Transactions
of the Institute of British Geographers

Royal Geographical Society with IBG
Advancing geography and geographical learning

Pressurised pastoralism in South Gobi, Mongolia: what is the role of drought?

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The desert-steppe region of southern Mongolia is susceptible to drought and extreme winter weather (*dzud*) that in combination form Mongolia's worst natural hazard. Low precipitation and high climatic variability in this dryland environment impact the landscape and affect pastoralism, the dominant rural lifestyle. Using the Standardised Precipitation Index (SPI), this paper identifies drought occurrence in South Gobi Province, Mongolia. It then examines the relationship of drought with climate factors, interaction with vegetation (derived from Normalised Difference Vegetation Index - NDVI - data), and local human and livestock populations, and the *dzuds* of 1999–2001. Results show that drought is recurrent in the region, reaching extreme intensity most recently in 2005–2006. In contrast with the prevailing concept of drought impacting *dzuds*, the study did not find a connection between drought and *dzud* in South Gobi Province. Though repeated events, these natural hazards occur independently in the region. Climatic variables show increasing temperatures (>1°C), fluctuating precipitation patterns and a decline in vegetation cover. The principal long-term correlation of drought is with human population rather than natural factors, *dzud* or livestock numbers.

key words drought *dzud* Mongolia Standardised Precipitation Index (SPI) natural hazard pastoralism

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revised manuscript received 4 March 2009

Introduction

Drought is an elusive natural disaster – onset, duration, intensity and conclusion are hard to identify – yet it affects more people than any other type of hazard (Kenyatash and Dracup 2002; Shinoda and Morinaga 2004). Often detrimental environmentally, socially, and economically, drought remains a poorly understood weather phenomenon (Wu *et al.* 2001). Appearing as below-average precipitation over an extended period of time but defined in detail in multifarious ways, it can develop into a severe climatic event affecting water-related processes and vulnerable communities (WMO 1986; Sonmez *et al.* 2005). Drought is trans-regional, occurring in both low and high rainfall areas in any season (Lloyd-Hughes and Saunders 2002).

Drought, generally regarded as significant negative variation from mean precipitation, is identified in three main forms. Hydrological drought entails a shortage in volume of water supply, including streamflow, surface storage and/or groundwater levels. Agricultural drought describes a lack of water for plant growth. Meteorological drought results from a precipitation deficiency and is the most appropriate for evaluating drought in dryland environments (Keyantash and Dracup 2002). Arid regions with limited water resources remain sensitive to precipitation fluctuation and shortages. Concurrently, additional features such as temperature extremes, high wind and low relative humidity can amplify a drought's intensity (Sonmez *et al.* 2005). In drylands, water deficit and climate factors can combine to exacerbate drought effects on local ecological conditions and populations. Physical

Trans Inst Br Geogr NS 34 364–377 2009
ISSN 0020-2754

impacts and socio-economic costs in affected areas have led to several studies of drought vulnerability in arid zones in recent years (Nicholson *et al.* 1998; Nasri *et al.* 2006; Wu *et al.* 2007).

Monitoring spatial extent and temporal progression of specific drought events is difficult: to address this problem scientists have consequently designed several drought indices. Since its introduction in 1965 the Palmer Drought Severity Index (PDSI) has been widely used to evaluate drought. More recently the Standardised Precipitation Index (SPI) has found broad application and acceptance for drought monitoring and research (Cancelliere *et al.* 2007). McKee *et al.* (1993) developed the SPI to track precipitation deficiencies and anomalies that create drought conditions in the western United States. As an index the SPI provides a clear quantitative assessment of drought characteristics and is effective for evaluating drought at multiple timescales. This index identifies the cumulative probability of precipitation for desired months over specified time periods at a given meteorological station (Rouault and Richard 2003). Currently applied in 60 countries (Wu *et al.* 2005), the SPI has been used for drought assessment in several arid and semi-arid regions, including East Africa (Ntale and Gan 2003), the Sonoran desert of Mexico (Hallack-Alegria and Watkins 2007), Northwest China (Wu *et al.* 2001), India's Thar Desert (Bhuiyan *et al.* 2003) and Australia (Prasad and Khan 2002). This paper takes drought indicated by SPI and expands its implications to understand how drought episodes at different timescales interact with climate variables and natural hazards to affect Mongolia's regional environment and pastoral community.

