Livestock Responses to droughts and severe winter weather in the Gobi Three Beauty National Park, Mongolia

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Abstract

We investigated how both droughts and *dzuds* (severe winter weather) control livestock mortality in a non-equilibrium steppe ecosystem of Mongolia, Gobi Three Beauty National Park. These steppe ecosystems have developed under high interannual variability of rainfall and nomadic grazing systems. Interannual precipitation variation was 39%, with 128 mm mean annual precipitation. The effect of climate variability and extreme events on livestock mortality is a critical aspect for the Mongolian economy. Analysis of drought and precipitation variability on livestock mortality rate was not significantly influenced by the index of mean annual precipitation and annual winter temperature. Overall, unlike hot dry regions, pastoral livestock mortality in the cold dry regions was affected more by *dzuds* and annual growing seasonal rain than by droughts. *Dzuds* can be frequent events, occurring as often as once every two and three years within a decade. The average annual livestock mortality for the combined drought and *dzuds* years (18 %) was 4.8% greater than the years with *dzuds* alone, and 7% greater than in years with only drought. Thus livestock mortality appears to be more sensitive to winter storms than to droughts, and that winter storms contributes more to livestock mortality even years where combined drought and winter storms occur..

Keywords: droughts, livestock mortality, *dzuds.*

INTRODUCTION

Non-equilibrium ecosystems

Dry ecosystems are controlled more by climatic events and sequences, particularly rainfall, than by equilibrating interactions among the biotic components of the system, and exhibit distinctly non-equilibrium dynamics (Holling, 1973; Noy-Meir, 1973; Breman & DeWit, 1983; Weins, 1984; Ellis & Swift, 1988; Westoby *et al*., 1989; Behnke & Scoones, 1993; Ellis & Galvin, 1994). Rainfall of arid and semiarid regions is a principal environmental factor affecting forage production (Noy-Meir, 1973; Lauenroth, 1979; Seligman *et al.*, 1989), and is highly variable throughout and between years (Noy-Meir, 1973). Productivity is low, and not controlled by biological factors such as herbivores (Bremen & DeWit, 1983; Ellis & Swift, 1988; Westoby *et al*., 1989; Behnke & Scoones, 1993) and severe droughts result in high levels of plant and livestock mortality (Sandford, 1982; Caughley *et al.*, 1987; Ellis & Swift, 1988; Westoby *et al*., 1989; Behnke & Scoones, 1993; Ellis & Galvin, 1994).

Caughley and his colleagues (1987) and Ellis (1995) made predictions about where non-equilibrium dynamics are likely to occur based on coefficients of variation (CV) in annual precipitation and mean annual precipitation. Caughley et al. (1987) and Ellis & Galvin (1994) suggested that the threshold where a system becomes more dominated by variability than by average condition occurs where rainfall CV nears or exceeds 30%. Coppock (1990) affirmed that a threshold for non-equilibrial dynamical behavior might occur between 300-400 mm rainfall per annum (Ellis *et al.*, 1991). For Mongolia the non-equilibrium dynamics are likely to occur where the coefficient of variation of annual precipitation are greater than 33% and mean annual precipitation is less than 250 mm (Ellis & Chuluun, 1993; Ellis, 1995). Fernandez-Gimenez and Allen-Diaz (1999) confirmed that the vegetation dynamics of desert steppe are under the control of climate rather than grazing pressure and exhibited non-equilibrium dynamics.

Droughts and *Dzuds*

Mongolia's land area is categorized as 21.8 % arid and 19.5 % as semiarid. The area has been grazed by domestic livestock (cattle, camels, goats, sheep and horses) under a nomadic pattern for thousands of years, and it appears to be a risky enterprise (Goldstein *et al.*, 1990). Standing fodder provides an estimated 97% of livestock forage intake throughout the yearly cycle (Chogsom, 1964). The dynamics of these grazing systems are characterized by highly variable precipitation, with droughts and *dzuds* (i.e., severe winter weather) causing frequent episodic mortality in herbivore populations (Batjargal, 2001; Chuluun & Ojima, 2001).

As one of the former socialist countries, Mongolia entered into a free market economy in 1991, and privatized all livestock to herders. Pastoralists were no longer supported by the state (Chuluun & Ojima, 2001), and subsequently became more vulnerable to ecological perturbations (Ojima, 2001). Severe winter weather has become a more serious problem for herders and their livestock. For example, the severe *dzuds* of 2000 struck over 70% of the territory of Mongolia, and resulted in a stock mortality rate of 9% nationally (Batjargal, 2001).

