats, mice, and people: rodent biology and management*. www.aciar.gov.au

Smith, A. T., & Foggin, J. M. (1999). The plateau pika (Ochotona curzoniae) is a keystone species for biodiversity on the Tibetan plateau. *Animal Conservation*, *2*(4), 235–240. https://doi.org/10.1111/j.1469-1795.1999.tb00069.x

Smith, A. T., Formozov, A. N., Hoffmann, R. S., Zheng, C., & Erbajeva, M. A. (1990). The pikas . In *Rabbits, hares, and pikas: status survey and conservation action plan*. IUCN.

Travina, I. V, Derviz, D. G., & Dmitriev, P. P. (2000). Relationships between Pikas (Ochotona, Mammalia) and Vegetation in Tuva. In *Original Russian Text Copyright* (Vol. 31, Issue 1).

UNDP. (2012). *Mongolia's Sustainable Development Agenda* .

Wang, G., Wang, Z., Zhou, Q., & Zhong, W. (1999). Relationship between species richness of small mammals and primary productivity of arid and semi-arid grasslands in north China. *Journal of Arid Environments* , *43*(4).

Wang, G., & Zhong, W. (2006). Mongolian gerbils and Daurian pikas responded differently to changes in precipitation in the Inner Mongolian grasslands. *Journal of Arid Environments*, *66*(4), 648–656. https://doi.org/10.1016/j.jaridenv.2005.12.003

Wang, G., Zhong, W., Zhou, Q., & Wang, Z. (2003). Soil water condition and small mammal spatial distribution in Inner Mongolian steppes, China. *Journal of Arid Environments*, *54*(4), 729–737. https://doi.org/10.1006/jare.2002.1083

Wang, G., Zhou, Q., Zhong, W., & Wang, Z. (2003). *Spatial overlap between sympatric Microtus brandti (Rodentia, Microtinae) and Ochotona daurica (Lagomorpha, Ochotonidae) in the steppes of inner Mongolia*.

Wang, M., Zhong, W., & Wan, X. (2000). A study of home range of Daurian pika (Ochotona daurica) through telemetry. *NActa Theriologic Sinica*, *20*(2).

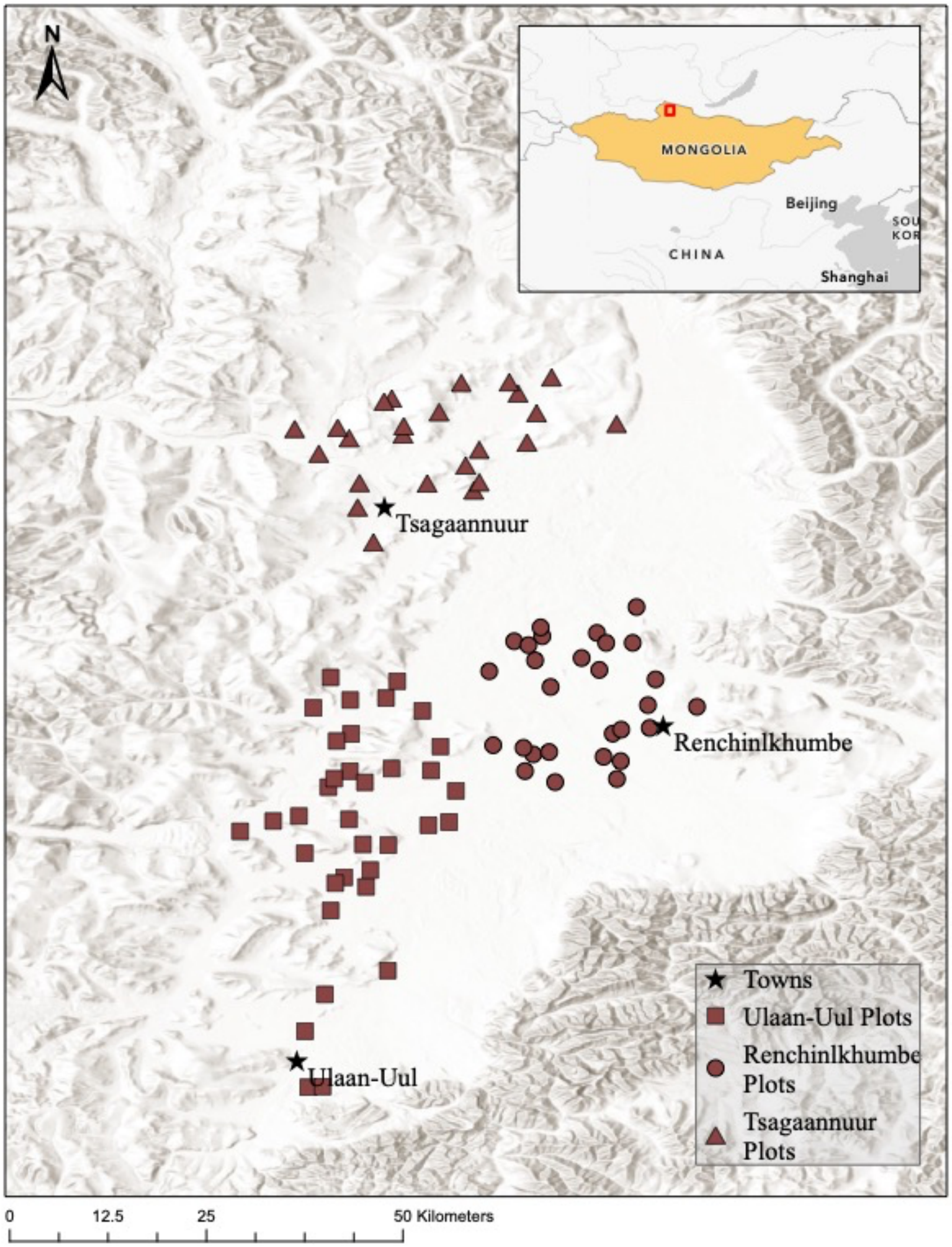
Wright, J. P., & Jones, C. G. (2006). The concept of organisms as ecosystem engineers ten years on: Progress, limitations, and challenges. In *BioScience* (Vol. 56, Issue 3, pp. 203–209). https://doi.org/10.1641/0006-3568(2006)056[0203:TCOOAE]2.0.CO;2

Zhang, Z., Pech, R., Davis, S., Shi, D., Wan, X., Zhang, W. Z., Davis, R., Shi, S., Zhong, X., Extrinsic, W. 2003, Zhang, Z., Wan, X., Zhong, W., & Shi, -D. (2003). Extrinsic and intrinsic factors determine the eruptive dynamics of Brandt's voles Microtus brandti in Inner Mongolia, China. In *OIKOS* (Vol. 100).

Zhong, W., Wang, G., Zhou, Q., Wan, X., & Wang, G. (2008). Effects of winter food availability on the abundance of Daurian pikas (Ochotona dauurica) in Inner Mongolian grasslands. *Journal of Arid Environments*, *72*(7), 1383–1387. https://doi.org/10.1016/j.jaridenv.2007.12.011

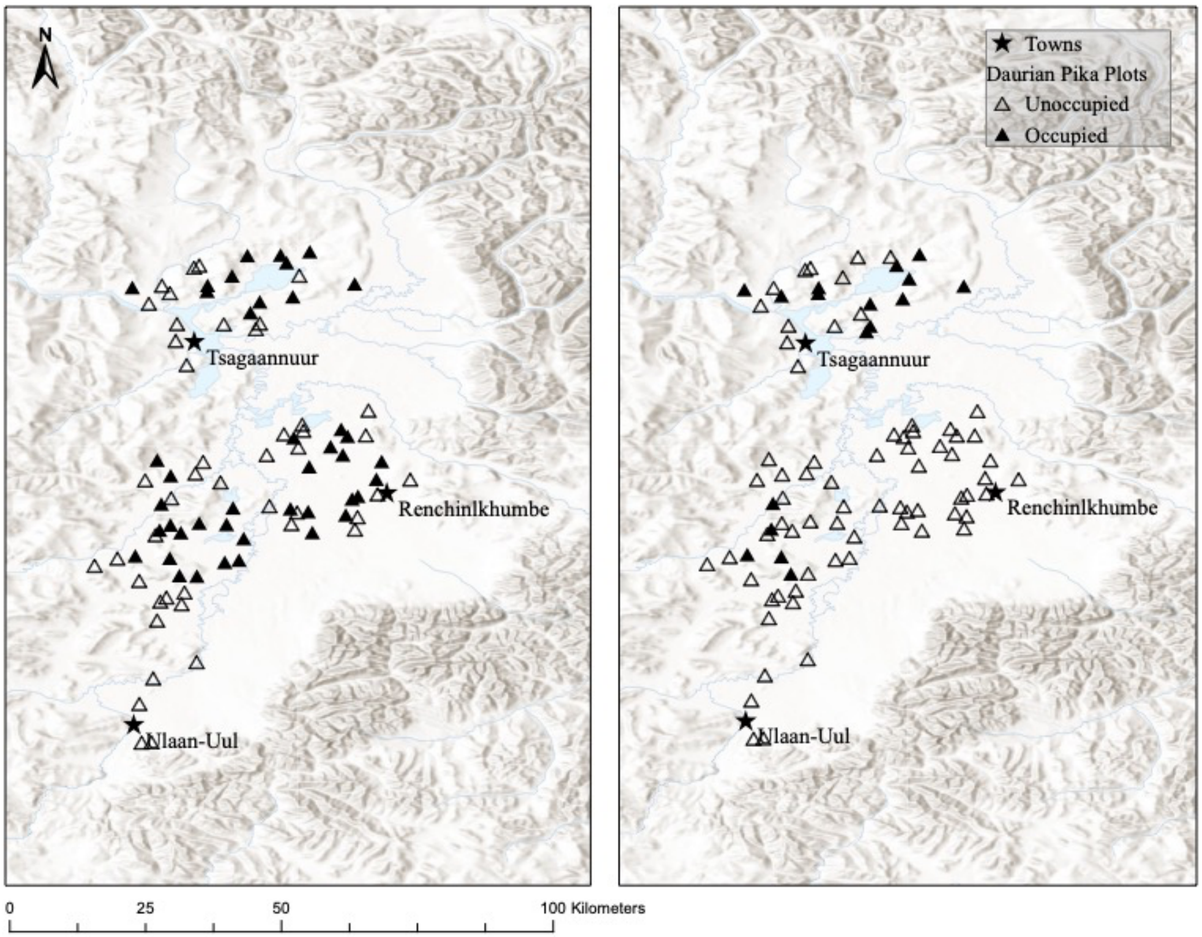
TABLES AND FIGURES

Figure 1



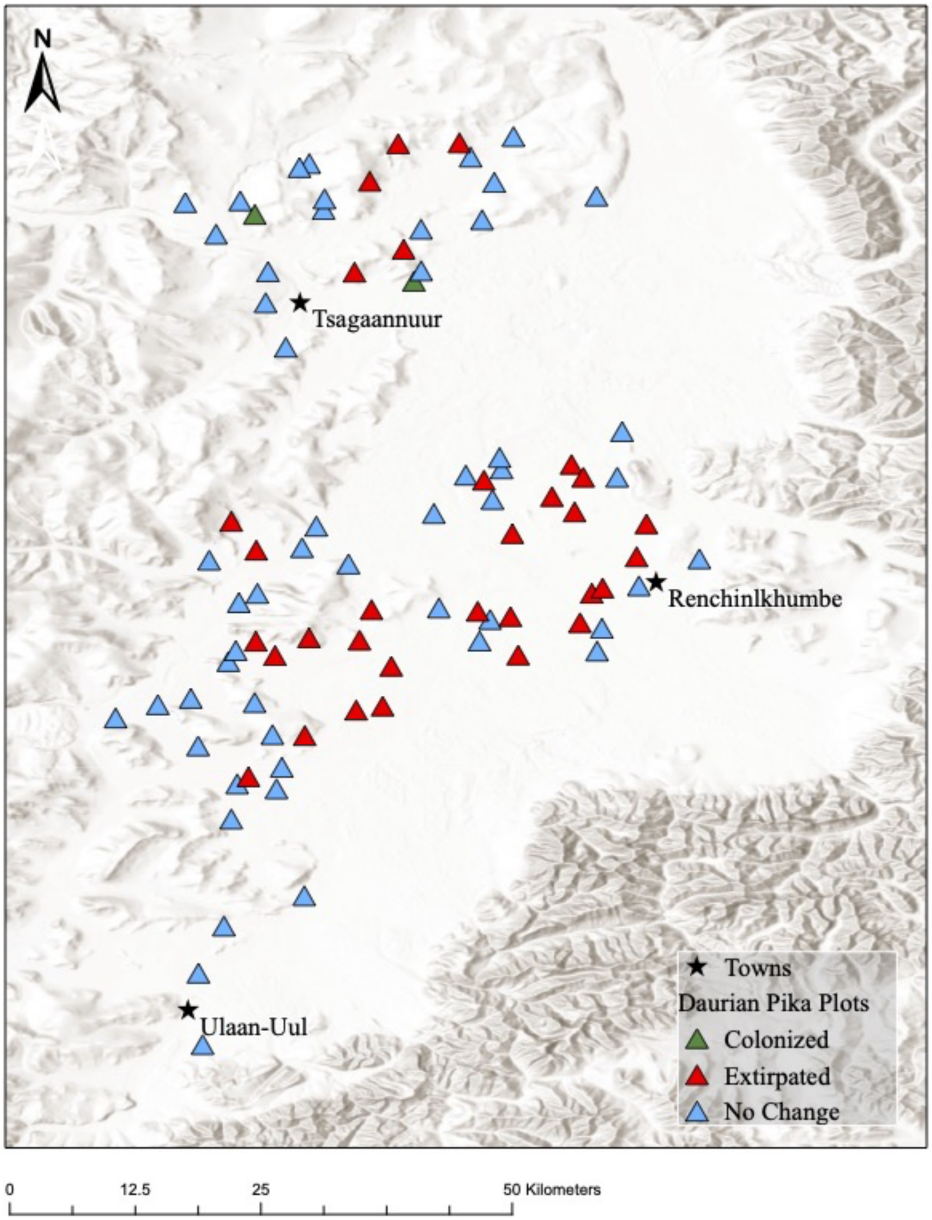
Study area in the Darhad Valley, Mongolia.