Drought in Mongolia

A prominent feature of Inner Asian desert and steppe landscapes, drought is a common natural hazard in Mongolia (World Bank 2002; FAO 2006; Johnson *et al.* 2006). The country's traditional nomadic pastoralism has evolved into mobile livestock-raising that enables herders to cope with recurrent hazards in a region where livestock production can be critically affected by climate variability and extreme events. This arid environment combines limited precipitation (concentrated in summer), a great annual temperature range and sparse vegetation, factors that can result in an unusual natural phenomenon known as *dzud*. A *dzud* occurs when extreme winter cold, snow and ice limit forage potential, threatening livestock survival. Drought, which reduces summer grazing potential and thus livestock weight gain, can magnify a *dzud's* intensity and impact (Shinoda and Morinaga 2004; Asian Development Bank 2005). Limited reports of *dzuds* suggest they occur from once in three to once in seven years (World Bank 2002; Begzsuren *et al.* 2004). A combination drought–*dzud* ('perfect storm') event happens periodically. The most recent was in 1999–2001, when livestock mortality reached 8–10 million animals, approximately 30 per cent of the national herd, in the worst natural disaster in Mongolia's recorded history (UNDPI 2000; Batima *et al.* 2005). This *dzud* affected South Gobi Province and 70 per cent of the country and led to international relief efforts from the UN, International Red Cross, European Commission and the World Bank (UN 2000 2001).

Using the SPI to determine drought occurrence in South Gobi Province, Mongolia, we examine the implications of drought and climate stress on local ecological and pastoral communities, including its potential interaction with *dzuds*. Temperature, precipitation and vegetation were correlated with human and livestock populations to highlight the role of drought in the pastoral context. Identification of the role of drought within the physical and social environment could inform governance, management and development at local and national levels and better comprehension can improve response and mitigation of drought processes in southern Mongolia. Particular attention is given to the 1999–2001 *dzud* to evaluate the contributory role of drought and climate stress to this extreme weather event and its impact on the local pastoral community. Perceived linkages between drought and *dzud* in rural Mongolia, despite its importance, has to date been inferred rather than based on research findings. This paper addresses this want of analysis by examining drought–*dzud* interactions and their potential correlation in South Gobi Province.

Standardised Precipitation Index

The Standardised Precipitation Index (SPI) is used to assess anomalous and extreme precipitation. It monitors meteorological drought at different timescales and enables comparison across regions and varied climatic zones. The SPI, used to calculate drought initiation, magnitude, duration, and frequency while providing spatial and temporal flexibility, reflects the probability of precipitation at selected timescales measured by the number of standard deviations of observed value from the long-term mean. The SPI for a specific time period at any location requires a monthly precipitation database for a continuous period of at least 30 years. Precipitation rates can be described by a gamma distribution that represents its frequency or probability; the resulting function can identify the cumulative precipitation probability for the month and timescale of interest (Rouault and Richard 2003). As precipitation is typically not normally distributed, data are transformed to have equal probability of normal distribution (McKee *et al.* 1993; Hayes *et al.* 1999). The SPI value is the difference of precipitation from the historic mean for the selected period divided by the standard deviation from the mean (Sonmez *et al.* 2005). Details of how the SPI algorithm is computed are found in work by Ntale and Gan (2005), Lloyd-Hughes and Saunders (2002), and Wu *et al.* (2005).

The precipitation for a specified time generates an SPI value where the magnitude of divergence from zero represents the probability of occurrence (Hayes *et al.* 1999). Positive values signify wet periods while negative values indicate dry conditions. A drought event occurs when the SPI value is continuously less than or equal to –1.0 and ends when the SPI attains a positive value. Fit to a typically normal distribution, an SPI value of less than –1.0 occurs 16 times in 100 years, less than –2.0 takes place two or three times in a century, and less than –3.0 happens once in approximately 200 years.

The chief value of SPI lies in its simplicity, the sole requirement being a long-term precipitation history. This makes it particularly suitable for developing countries such as Mongolia, where limited data availability can be a challenge to drought quantification. Though straightforward, the SPI is robust, having been favourably evaluated relative to other drought indices, including the Palmer Drought Severity Index (Guttman 1999; Keyantash and Dracup 2002). Other advantages of the SPI are its statistical consistency, ability to describe short- and long-term drought episodes, and its potential when carrying out drought risk analysis (Cancelliere *et al.* 2007). The US National Drought Mitigation Center adopted the SPI after Hayes *et al.* (1999) demonstrated its use for detecting the onset, spatial extent and temporal progression of droughts. Worldwide use of SPI (Wu *et al.* 2007), including in Europe (Lloyd-Hughes and Saunders 2002), South Africa (Rouault and Richard 2003) and East Asia–Korea (Min *et al.* 2003) and China (Bordi *et al.* 2004) – shows its broad acceptance as a technique for real-time drought monitoring and retrospective analysis.