Drought is caused by a prolonged absence of rainfall, and is a chronic feature of arid regions (Elliot *et al.*, 1991). *Dzud* is caused by deep or no snowfall, extreme coldness and heavy wind, resulting in large animal losses due to starvation (Chogsom, 1964; Natsagdorj & Dulamsuren, 2001). Mongolian researchers classified *dzuds* into 5 types: 1) white - deep snow, 2) black - no accumulated snow, 3) combined - deep snow, sudden temperature drop, windy, 4) storm - increased wind speed and heavy snow and 5) iron - impenetrable ice covers over the pastures. The season for *dzuds* starts at the end of October or beginning of November and continues to the end of March, lasting nearly 150 days. *Dzuds* frequently occur in some portions of Middle East Asia, in particular the republics of the former Soviet Union, Mongolia and northern part of China (Natsagdorj & Dulamsuren, 2001). Black *dzuds* mainly occur in the Gobi desert area about once every two years (Natsagdorj & Dulamsuren, 2001).

Most studies on non-equilibrium dynamics have focused on livestock dynamics and were conducted in Africa with frequent droughts (Behnke & Scoones, 1993; Coppock, 1993; Scoones, 1993), and with a maximum of 50% livestock mortality (Ellis *et al.*, 1991). However there is little research for dry, cold regions where grazing systems are subject to *dzuds* and droughts. The question remains, which one is more severe to pastoral livestock mortality, *dzuds* or droughts?

This study was conducted to understand the factors contributing to climate related mortality of livestock in cold, dry pastoral ecosystems. Mongolian herdsmen are able to avoid droughts by moving in summer. However during winters with dzuds, herdsmen are faced with two constraints, first a reduced access to pastoral forage and secondly, non-availability of forage. The general premise for the study is that:

- *Dzuds* or snowfall are more likely to result in mass death of livestock than low growing season rain (droughts) and that livestock mortality is higher in the years of combined drought and *dzuds* than years of *dzuds* alone. This occurs because in drought years, animals do not fatten well enough to overcome a subsequent harsh winter (*dzuds*).

METHODS

Study Area

The study was carried out in southern Mongolia, at the GTBNP (bounded by 43 ^{o} 21' N and 44 ^{o} 07' N latitude, and 89 ^{o} 25' E and 104 ^{o} 17' E longitude), an area of 20,000 km^2. The climate is strongly continental and arid, characterized by cold winters (to –42.5^{o} C), dry, windy springs, and relatively hot summers (40 ^{o} C). Precipitation is low, averaging 128 mm yr^{-1}. About 85-90 % of the total annual precipitation falls in April through September. The annual frost free period is 102-136 days.

Vegetation is scarce, especially in the southern part of GTBNP, and generally increases northward. A total of 290 species in 164 vascular plant families have been identified, of which 18 are endangered and 48 endemic species (unpublished data, Chimedregzen & Dash 1996). Common native vegetation species are junegrass, fringed sage, common reed and winterfat, and genera are: *Artemisia*, *Allium, Ephedra, Aristida, Stipa, Calamagrostis, Trisetum, Elymus, Juniperus*, *Kochia*, *Populus* and *Ulmus* (Bedunah & Schmidt, 2000). The region is characterized by brown Gobi soils, with rolling topography and elevations ranging from 706 m to 2825 m. The soils of the desert steppe are low in nutrients with sparse vegetation. Plant biomass increases slowly through the spring, and reaches a maximum by mid summer.

Data

Data for adult animal mortality are from the “Annual Statistics Book” published by the Mongolian Government every year (Annual Statistics, 1998). These data include mortality of young animals and number of animals miscarried, animals that died in summer cold rain, lost by floods, and even animals killed by predators like wolves, but not animal death from disease. Thus, some mortalities caused by *dzuds* may not be recorded in these statistical records. There is a certain amount of livestock mortality, which can be called “ordinary mortality,” estimated at 7.9% of total number of livestock per year (Natsagdorj & Dulamsuren, 2001). The annual livestock mortality rate was estimated for each of the following four different climatic classifications: no drought-no *dzud*, *dzuds*, droughts, and drought- *dzud* years.