Figure 2



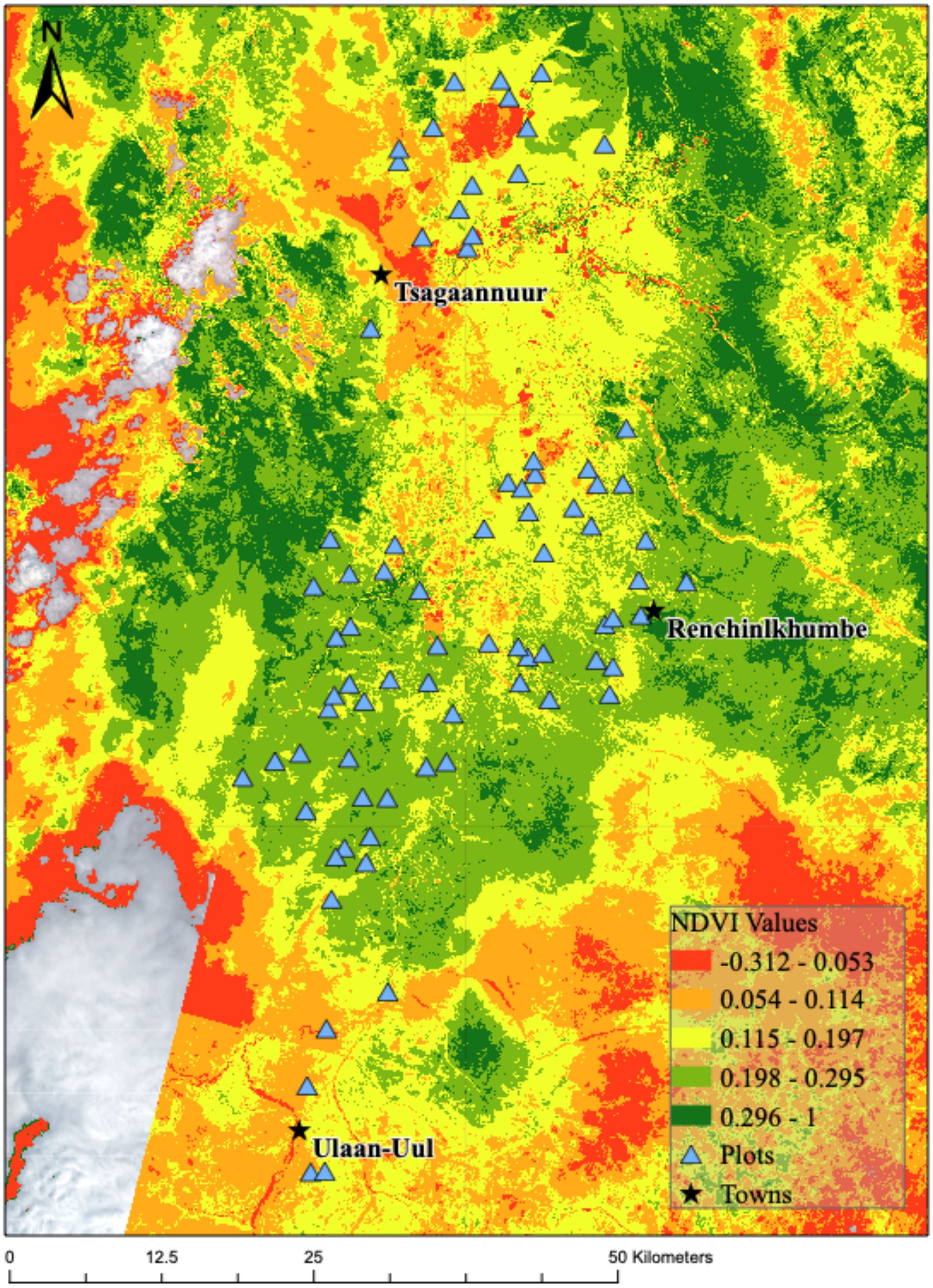
Daurian pika plot occupancy status in 2019 (left) and 2022 (right).

Figure 3



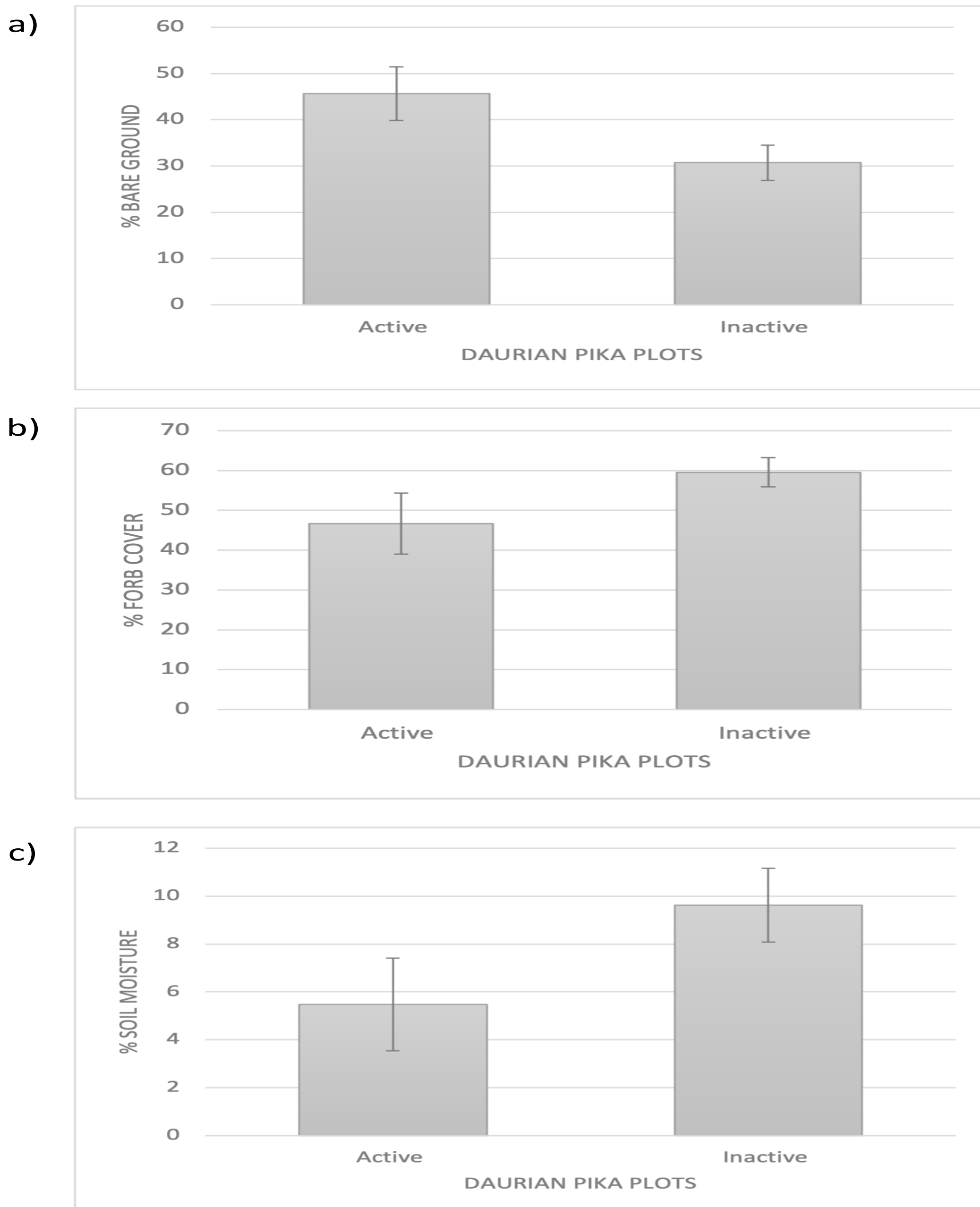
Daurian pika plot occupancy changes between 2019 and 2022.

Figure 4



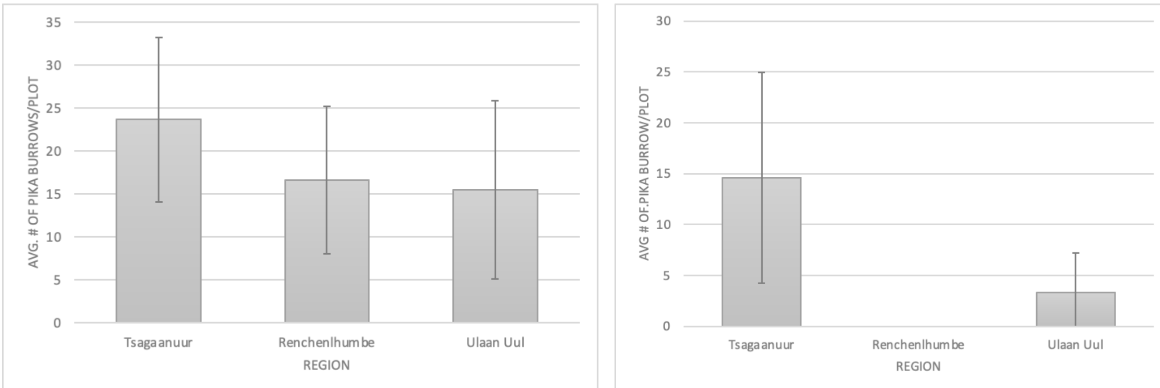
Normalized Difference Vegetation Index of the Darhad Valley, Mongolia, July 8, 2022.

Figure 5



Analyses according to Daurian pika plot occupancy status with 95% confidence intervals: a) Percent Bare Ground ("BareGrd"); b) Percent Forb Cover ("ForbCvr"); and c) Percent Soil Moisture.