However, because SPI is normally distributed it identifies drought events that can reflect local aberrations. Thus on a national scale it does not distinguish regions that are more ‘drought-prone’ than others. As Wu *et al.* (2007) demonstrated, skewed precipitation distributions may reflect short timescale dry seasons in arid locations where relatively small precipitation anomalies can produce large SPI values. Therefore duration of drought is a critical feature when using SPI in arid climates.

Study area

South Gobi Province, Mongolia, lies in the country’s southern desert steppe region bordering China, 560 km southwest of the capital city Ulaan Baatar and approximately 1000 km northwest of Beijing (Figure 1). This study is focused on the region around Dalanzadgad, the province capital (43.57° N, 104.43° E), and Bulgan district (44.01° N, 103.53° E), 100 km to the northwest. The study sites are located north of the Gurvan Saixan Mountain range on rolling gravel plains at an elevation of 1000–1500 m.

The province, covering 165 000 km^2, is inhabited by semi-nomadic pastoralists raising sheep, goats, horses, cattle and camels in the arid environment. Over the last century their traditional livelihood has evolved in distinct phases, from a feudal approach through 70 years of Soviet rule to become, since 1990, a market-oriented democracy (Fernandez-Gimenez 1999). As systems have changed, herding inputs, demands and challenges have modified. Since the end of the collective system the once-dominant government role, which provided wells, emergency fodder and transport, has given way to private livestock ownership and individual responsibility. The impact of natural disasters has increased in the region (Begzsuren *et al.* 2004) following withdrawal of previous external support and mitigation efforts when needed.

Two natural hazards dominate in the South Gobi – drought and extreme winter *dzuds*. The former inhibits vegetation growth, reduces livestock summer weight gain and results in livestock concentrating around water points and overgrazing; the latter restricts the ability of

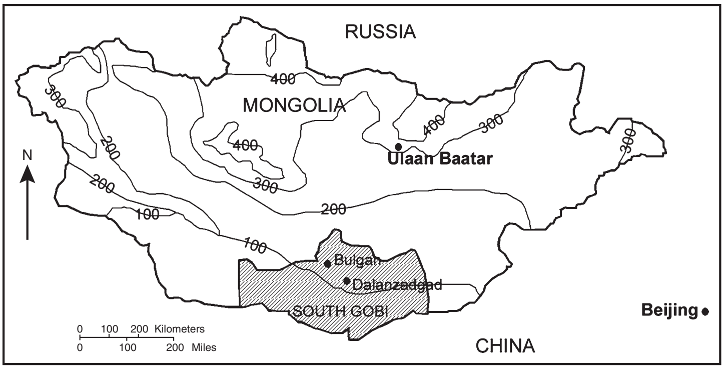

Figure 1 Map of Mongolia with precipitation isohyets (mm)

Table I Recent drought and *dzud* events in Mongolia

Natural disasters	
Year	*Type of disaster*
1944–45	*Dzud* + drought
1954–55	*Dzud*
1956–57	*Dzud*
1967–68	*Dzud* + drought
1976–77	*Dzud*
1986–87	*Dzud*
1993–94	*Dzud*
1996–97	*Dzud*
1999–00	*Dzud* + drought
2000–01	*Dzud* + drought

Source: Reading *et al.* (2006)

animals to forage and threatens livestock survival (Suttie 2006) (Table I). Insects, disease, wind and dust storms, and harsh temperatures – both in degree and range – are further potentially disrupting events. Based on an aridity index (P/PET) and 121 mm average annual precipitation at the two sites over the length of the study, the region is arid and sensitive to precipitation fluctuations and timing (Middleton and Thomas 1992; Shinoda *et al.* 2007). The interrelationship of drought and *dzud* hazard episodes is examined in this paper.

Livestock raising is the dominant livelihood in South Gobi Province, with goat cashmere, meat, dairy products and wool the main income sources. Animals represent sustenance, wealth and material for herders' tent homes and lifestyles. Livestock, and thus herders, are dependent on summer vegetation growth for adequate animal-fat gain to survive through winter. In addition to natural factors, anthropogenic input such as water resources (wells), grazing patterns, emergency fodder, external public support and 'market economics' can impact this ecosystem and affect livelihoods.