Since the livestock census is taken at the end of December, we made some assumptions for our analyses. Snowfall records from November, December of that year, and January and February of the following year were regressed against the livestock mortality for that year. Summer growing season rainfall from May to August was regressed against livestock mortality for the following year to see the impacts of combined droughts and *dzuds*. Mean monthly temperatures from November, December for that year, and January and February for the following year were regressed against livestock mortality for that year. Mean annual precipitation (MAP) was regressed against livestock mortality for that year.

A 51 year precipitation record from three stations was used: *Bulgan* (44.08 °N, 103.54 °E), *Dalanzadgad* (43.58 °N, 104.4 °E) and *Gurbantes sum* (43.23 °N, 101.03 °E). Difficulties in data collection in the last years of socialist control prevented us from developing a continuous record. Precipitation was available from 1939 to1983 and from 1990 to1997.

Statistical Analysis

Several statistical analyses were used to explore the objectives. The coefficient of variation for long term mean annual precipitation (128mm) at GTBNP was calculated for the 51 years. The coefficient of variation, CV, is calculated as CV=(S/X) x 100%, X being the mean annual precipitation and S is the standard deviation.

Regression analysis was computed to establish a quantitative relationship between climate variables and the percentage of annual livestock mortality using SAS 8.1. Such climatic variables as annual snowfall, mean annual precipitation and annual growing season rain were used in the linear regression analysis. To make residuals of linear regression analysis more easily interpretable, the “studentized” residual (a division of each residual by its standard error) was used. The multiple regression model was computed to relate livestock mortality rate simultaneously to annual snowfall and annual growing season rainfall. To test whether the two slopes of the regression model are significantly different from one another, an F test was performed. P-values were considered significant at the 0.05 level in all analyses.

RESULTS

The mean annual precipitation for GTBNP over the 51 years of data (1939-1983, 1990-1997) was approximately 128 mm. It ranged from 51.5 mm to 238.2 mm, CV = 39%, and SD = 49 %. This high CV of mean annual precipitation qualifies this region as one which would display non-equilibrial dynamics (Ellis and Galvin 1994). Figure 1 displays the percentage deviation from long term mean annual precipitation (MAP) and shows large patterns of variation. Below average precipitation years occurred for 29 years out of 51-year sequence For the first 20 year period between 1939-1959, the GTBNP received a relatively large amount of precipitation, reaching 200mm or above three times (Fig. 2). Then from 1960 onward this amount decreased slightly with annual precipitation never reaching 200mm. MAP was a three mm less in 1960-1983 that in 1990-1997 or in1939-1959.

Figure 3a displays the regression analysis between percentage of annual livestock mortality and annual snowfall:

$$y = -3.45 + 0.49 * x, r^2=0.35, \text{p-value}=0.002.$$

The finding showed that a ten mm increase in snowfall is associated with a 4.9% increase in livestock mortality. The graph of the regression analysis (Fig. 3a) illustrates higher frequency of black *dzuds* (under 16 mm mean annual snowfall) than white *dzuds*. If we take out 7.9% as ordinary mortality (Natsagdorj & Dulamsuren, 2001) from this graph, black *dzud* happened nine times, while white *dzud* happened six times. Mean annual livestock mortality for the white *dzud* was 17% at 20 mm mean annual snowfall, and 14.5% annual livestock mortality at 12.1 mm mean annual snowfall for the black *dzud*.

Figure 3b portrays a regression analysis between percentage of annual livestock mortality and annual growing season rain:

$$y = 26.21 - 0.13 * x, r^2=0.38, \text{p-value}=0.001.$$

Livestock mortality decreased significantly with increasing growing season rain. A ten mm decrease of annual growing season rain is associated with 1.3% increase in livestock mortality. The p–value for the regression between percentage of annual livestock mortality and mean annual precipitation (MAP) was high ($y = 24.55 - 0.09 * x$, $r^2=0.22$, p-value=0.06), which suggests that MAP is not as a good predictor as growing season rain. Instead, lower p-values (0.002) for *dzuds* and for annual growing season rain (p-value=0.001) reflect stronger relationships to livestock mortality. Therefore, the severe winter weather (*dzuds)* and sudden snowfall were more detrimental to herders, causing high livestock mortality.

Natsagdorj and Dulamsuren (2001) found that livestock mortality increases with decreasing winter temperature in Mongolia. The regression analysis for the GTBNP did not support their perception (p-value =.19).