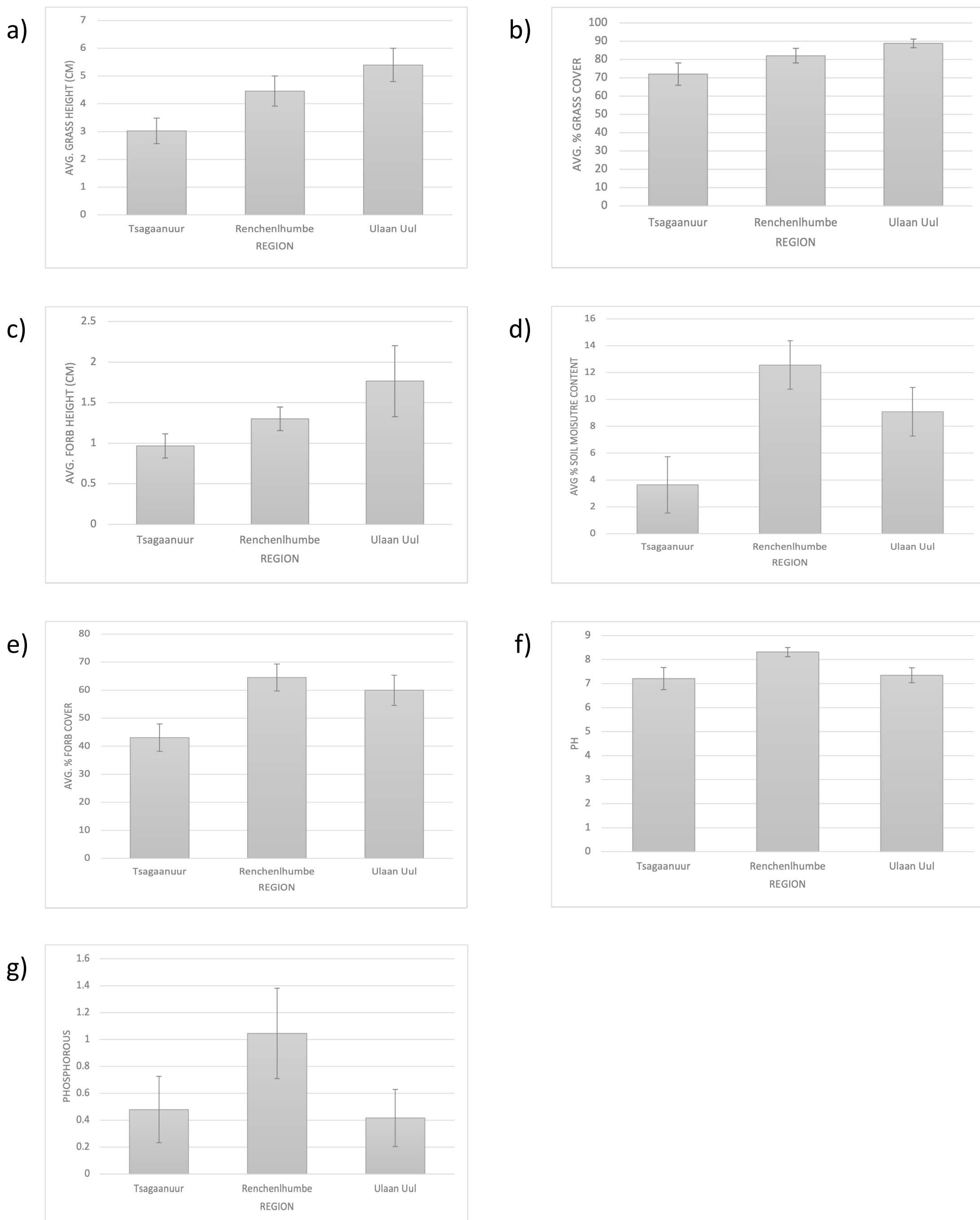
Figure 6



Regional abundance of Daurian pika in 2019 (left) and 2022 (right) with 95% Confidence Intervals

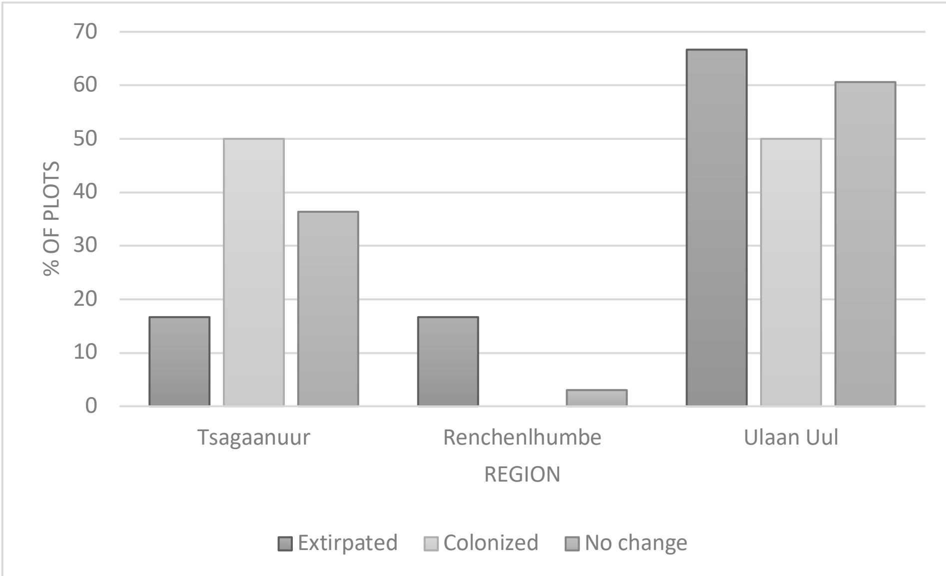
Please note the regional extirpation of Daurian pika in the Renchinlhumbe region in 2022 (right figure).

Figure 7



Vegetation and grazing intensity analyses according to region of Daurian pika plots with 95% confidence intervals: a) Average Grass Height ("GrassHt"), b) Average Percent Grass Cover ("GrassCvr"), c) Average Forb Height ("ForbHt"), d) Average Percent Soil Moisture ("SoilMoist"), e) Average Percent Forb Cover ("ForbCvr"), f) Average pH ("pH"), and g) Average phosphorous levels ("P").

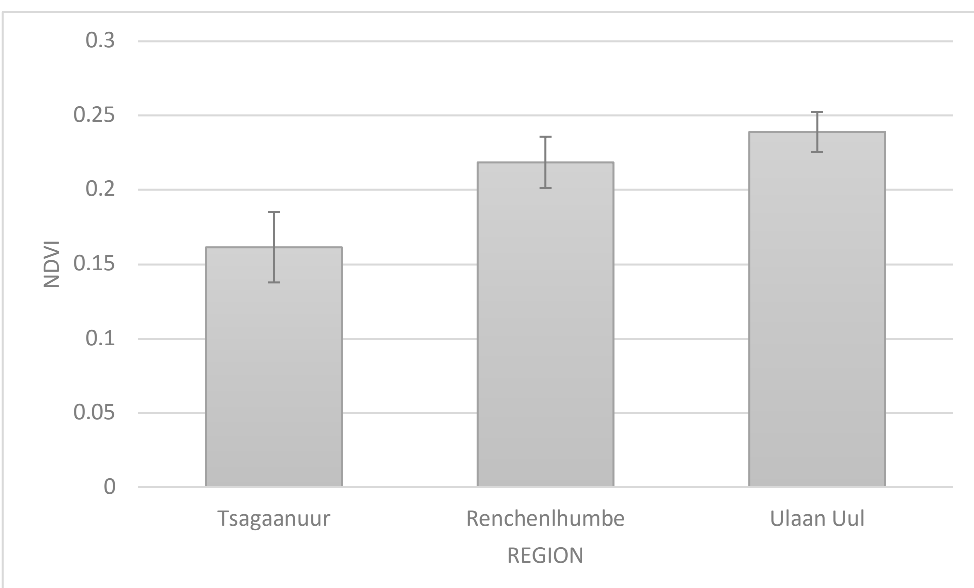
Figure 8



Percentage of Daurian pika plots by region that were extirpated, colonized, or experienced no occupancy change between 2019 and 2022 with 95% confidence intervals.

Note. Please note that Renchinlhumbe experienced no colonization events.

Figure 9



Average NDVI values from August 9, 2022 ("NDVI2022") of Daurian pika plots by region with 95% Confidence Intervals

Table 1

Generalized linear model results of Daurian pika occupancy, 2022

	K	AICc	Delta_AICc	AICcWt	Cum.Wt	LL
Region + Bareground	4	64.7	0	0.93	0.93	-28.1
Region	3	70.69	5.99	0.05	0.98	-32.2
Region + Percent Forb	4	72.38	7.68	0.02	1	-31.94
Bareground + Percent Forb	3	79.08	14.38	0	1	-36.39
Bareground	2	81.37	16.67	0	1	-38.61
Percent Forb	2	84.93	20.23	0	1	-40.39

Table 2

Generalized linear model results of Daurian pika abundance, 2022

	K	AICc	Delta_AICc	AICcWt	Cum.Wt	LL
Region + Bareground	5	241.19	0.00	0.60	0.60	-115.21
Region	4	244.22	3.04	0.13	0.73	-117.86
Region + NDVI	5	244.29	3.10	0.13	0.86	-116.76
Region + Percent Forb	5	246.16	4.97	0.05	0.91	-117.70
Region + Soil Moisture	5	246.42	5.23	0.04	0.95	-117.83
Region + Percent Grass	5	246.48	5.30	0.04	1.00	-117.86
Percent Forb	3	253.48	12.29	0.00	1.00	-123.59
Percent Forb + NDVI	4	254.77	13.58	0.00	1.00	-123.13
NDVI	3	254.83	13.64	0.00	1.00	-124.27
Soil Moisture + NDVI	4	254.98	13.80	0.00	1.00	-123.24
Bareground	3	256.95	15.76	0.00	1.00	-125.33
Soil Moisture	3	257.75	16.56	0.00	1.00	-125.72
Percent Grass	3	261.41	20.22	0.00	1.00	-127.56
Null	2	262.16	20.97	0.00	1.00	-129.01

Table 3

Results of a paired two sample for means t-Test for pH of on-borrow vs. off-burrow soil samples.

	On-burrow sample pH	*Off-burrow sample pH*
Mean	7.916666667	7.452381
Variance	0.802083333	1.585119
Observations	21	21
Pearson Correlation	0.334423393	
Hypothesized Mean Difference	0	
df	20	
t Stat	1.664934401	
P(T<=t) one-tail	0.055757236	
t Critical one-tail	1.724718243	
P(T<=t) two-tail	0.111514472	
t Critical two-tail	2.085963447	

Table 4

Results of a paired two sample for means t-Test for phosphorous levels of on-borrow vs. off-burrow soil samples.

	On-burrow sample P	*Off-burrow sample P*
Mean	1.071429	0.511905
Variance	1.400893	0.365476
Observations	21	21
Pearson Correlation	0.610181	
Hypothesized Mean Difference	0	
df	20	
t Stat	2.713094	
P(T<=t) one-tail	0.006694	
t Critical one-tail	1.724718	
P(T<=t) two-tail	0.013389	
t Critical two-tail	2.085963	

Table 5
Results of a paired two sample for means t-Test for soil moisture content of on-borrow vs. off-burrow soil samples.

	On-burrow sample soil moisture content (%)	*Off-burrow sample soil moisture content (%)*
Mean	4.485238095	6.371429
Variance	15.21927619	36.94014
Observations	21	21
Pearson Correlation	0.729309178	
Hypothesized Mean Difference	0	
df	20	
t Stat	-2.06183963	
P(T<=t) one-tail	0.026229437	
t Critical one-tail	1.724718243	
P(T<=t) two-tail	0.052458874	
t Critical two-tail	2.085963447	

Table 6
Independent variables used to predict pika occupancy & abundance. Variables were collected within five main categories of vegetation, grazing intensity, soil composition, region, and weather.

Category	*Variable*	*Description*
Vegetation & grazing intensity	GrassHt	The tallest grass in contact with the meter stick (cm). Collected at 1-m intervals along each 50-m transect at each plot.
	ForbHt	The tallest forb in contact with the meter stick (cm). Collected at 1-m intervals along each 50-m transect at each plot.
	GrassCov	The percentage observations within a plot where "GrassHt" was greater than 0.

ForbCov	The percentage of observations within a plot where "ForbHt" was greater than 0.
NDVI2022	NDVI value for each plot obtained through Landsat imagery in ArcGIS Pro.
Overgraz	The percentage of observations where Stipa (*Stipa baicalensis*), Artemisia (*Artemisia sp.*), and/or Cinquefoil species (*Potentilla sp.)* was present at each 1-m interval along each 50-m transect at each plot.
BareGrnd	The percentage of observations where bare ground was recorded, defined as a 75% or greater absence of vegetation within a 1.5-cm diameter circle under the meter stick at each 1-m interval along each 50-m transect at each plot.
Scat	The percentage of observations where livestock scat was present (categorized as "goat/sheep," "cow/yak," and/or "horse") within 10-cm of the base of the meter stick. Collected at 1-m intervals along each 50-m transect at each plot.
GrazPres	Qualitative observation of grazing pressure by Dr. Dovchin at each

		plot. Categorized as “low,” “medium,” or “high.”
Soil composition Soil composition collection sites were established within a 3-m radius of the center of each plot. If the plot was determined active, a secondary collection site was established at the mouth of an active Daurian pika burrow using the same collection methods. All data was collected using the Luster Leaf 1665 Professional Soil Kit (LaMotte Inc).	pH	pH level collected at each soil composition collection site.
	N	Nitrogen level at each soil composition collection site.
	P	Phosphorous level at each soil composition collection site.
	K	Potassium level at each soil composition collection site.
	SoilMoist	Soil moisture content (%) collected at each plot site at a depth of 5-10 cm within the A horizon using a soil moisture probe.
Region	Region	Regional location of each plot site. Categorized as “Ulaan-Uul,” “Renchinlhumbe,” or “Tsagaannuur” (Figure X).
Weather *Daily weather data was obtained from weather stations located at the town centers of Renchinlhumbe, Ulaan Uul, and Tsagaannuur.*	AvgAirTemp	Daily average air temperature observed, ºC
	MaxAirTemp	Daily maximum air temperature observed, ºC
	MinAirTemp	Daily minimum air temperature observed, ºC
	Precip	Daily precipitation, mm
	SnowHt	Daily snow height, cm

Table 7
Dependent variables used to analyze the relative effect(s) of the independent variables on Daurian pika occupancy and abundance.