Articles and reports, stressing drought frequency (World Bank 2002; Johnson *et al.* 2006) and the severity of extreme winter weather, state that summer droughts in 1999–2001 caused *dzuds* (Batima *et al.* 2005; Asian Development Bank 2005; Natsindorj *et al.* 2007). These studies recognise how water and forage resources affect livestock conditions and herder well-being and then infer a causal role for summer droughts in *dzud* events. As this multi-year event imprints itself on the nation's consciousness, we take the opportunity to draw together the above-mentioned factors to assess the causes, impacts and relationships that now define the 1999–2001 disaster.

Methodology

Use of the SPI is particularly appropriate in Mongolia because of the limited amount of data required compared with soil moisture, evapotranspiration and the recharge-rate data needed to calculate the PDSI. The SPI highlights meteorological drought in this region with little surface water and minimal agricultural production. Daily precipitation records dating from 1970 were obtained from the state Meteorological Institute for Dalanzadgad and the Bulgan district. Further statistical information was provided by the provincial government. Six factors that interact with natural hazards in the region were examined: drought (as measured by the SPI), precipitation, temperature, the human and livestock population, and the Normalised Difference Vegetation Index (NDVI) (Pettorelli *et al.*

2005). Data were analysed with SPSS 14.0 (SPSS Inc., Chicago) to establish if drought plays a role in the natural and social environment in the South Gobi. Pearson correlation coefficients were used to determine the significance of relationships between variables (two-tailed, Pearson's *r*, P = 0.05).

Drought was examined at 3, 6, 12, 24 and 60-month timescales using the SPI software program from the US National Drought Mitigation Center. This study focuses on drought events only when they are at moderate, severe and extreme levels, thus continuously less than or equal to –1. To best monitor summer drought at several temporal phases, given the short (90–130 frost-free days) vegetation growth phase and intensive grazing season (FAO 2006), annual SPI values were measured from September through to the end of August of the following year. This period coincides with high seasonal precipitation, with ≥60 per cent falling during June, July and August and ≥80 per cent between May and September (Hilbig 1995).

As the SPI is based on precipitation records, local conditions need to be understood to clarify the role of precipitation in a region dependent on livestock-raising. We investigated precipitation amount, frequency, inter-annual variation, decadal change and any correlation to *dzuds* over the long-term record based on daily climate data obtained from the National Institute of Meteorology and Hydrology. Using the coefficient of variation (CV) for the mean annual precipitation at both sites (121 mm), the variation was calculated as $CV=(S/X)\times 100$ per cent, with X being mean annual precipitation and S standard deviation.

Temperature becomes an important factor in the region as cold weather relates to *dzud* events in winter and high temperatures increase evapotranspiration in summer, affecting both summer vegetation growth and potential winter hazards. South Gobi Province, with a continental climate, experiences dramatic annual temperature ranges of >65°C. Temperature was evaluated for long-term change and potential relationship to drought or *dzud* events.

NDVI is used as a measure of vegetation cover to assess if drought and climate stress affect growth patterns and forage resources over time. Data were derived using Spot-4 1-km resolution satellite data available from 1998 to 2006. Thirty-day digital number values were calculated at 20 sites in each district for April through October, matching the maximum potential vegetation growth period. Results were averaged to provide a yearly NDVI value. While NDVI has limitations (Richard and Poccard 1998), it is used here to provide an estimate of vegetation density and land cover relating to drought events.

Local human (1981–2006) and livestock (1980–2006) population data from annual spring censuses were obtained from the provincial government. The data were used to assess how drought and climate stress affect pastoralists and livestock. The relationships between population fluctuations, natural variables and livestock were examined.

Results

Time series – 3, 6, 12, 24 and 60-month SPI

To derive a climatology of drought events at different timescales, the SPI was applied to a time series over the South Gobi Province 37-year historic record. Figure 2 shows SPI values at the end of August at Dalanzadgad and Bulgan. At shorter time periods a pattern emerges: the 1970s were mixed – dry to wetter, the 1980s drier, the 1990s moderate and the 2000s drier with drought more pronounced on longer timescales. Between the sites there was greater variance in the shorter term. At the end of 2006 Dalanzadgad was drought stricken at all timescales, whereas Bulgan had mildly wet conditions. The 1980s was the most significant drought period, with both sites having negative SPI values for multiple years, reflected at major timescales in Figure 3.

There are multiple drought episodes throughout the historic record, identified by peak drought intensity (Table II). The two sites experienced a similar number of events differing in timing, intensity and duration. Seven droughts were simultaneous, one concurrent with two of the same intensity, for 27 months. In the 2000s Dalanzadgad had severe and extreme droughts, whereas Bulgan experienced only short–moderate droughts. Conversely in the 1970s Bulgan had three long extreme drought episodes, while Dalanzadgad had shorter moderate and severe droughts, reflecting inter-site differences.