To evaluate the effects of combined drought and dzuds on livestock mortality, a multiple regression analysis of livestock mortality on growing seasonal rainfall and annual snowfall was performed (Fig. 4)

y=16.9 – 0.1 * growing seasonal rain + 0.35 * annual snowfall,

$r^2=0.53$, p-value=0.0002.

Livestock mortality decreased with increasing summer growing season rain, and at the same time increased with annual snowfall amount. From F-value tables, we found $F_{1, 22}$ (0.05)=4.30. Because the calculated F-values for snowfall were 16.4, and 9.0 for rainfall, we concluded that the two slopes from the regression model were significantly different from one another. This finding also supports the premise that when droughts and *dzuds* are combined, herders suffer more livestock mortality than years with only in single *dzuds* and drought. The highest stock mortalities, 32% and 24% (1962, 1983), were caused by combined drought and *dzuds* years; in contrast white *dzuds* in 1964 caused 19% stock mortality, which was much lower than the combined drought and *dzuds* years. For the black *dzuds*, eight incidents of 9% mortality were also from combined drought and black *dzuds*. Interestingly, combined drought and black *dzud* years occurring sequentially in two or three years were the primary causes of livestock mortality. This was not true for white *dzuds*, which occurred once every two or three years and were followed by a good rainfall season.

Figure 5 shows the percentage of mean annual livestock mortality in relation to drought and *dzuds* for each of the following situations: no drought-no *dzud*, droughts, *dzuds*, and combined drought – *dzuds*. Years with d*zuds* and drought combined showed higher percentage of livestock mortality (mean 13.3 %, 18%) than years with neither drought nor *dzud*, or years with drought (mean of 6.6% and 11%). The maximum mortality occurred in years in which there were both drought and white *dzuds* (32% and 24.1%). The ranges of livestock mortality were highest for drought- *dzuds* years, and second highest for *dzud* years. This result also confirmed the regression analysis (Fig. 4) that the years with both drought and *dzud* cause especially high livestock mortality.

DISCUSSION

In Mongolia rainfall is highly variable between years and regions, so that the climate of the GTBNP contributes to non-equilibrium dynamics in livestock populations, with the CV of mean annual precipitation of 39% (Fig.1). MAP is low (128 mm) with high variability supporting the notion by Conrad (1941) that the lower the rainfall, the higher the variability. MAP for 1960-1997 has decreased by three mm compared to the earlier period, 1939-1959 (Fig. 2).

Another impact of variable low mean annual precipitation is that Mongolian herders usually face a harsh and unpredictable climate, including summer droughts and extremely cold severe winters. Under these climate perturbations, livestock populations frequently reduced by density-independent causes, and therefore, they never reach an equilibrium with plant biomass. Our findings demonstrated that frequent severe droughts, *dzuds,* and long term shifts in the magnitude of precipitation characterized the GTBNP. Droughts and *dzuds* may occur as often as once every two or three years, which was twice as high as drought frequency in South Turkana, Kenya, the ecosystem which inspired Ellis and Swift to posit that non-equilibrial dynamics are of prime importance in arid grazing systems (Ellis and Swift 1988, Coppock, 1993).

Livestock mortality was correlated with annual snowfall and growing season rain over the period 1960–1993 (Fig. 3). The slope of regression analysis for snowfall (*dzuds*) was four times as much as growing season rain (droughts). Livestock mortality rate, however, was not significantly influenced by the index of mean annual precipitation and annual winter temperature. Dulamsuren and Natsagdorj (2001) have found that sudden temperature drops in northern Mongolia reduce animal numbers. The regression analysis did not support their findings. Their findings were based on the notion that when temperature drops, accumulated snow turns into ice, resulting in livestock mortality. When it overlaps with high wind, the windy *dzuds* will occur and livestock mortality abounds. Winter temperature might be an important determinant of livestock mortality in high winter snowfall regions of Mongolia, but that is not the case for our study site with low mean annual snowfall (16 mm), and low frequency of ice formation and snow storms.

The pastoral systems in the GTBNP may be more vulnerable to winter livestock mortality due the limited mobility during the winter. Winter forage sites are selected areas and restricted in area. Mobility is limited due to the harsh winter conditions under which long-distance movements of livestock and pastoralists are not possible. During *dzuds* conditions, reduction of forage availability due to either white or black *dzusd* increases the vulnerability of the herd. During droughts, pastoralists in the regions are more able to move their livestock to regions with higher forage availability and therefore reduce the risk associated with droughts.