Occupancy and abundance	PikaOccupied	Presence or absence of Daurian pika at each plot site in 2019.
	Pika2019	The number of active Daurian pika burrows within each plot site in 2019.
	PP	The presence or absence of Daurian pika at each plot site in 2022.
	PF	The number of active Daurian pika burrows within each plot site in 2022.
	OP	The number of old Daurian pika burrows within each plot site in 2022.
	GS	The presence or absence of ground squirrels at each plot site in 2022.

Table 8

Results of a paired two sample for means t-Test for 2018 winter snow cover of Ulaan Uul and Renchinlhumbe.

2018 winter snow cover
t-Test: Paired Two Sample for Means

	Variable 1-UU	*Variable 2- R*
Mean	5.799799583	2.914626536
Variance	25.36752129	8.30031846
Observations	12	12
Pearson Correlation	0.286964114	

Hypothesized Mean Difference	0
df	11
t Stat	1.985459779
P(T<=t) one-tail	0.036294232
t Critical one-tail	1.795884819
P(T<=t) two-tail	0.072588463
t Critical two-tail	2.20098516

Table 9

Results of a paired two sample for means t-Test for 2021 winter snow cover of Ulaan Uul and Renchinlhumbe.

2021 winter snow cover

t-Test: Paired Two Sample for Means

	Variable 1 - R	*Variable 2 - UU*
Mean	6.285426267	3.208560015
Variance	29.28324221	8.98476404
Observations	12	12
Pearson Correlation	0.105808301	
Hypothesized Mean Difference	0	
df	11	
t Stat	1.80587748	
P(T<=t) one-tail	0.049173099	
t Critical one-tail	1.795884819	
P(T<=t) two-tail	0.098346199	
t Critical two-tail	2.20098516	

Table 10

Results of a paired two sample for means t-Test for 2021 winter snow cover of Renchinlhumbe and Tsagaannuur.

2021 winter snow cover

t-Test: Paired Two Sample for Means

	Variable 1 - R	*Variable 2 - T*
Mean	6.285426267	3.479781106
Variance	29.28324221	28.96811784
Observations	12	12
Pearson Correlation	0.446713964	

Hypothesized Mean Difference	0
df	11
t Stat	1.711957235
P(T<=t) one-tail	0.057457924
t Critical one-tail	1.795884819
P(T<=t) two-tail	0.114915848
t Critical two-tail	2.20098516

Table 11

*Vegetation variables according to plot occupancy status, including averages and confidence intervals. *Denotes statistical significance.*

	Forb cover (%)	Bare ground (%)	Soil moisture (%)
Active	*M*=46.68%, *SD*=7.64%	**M*=45.63%, *SD*=3.63%	*M*=5.48%, *SD*=1.94%
Inactive	**M*=59.56%, *SD*=3.63%	*M*=30.70%, *SD*=3.83%	*M*=9.62%, *SD*=1.54%

I

Table 12

*Vegetation variables according to region, including averages and confidence intervals. *Denotes statistical significance.*

	Grass height (cm)	Forb height (cm)	Grass cover (%)	Forb cover (%)	NDVI
Renchinlhumbe	*M*=4.46 cm,	*M*=1.30 cm, *SD*=0.14	*M*=82.12%, *SD*=3.97	*M*=64.50%, *SD*=4.77	*M*=0.22, *SD*=0.02

	SD=0.54 cm				
Tsagaannuur	**M*=3.02 cm, *SD*=0.46 cm	**M*=0.97 cm, *SD*=0.15 cm	**M*=72.04%, *SD*=6.15	**M*=43.08%, *SD*=4.89	**M*=0.16, *SD*=0.02
Ulaan Uul	*M*=5.40 cm, *SD*=0.60 cm	*M*=1.76 cm, *SD*=0.44	**M*=88.85%, *SD*=2.36	*M*=59.94%, *SD*=5.37	*M*=0.24, *SD*=0.01

Table 13
*Soil characteristics according to region, including averages and confidence intervals. *Denotes statistical significance.*

	Soil Moisture (%)	pH level	Phosphorous level
Renchinlhumbe	*M*=12.56%, *SD*=1.80	**M*=8.31, *SD*=0.19	*M*=1.04, *SD*=0.34
Tsagaannuur	**M*=3.63%, *SD*=2.11	*M*=7.21, *SD*=0.46	*M*=0.48, *SD*=0.25
Ulaan Uul	*M*=9.08%, *SD*=1.82	*M*=7.35, *SD*=0.31	**M*=0.42, *SD*=0.21

Table 14

*Total yearly precipitation levels in Renchinlhumbe, Tsagaannuur, and Ulaan Uul from 2019-2022. *Denotes significantly higher or lower precipitation levels.*

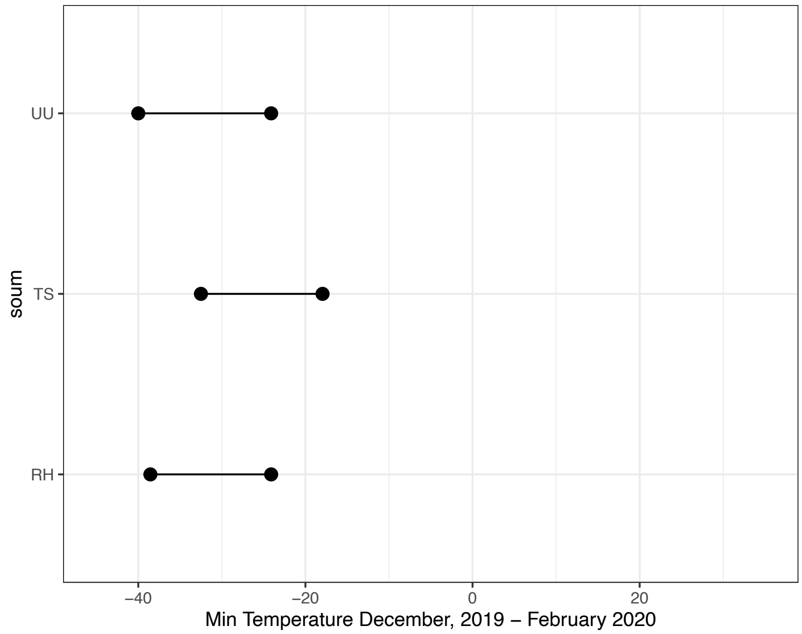
	Renchinlhumbe precipitation (mm)	Tsagaannuur precipitation (mm)	Ulaan Uul precipitation (mm)
2019	*M*=273.7 mm, *SD*=19.25	*M*=246.6 mm, *SD*=15.39	**M*=321.1 mm, *SD*=18.78
2020	**M*=232.3 mm, *SD*=14.47	*M*=148.1 mm, *SD*=11.75	*M*=161.8 mm, *SD*=11.61
2021	*M*=285.2 mm, *SD*=16.75	*M*=298.4 mm, *SD*=16.50	**M*=387.3 mm, *SD*=24.1
2022 (January – October)	**M*=143.1 mm, *SD*=15.46	**M*=200.9 mm, *SD*=19.70	*M*=189.4 mm, *SD*=19.99

Table 15

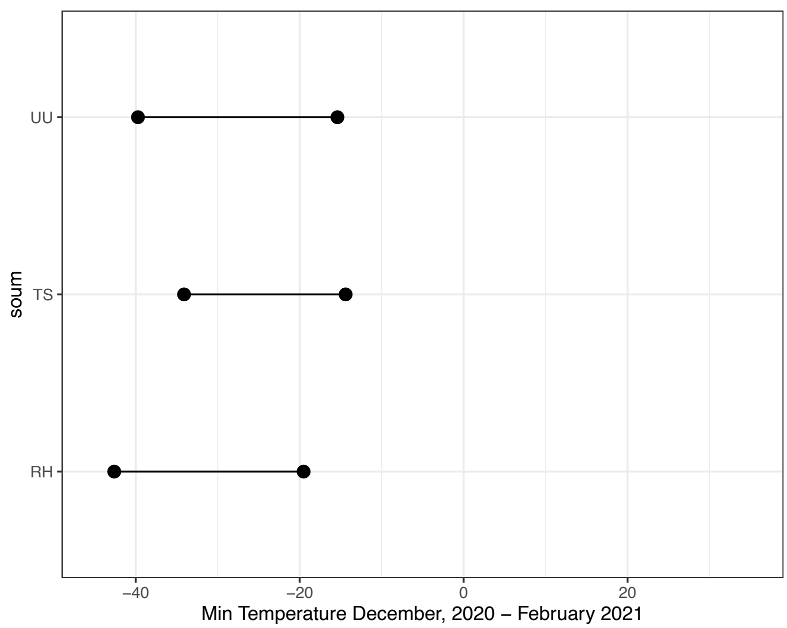
*Snow cover in the Darhad Valley according to region. Please note that the years of 2019, 2020, and 2022 demonstrated no significant differences between the three regions. *Denotes statistical significance.*

	Renchinlhumbe snow cover (cm)	Tsagaannuur snow cover (cm)	Ulaan Uul snow cover (cm)
2018	*M*=2.91	n/a	**M*=5.80
2021	**M*=6.29	*M*=3.48	*M*=3.21

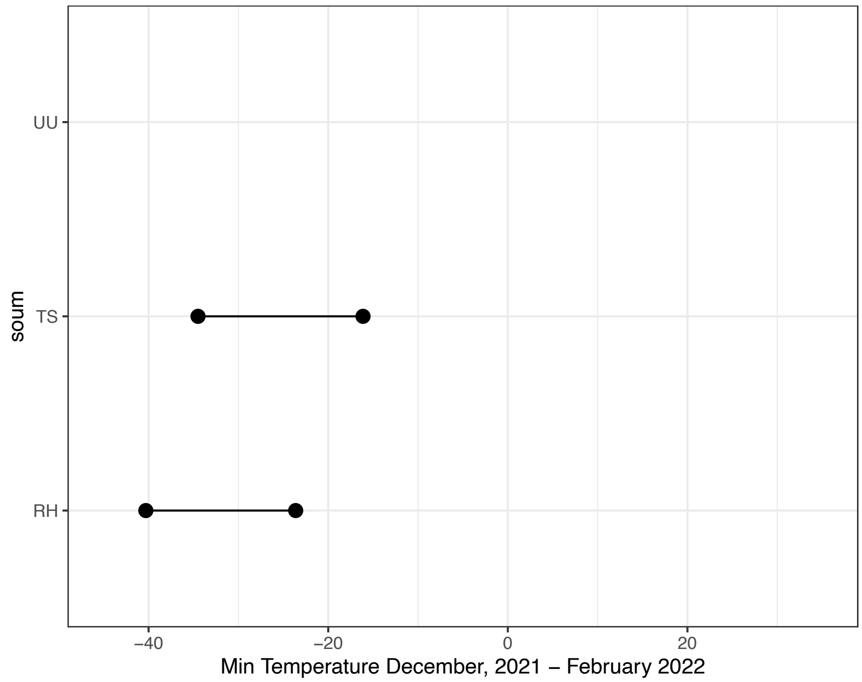
Appendix A



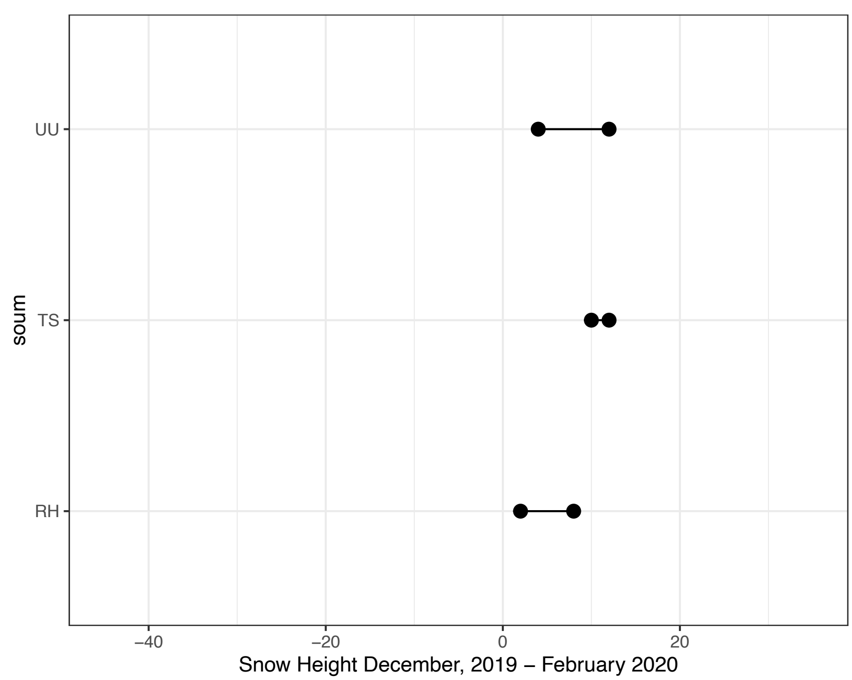
90% quantile of minimum temperature across Ulaan Uul (UU), Tsagaannuur (TS), and Renchinlhumbe (RH) (December 2019 – February 2020)