The mean value of livestock mortality for combined drought and *dzuds* years (18 %) was 4.8% higher than the *dzuds* years,and a seven percent higher than in drought years (Fig. 5). Unlike hot dry regions, pastoral livestock in the cold dry regions were controlled more by *dzuds* than droughts. When drought combined with *dzuds*, their impacts on livestock population were almost doubled.

The frequency and duration of *dzuds* and droughts are the main factors controlling animal numbers. The GTBNP was subjected more often to black *dzuds* than white *dzuds*. The subsequent drought and black *dzuds* in 1965-1966, 1968-1969, 1979-1980, and drought and white *dzuds* in 1964 resulted in livestock mortality rates from 12% to 20% (Fig. 4). The livestock mortality rate increased from three to six percent for the subsequent harsh *dzuds* year. Comparison of livestock mortality rate between drought-black *dzuds* and drought-white *dzuds* showed drought-white *dzuds* mortality to be twice as high. Thus the combined drought and *dzud* years result in more livestock mortality than years in which *dzuds* are followed by a good rainfall season. High mortalities due to drought and black *dzuds* were more frequent when such events occurred in two to three consequtive years while mortality due to drought and white *dzuds* occurred in only one year of such events.

The GTBNP pastoral ecosystem is controlled largely by frequent drought and *dzuds* perturbations and therefore the system likely operates under non-equilibrium dynamics. In this system, it seems that both droughts and *dzuds* play important roles in affecting livestock mortality in a density-independent fashion. Population size is especially limited by droughts and black *dzuds* occurring within the same year. However, even when drought-*dzuds* driven livestock mortality is severe, recovery is relatively rapid due to rapid reproductive rates of sheep and goats (Goldstein *et al.*, 1990).

Here, we have not attempted to show the relative importances of density dependent and density independent controls on livestock population dynamics, as we did not assess density dependendence. However, it is clear that a large portion of the variations in livestock numbers is due to weather, rather than competition for forage. Management and policy decisions in this, and similar systems, must therefore consider this source of variation, and ensure that appropriate coping mechanisms remain intact.

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Figure legends

Figure 1. Percentage deviation from long-term mean annual precipitation at GTBNP, Mongolia 1939-1983, 1990-1997

Figure 2. Annual precipitation, GTBNP, Mongolia, 1939-1983, 1990-1997, with 3-year running mean

Figure 3. The relationship between a. livestock mortality and snowfall; b. Livestock mortality and annual growing seasonal rain. The downward pointing arrow denotes the mean annual snowfall.

Figure 4. The relationship between livestock mortality, snowfall, and mean annual growing seasonal rain.

Figure 5. Annual livestock mortality in relation to drought and *dzuds* occurrence.

Figure 1.

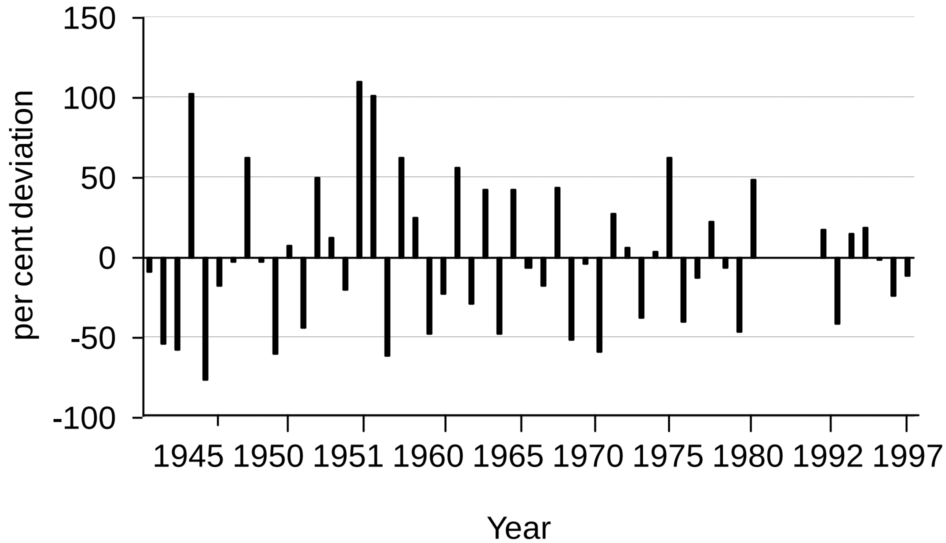

150
100
50
0
-50
-100
per cent deviation
1945 1950 1951 1960 1965 1970 1975 1980 1992 1997
Year

Figure 2.

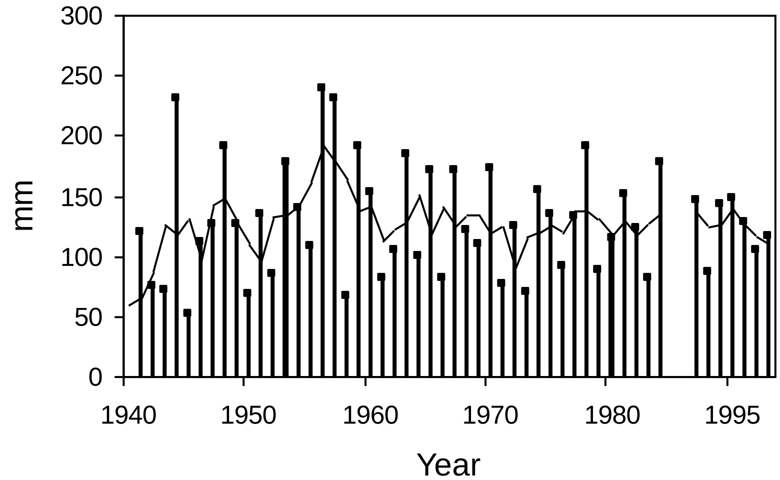
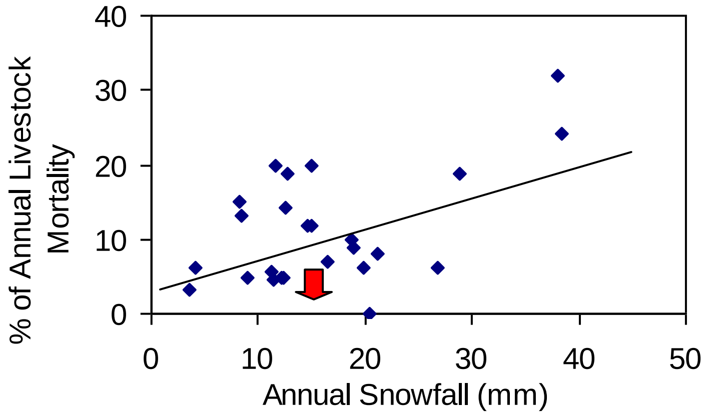
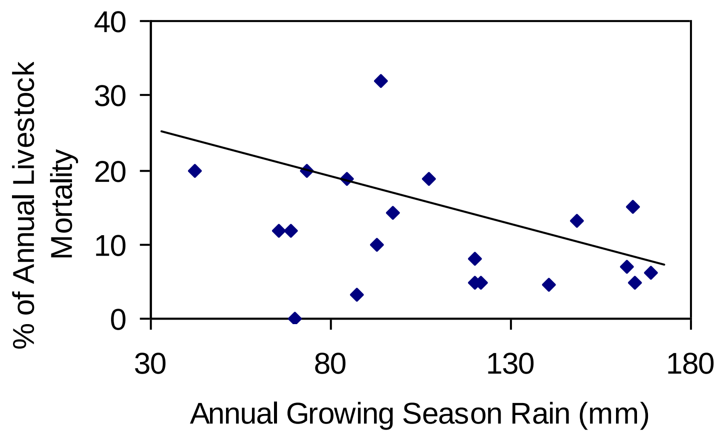


Figure 3.