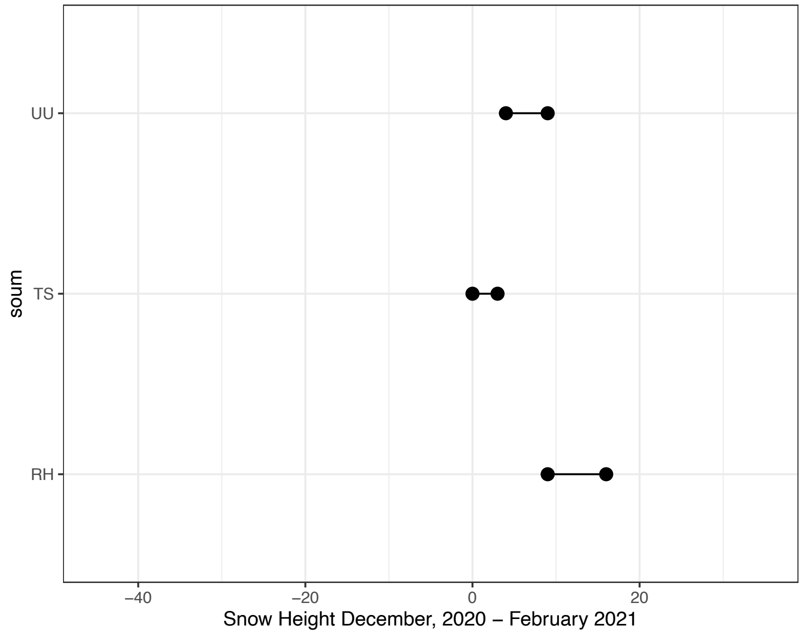
90% quantile of minimum temperature across Ulaan Uul (UU), Tsagaannuur (TS), and Renchinlhumbe (RH) (December 2020 – February 2021)



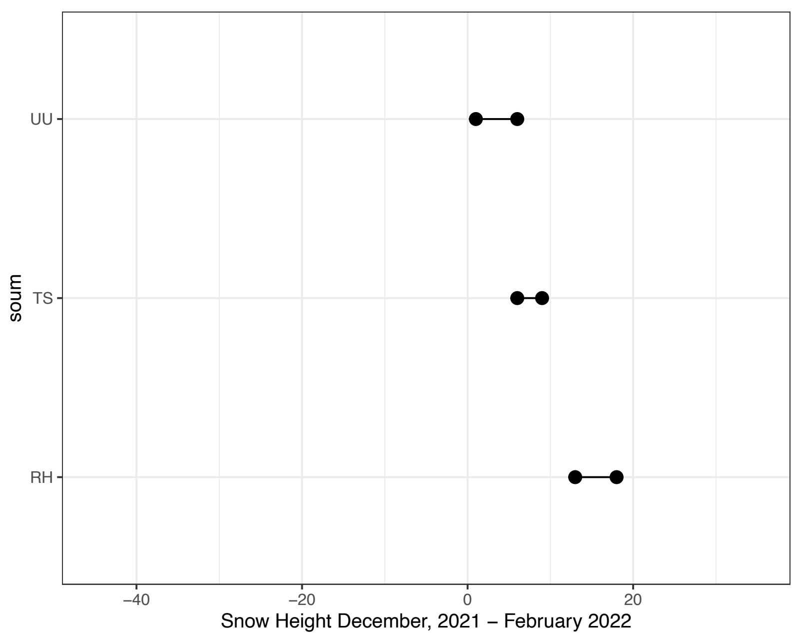
90% quantile of minimum temperature across Ulaan Uul (UU), Tsagaannuur (TS), and Renchinlhumbe (RH) (December 2021 – February 2022). Ulaan Uul lacked data for this time.



90% quantile of snow height across Ulaan Uul (UU), Tsagaannuur (TS), and Renchinlhumbe (RH) (December 2019 – February 2020)

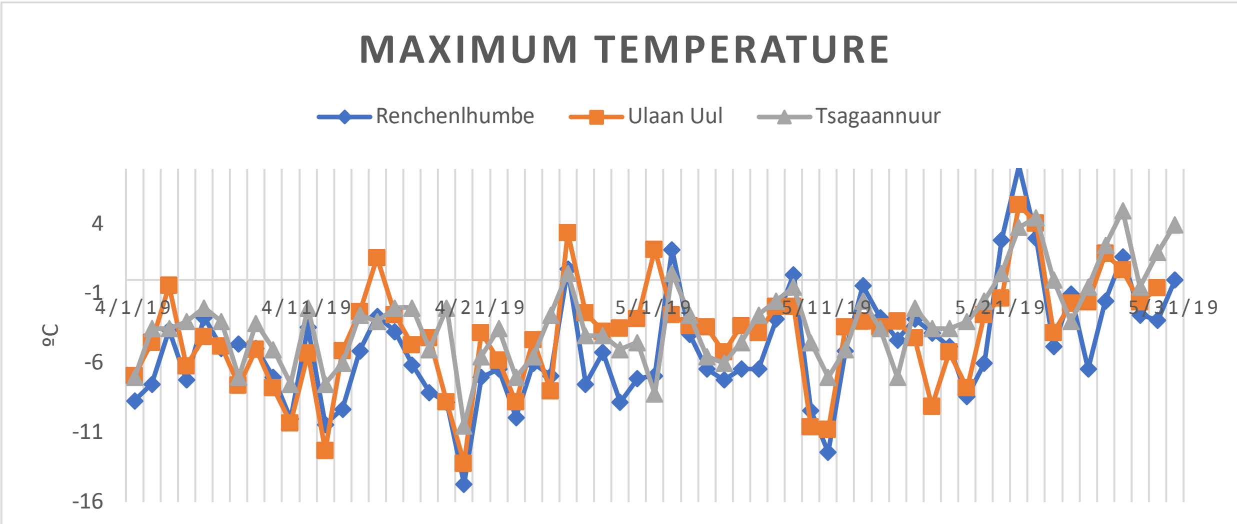


90% quantile of snow height across Ulaan Uul (UU), Tsagaannuur (TS), and Renchinlhumbe (RH) (December 2020 – February 2021)

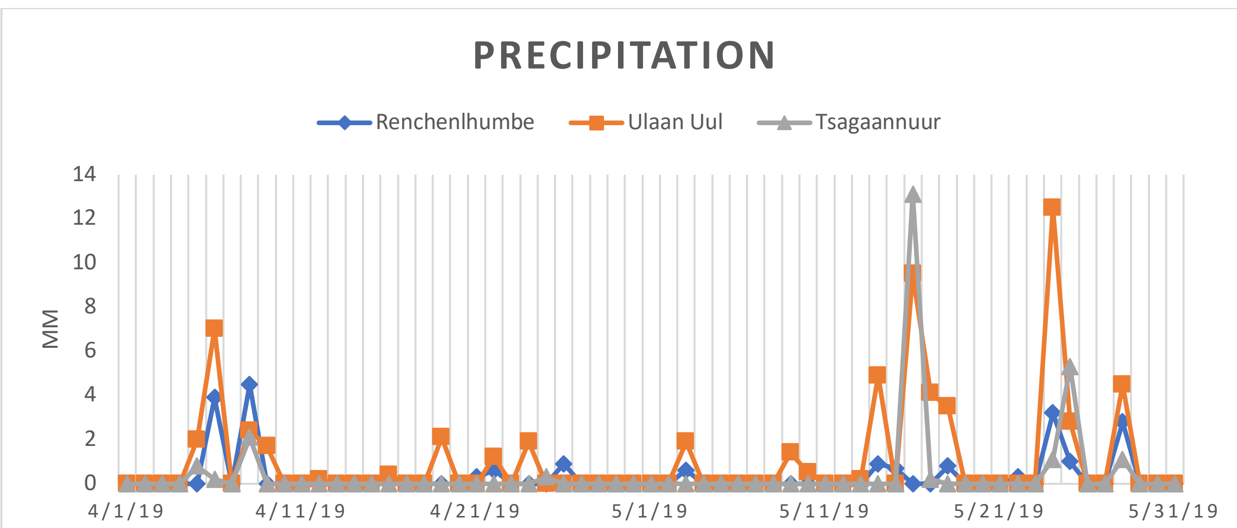


90% quantile of snow height across Ulaan Uul (UU), Tsagaannuur (TS), and Renchinlhumbe (RH) (December 2021 – February 2022)

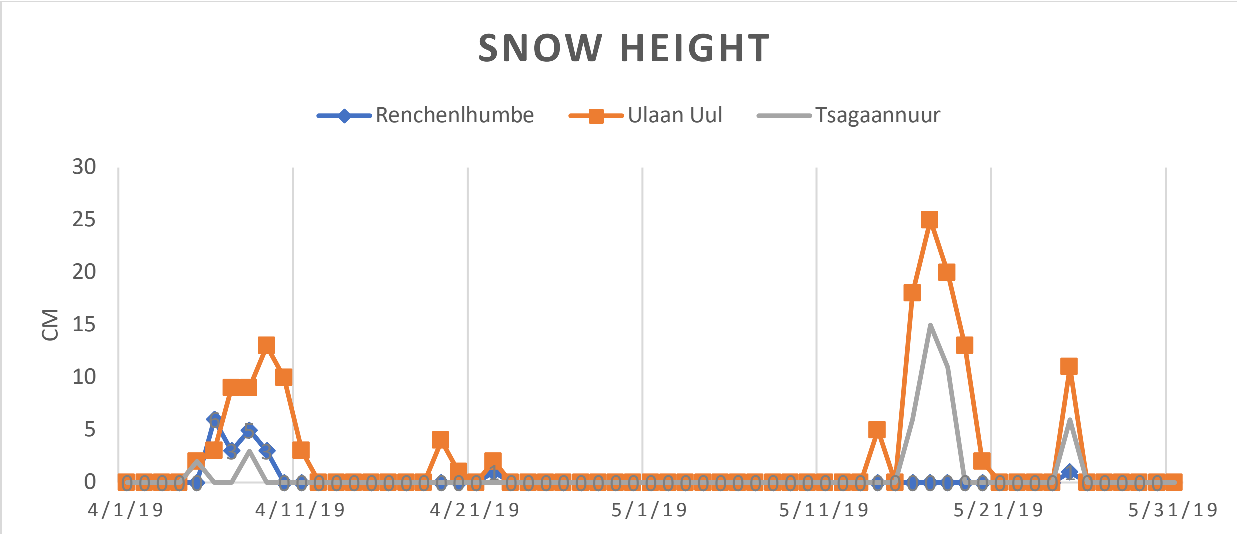
Appendix B



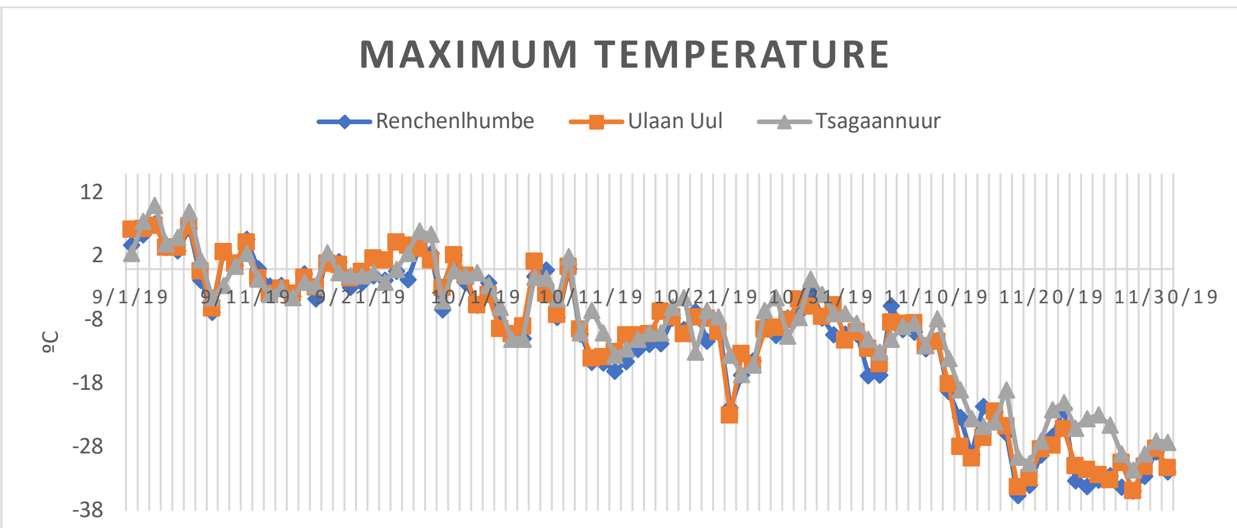
Maximum temperature in Renchinlhumbe, Ulaan Uul, and Tsagaannuur during the months of April – May 2019.



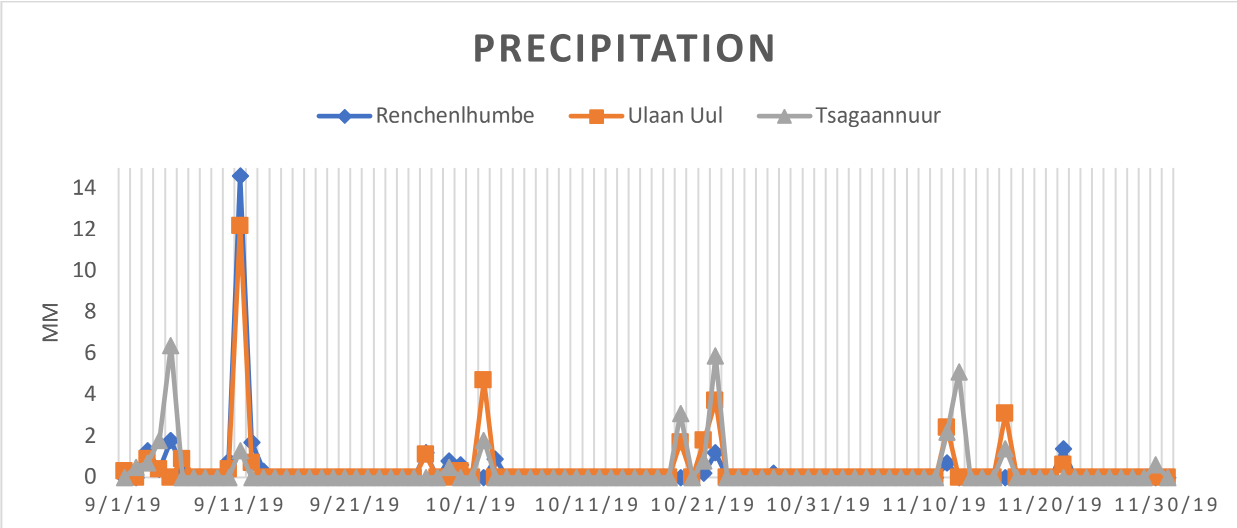
Precipitation levels in Renchinlhumbe, Ulaan Uul, and Tsagaannuur during the months of April – May 2019.



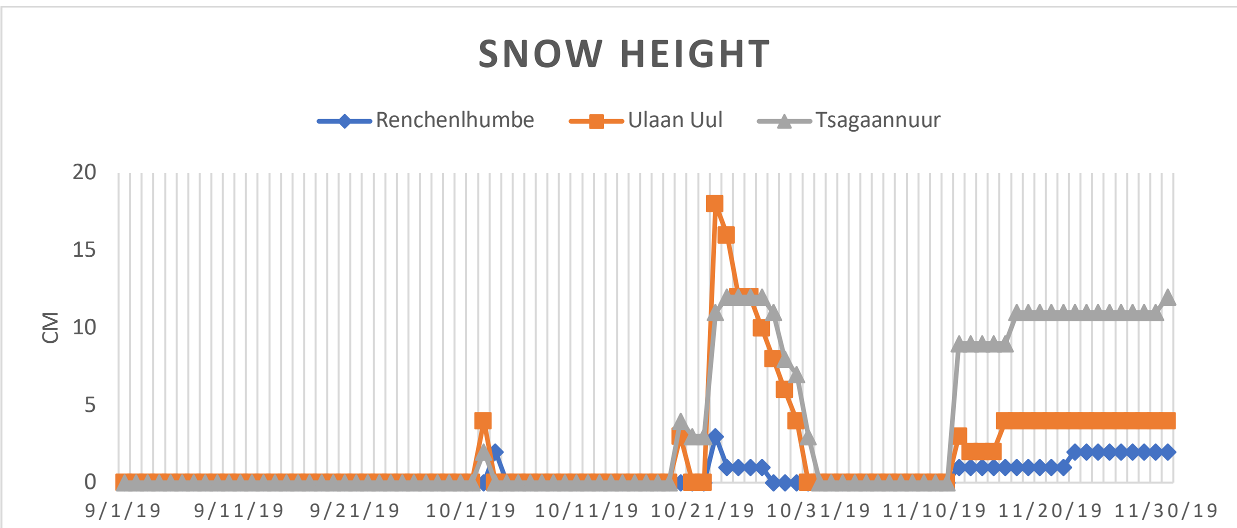
Snow height in Renchinlhumbe, Ulaan Uul, and Tsagaannuur during the months of April – May 2019.



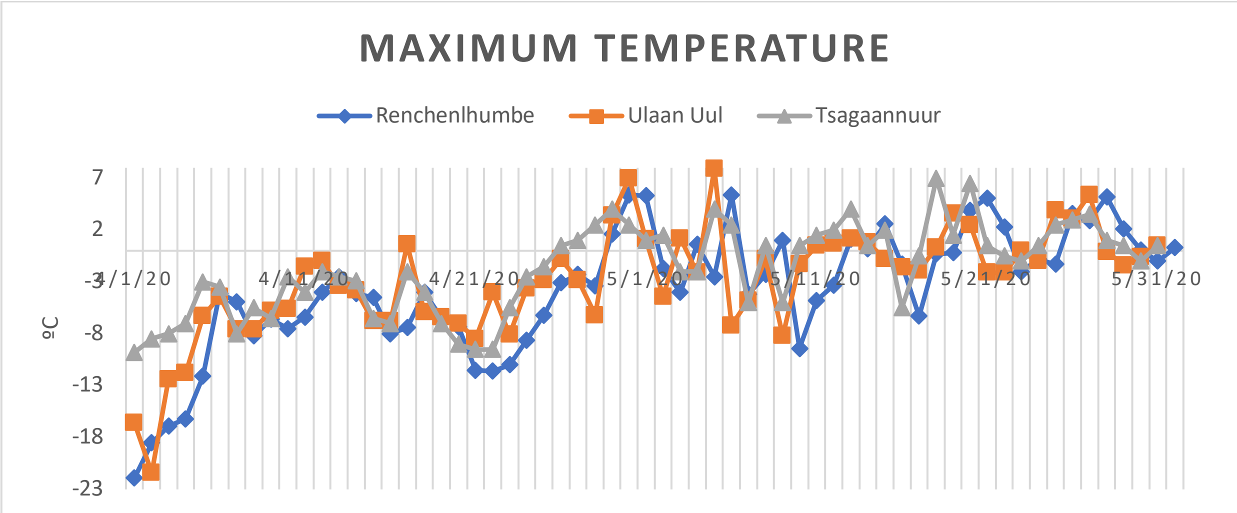
Maximum temperature in Renchinlhumbe, Ulaan Uul, and Tsagaannuur during the months of September – November 2019.



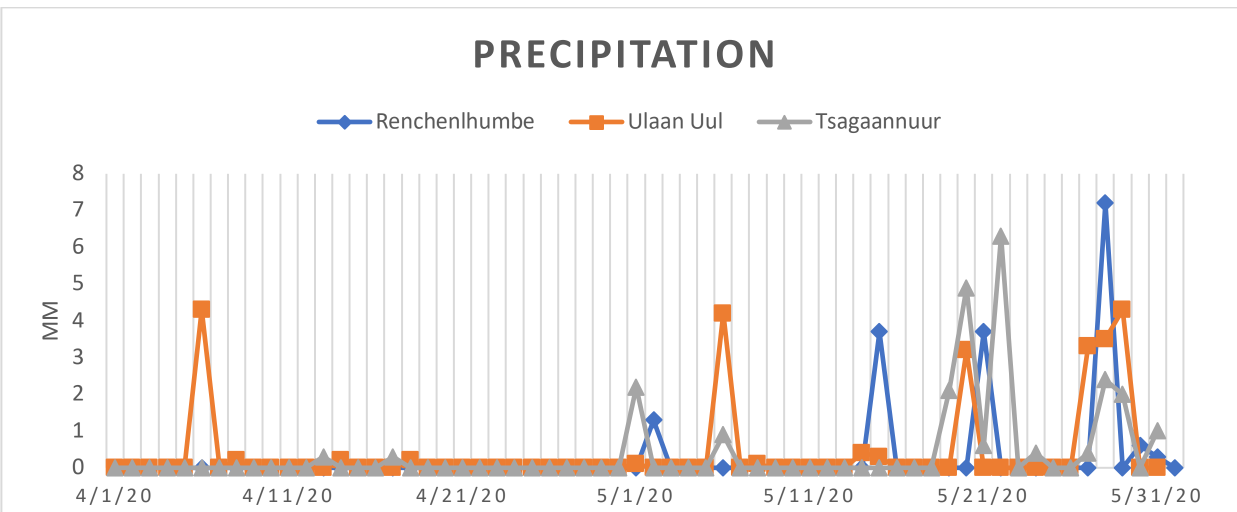
Precipitation levels in Renchinlhumbe, Ulaan Uul, and Tsagaannuur during the months of September – November 2019.



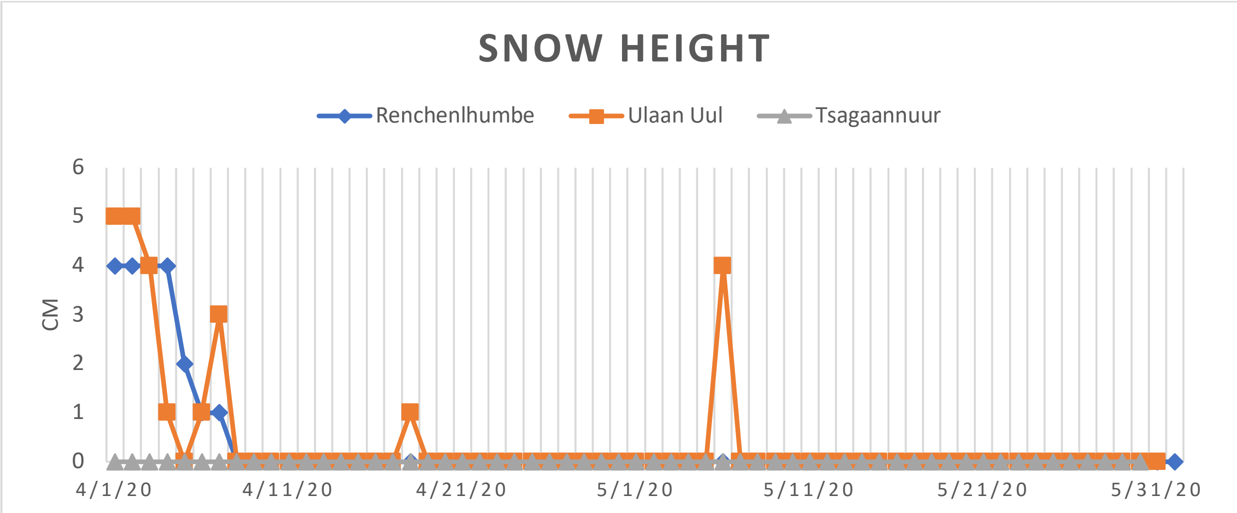
Snow height in Renchinlhumbe, Ulaan Uul, and Tsagaannuur during the months of September – November 2019.



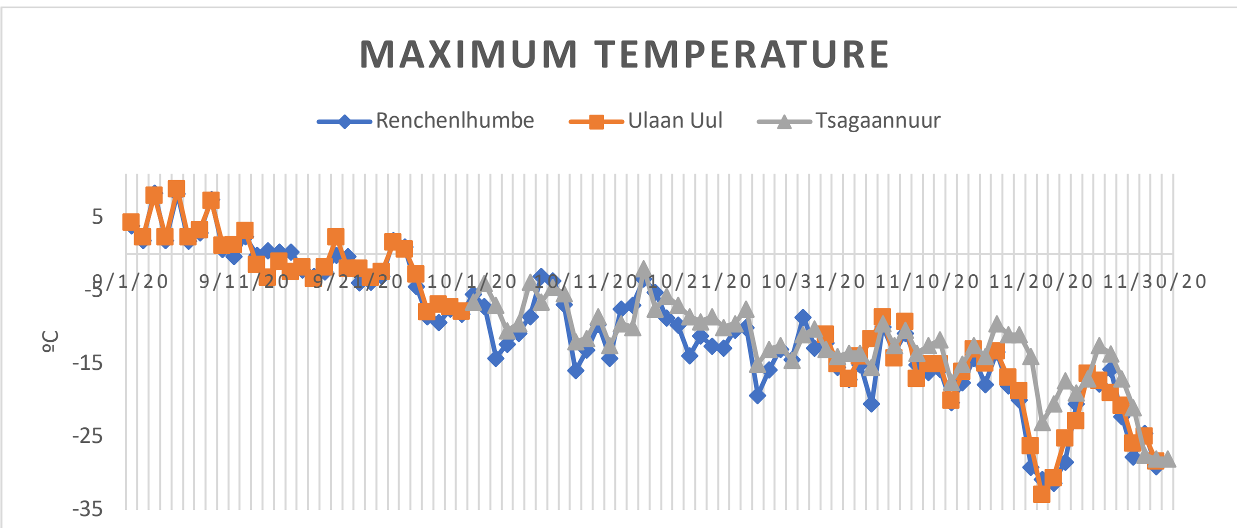
Maximum temperature in Renchinlhumbe, Ulaan Uul, and Tsagaannuur during the months of April – May 2020. Please note the oscillation between above-freezing and sub-zero temperatures starting in late April.