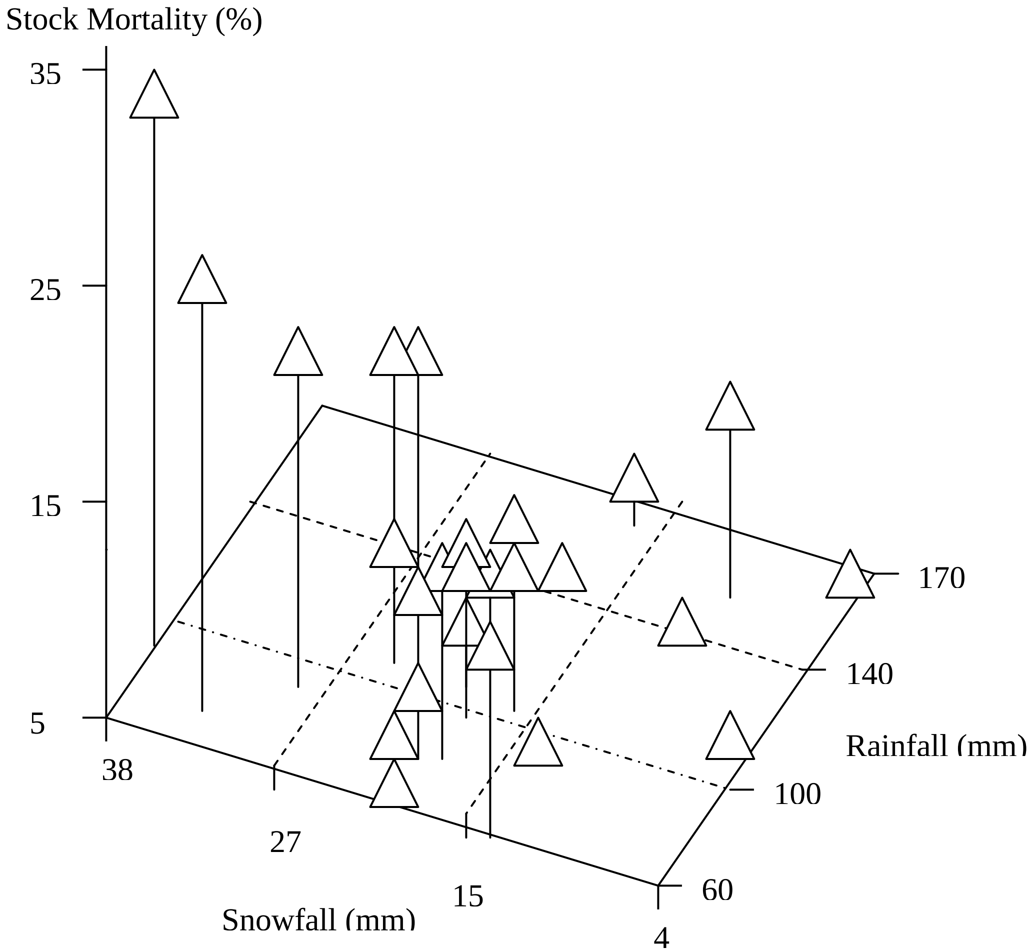
40
30
20
10
0
% of Annual Livestock Mortality
0
10
20
30
40
50
Annual Snowfall (mm)

a.



40
30
20
10
0
% of Annual Livestock Mortality
30
80
130
180
Annual Growing Season Rain (mm)

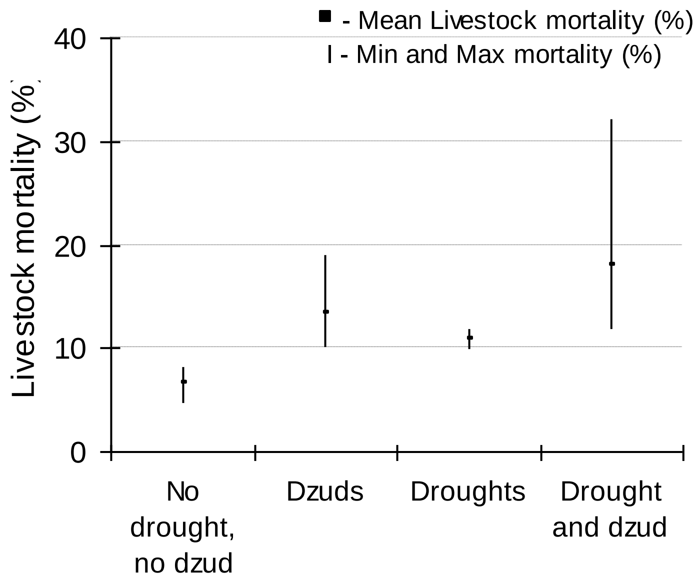
b.



Stock Mortality (%)
35
25
15
5
38
27
15
4
Snowfall (mm)
170
140
100
60
Rainfall (mm)

Figure 4.

Figure 5.


■ - Mean Livestock mortality (%)
I - Min and Max mortality (%)
Livestock mortality (%)
40
30
20
10
0
No drought, no dzud
Dzuds
Droughts
Drought and dzud