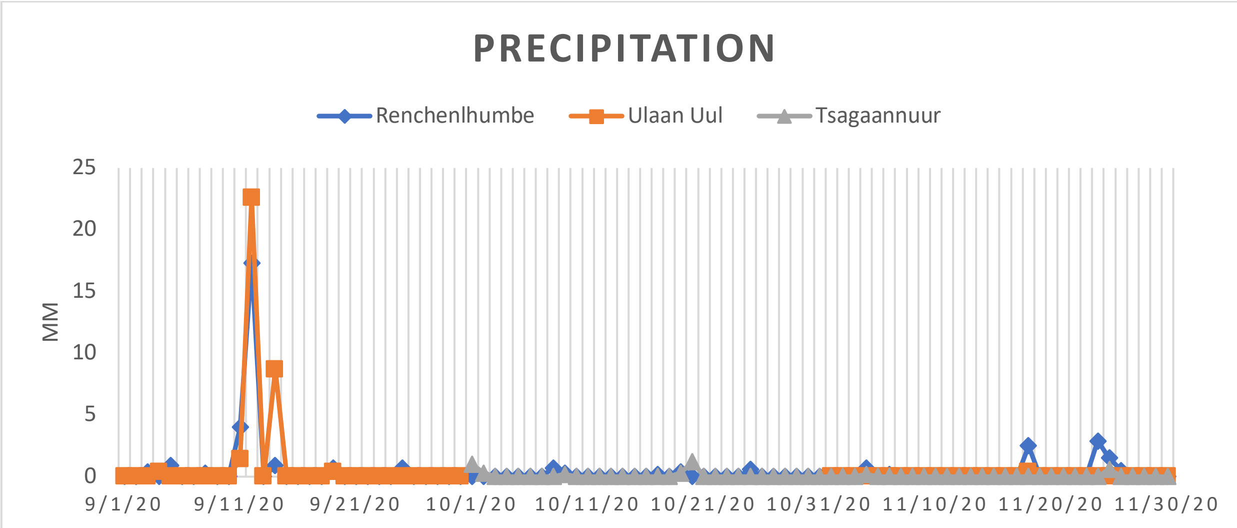
Precipitation levels in Renchinlhumbe, Ulaan Uul, and Tsagaannuur during the months of April – May 2020. Please note the multiple precipitation events in Renchinlhumbe between 5/15/20 and 5/30/20.



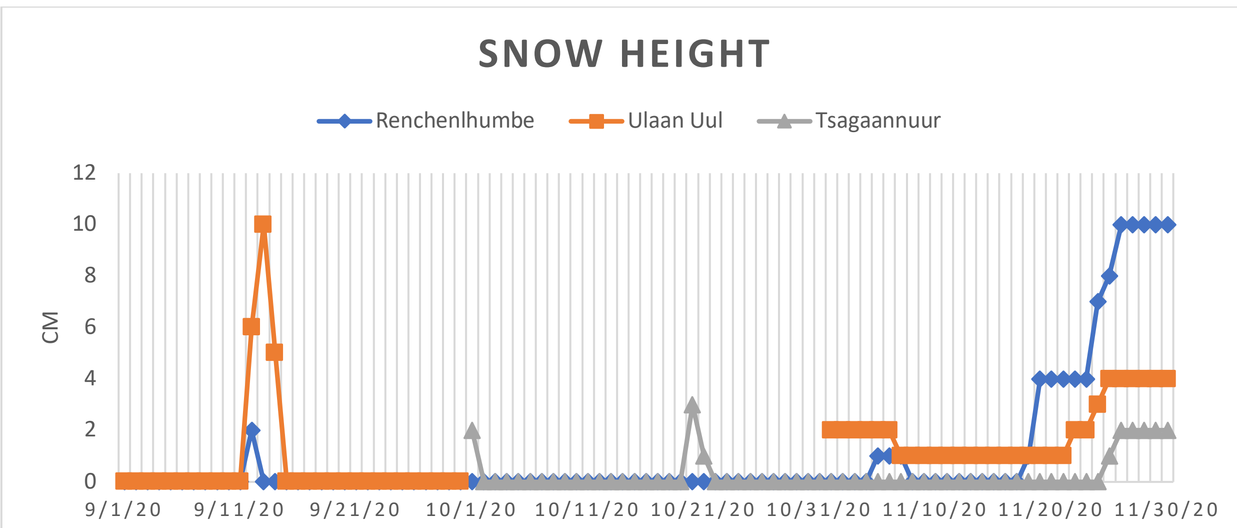
Snow height in Renchinlhumbe, Ulaan Uul, and Tsagaannuur during the months of April – May 2020. Please note that the precipitation events in Renchinlhumbe observed above were received as rainfall.



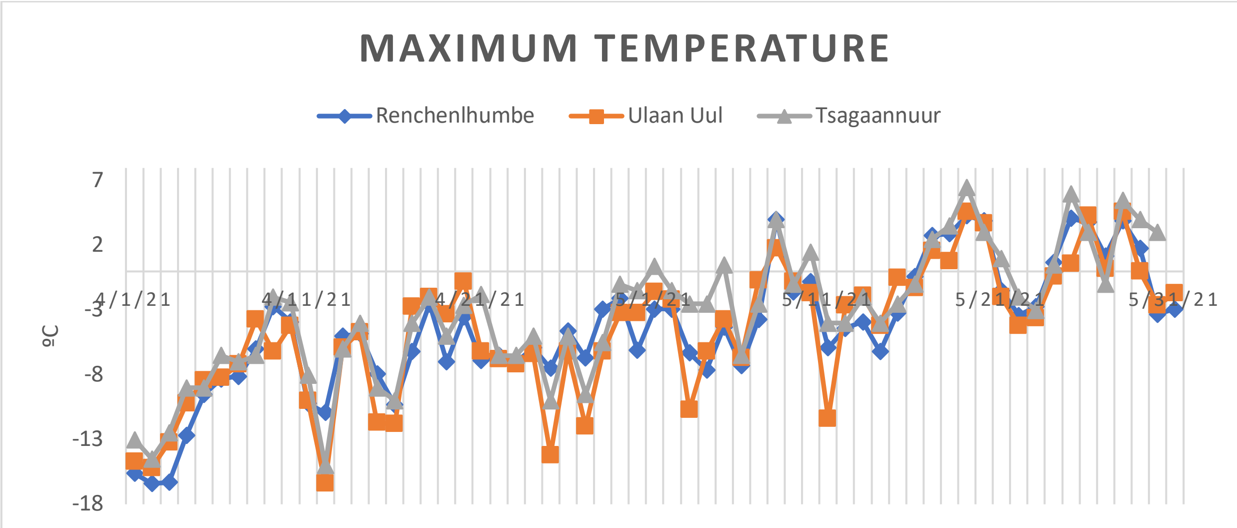
Maximum temperature in Renchinlhumbe, Ulaan Uul, and Tsagaannuur during the months of September – November 2020.



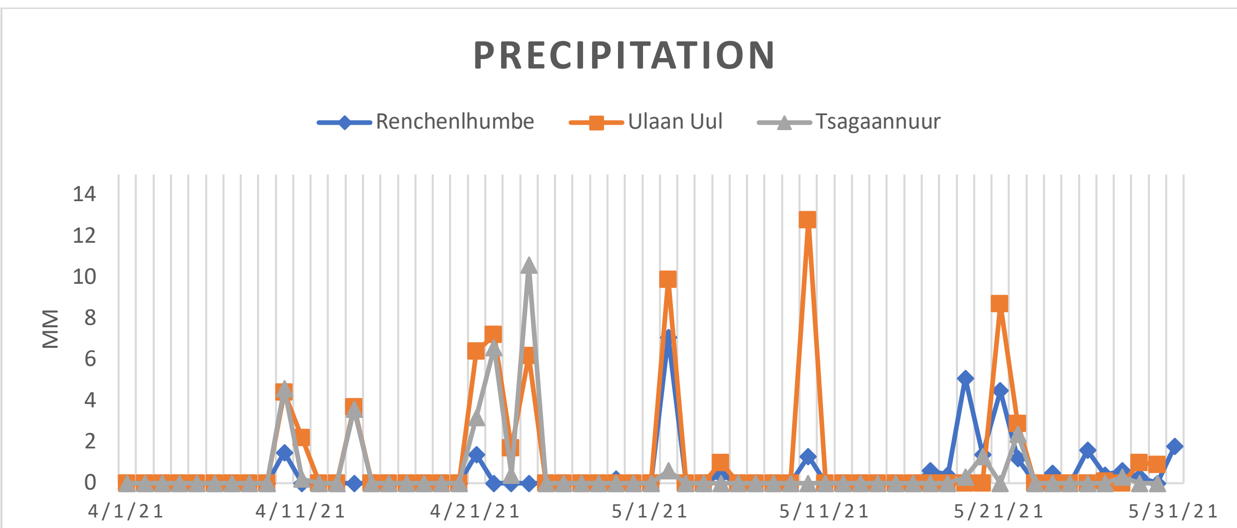
Precipitation levels in Renchinlhumbe, Ulaan Uul, and Tsagaannuur during the months of September – November 2020.



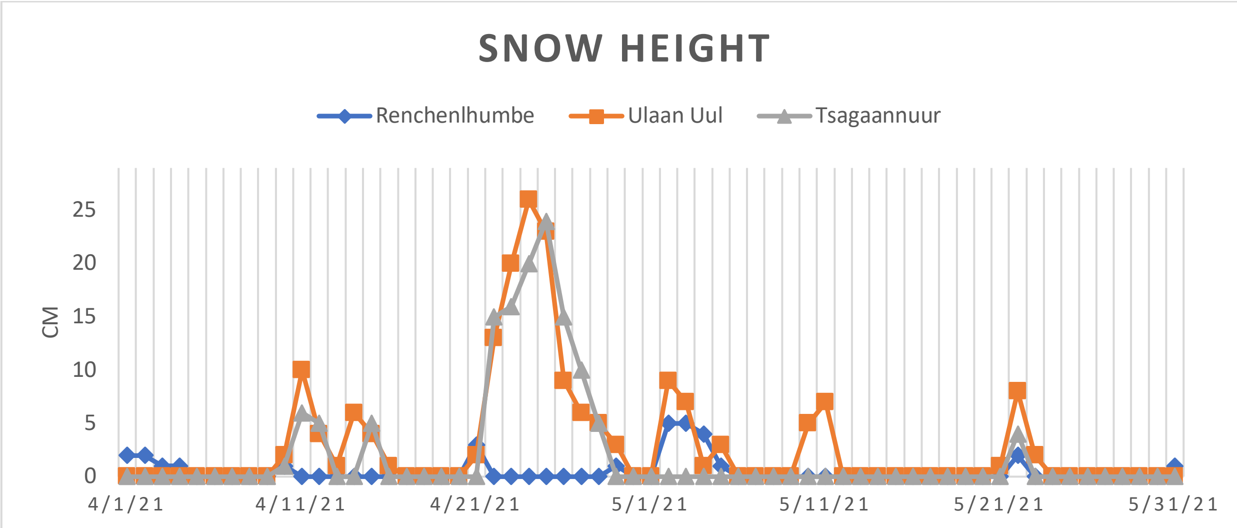
Snow height in Renchinlhumbe, Ulaan Uul, and Tsagaannuur during the months of September – November 2020.



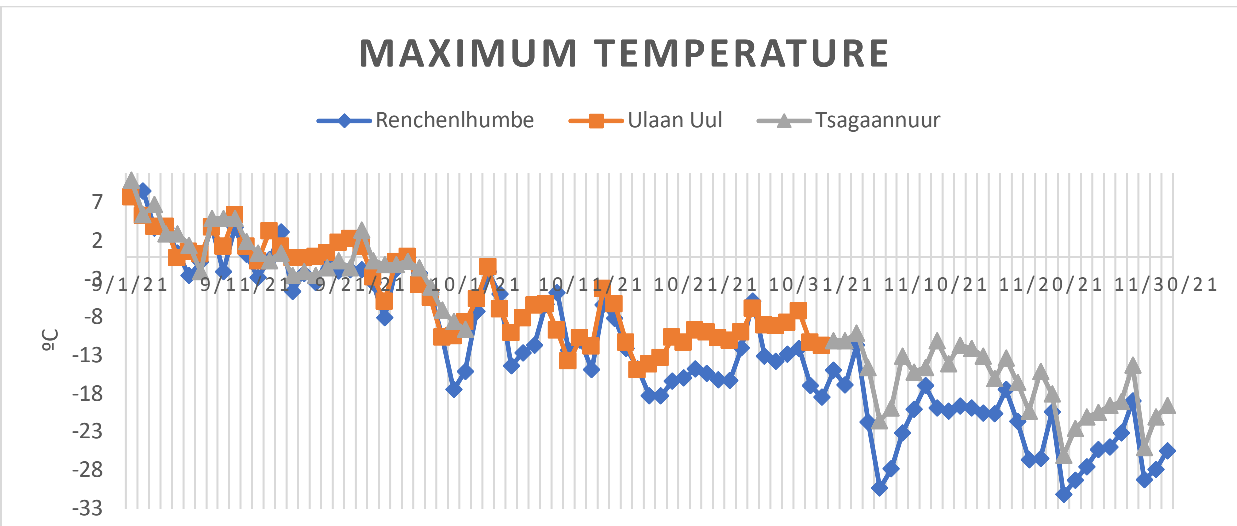
Maximum temperature in Renchinlhumbe, Ulaan Uul, and Tsagaannuur during the months of April – May 2021.



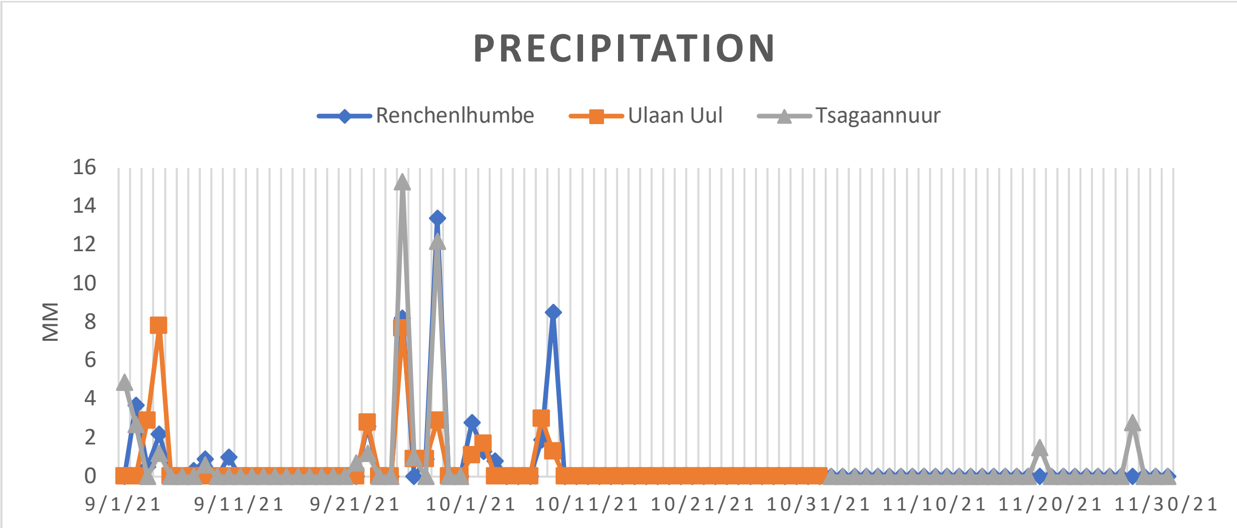
Precipitation levels in Renchinlhumbe, Ulaan Uul, and Tsagaannuur during the months of April – May 2021.



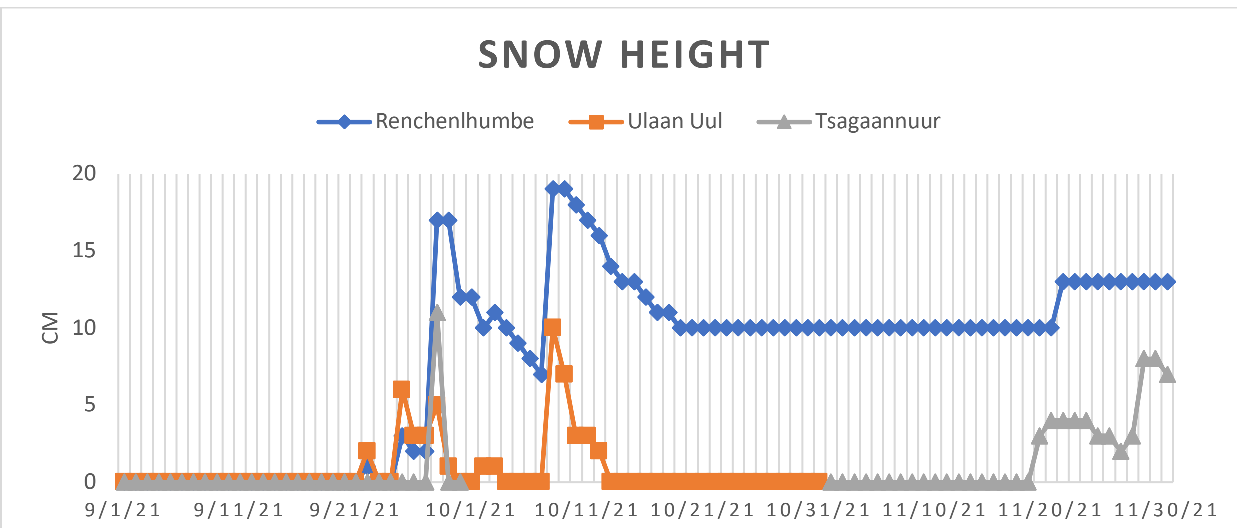
Snow height in Renchinlhumbe, Ulaan Uul, and Tsagaannuur during the months of April – May 2021.



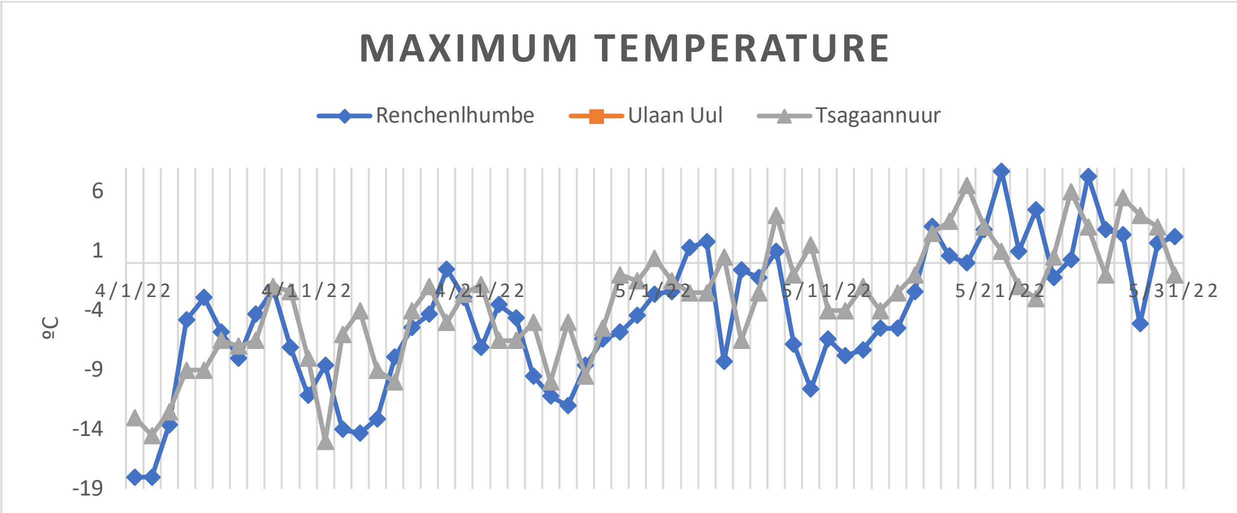
Maximum temperature in Renchinlhumbe, Ulaan Uul, and Tsagaannuur during the months of September – November 2021.



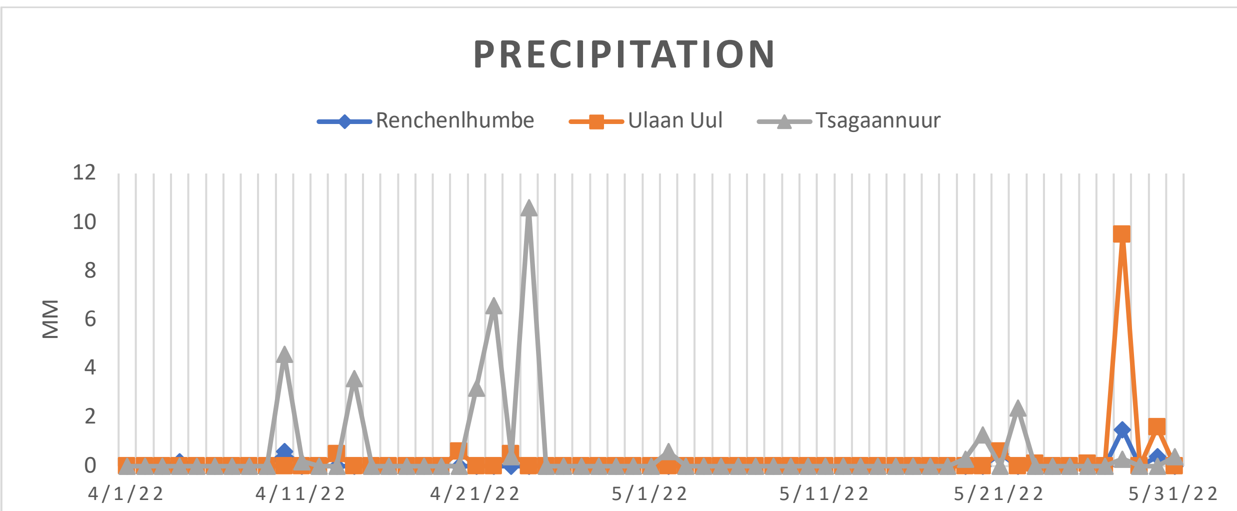
Precipitation levels in Renchinlhumbe, Ulaan Uul, and Tsagaannuur during the months of September – November 2021.



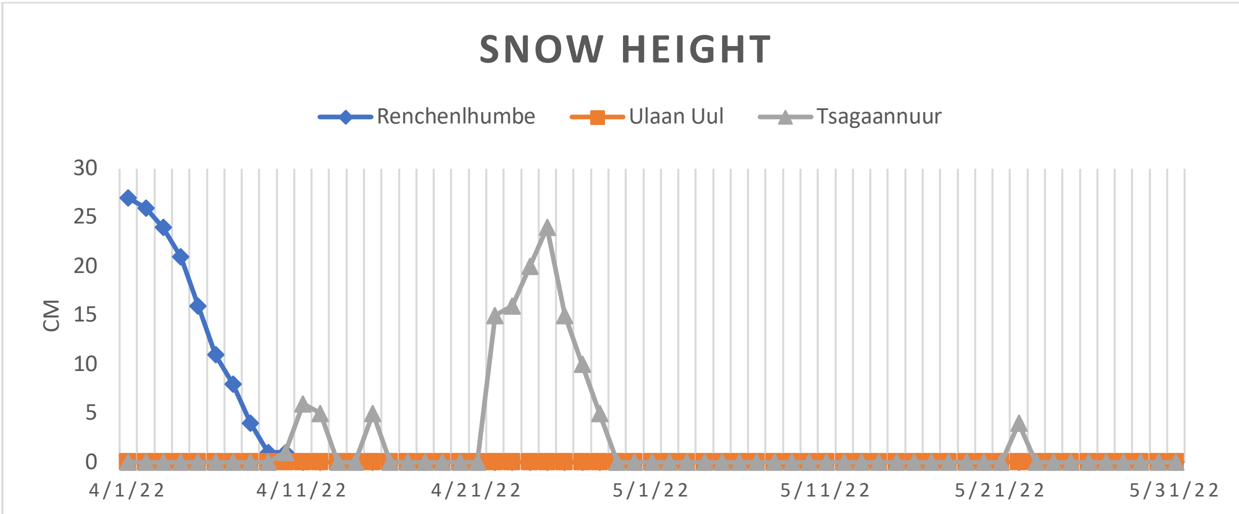
Snow height in Renchinlhumbe, Ulaan Uul, and Tsagaannuur during the months of September – November 2021.



Maximum temperature in Renchinlhumbe, Ulaan Uul, and Tsagaannuur during the months of April – May 2022.



Precipitation levels in Renchinlhumbe, Ulaan Uul, and Tsagaannuur during the months of April – May 2022.



Snow height in Renchinlhumbe, Ulaan Uul, and Tsagaannuur during the months of April – May 2022.