Table III clarifies drought frequency and intensity, showing different overall rates of drought at the two sites. Dalanzadgad had higher than expected rates at 6, 12 and 60 months and elevated severe drought percentages at 3, 24 and 60 months. Bulgan exhibited lower than expected moderate drought frequency yet consistently high rates of

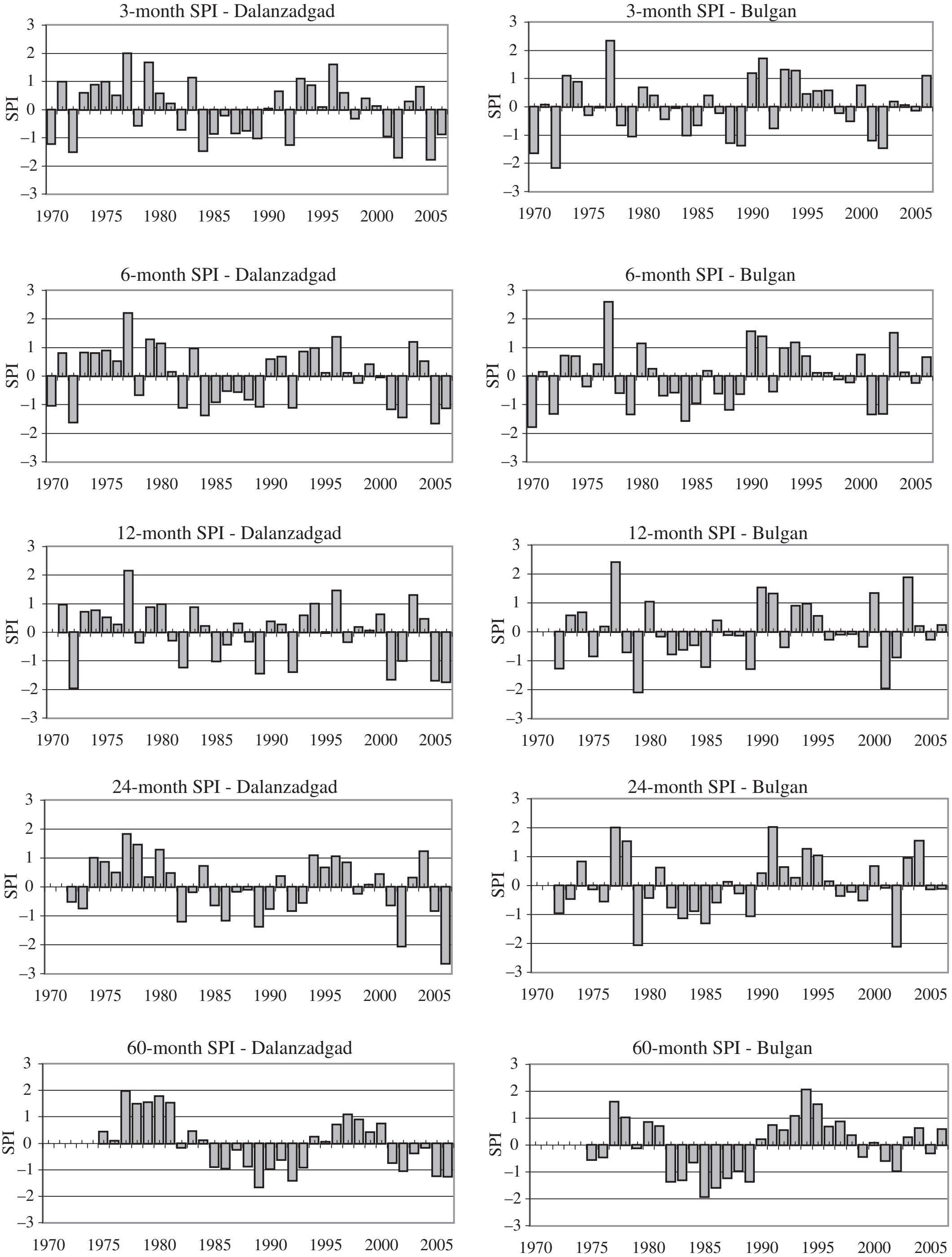

Figure 2 Standardised Precipitation Index at 3, 6, 12, 24 and 60-month timescale (top to bottom) at the end of August, 1970–2006

ISSN 0020-2754

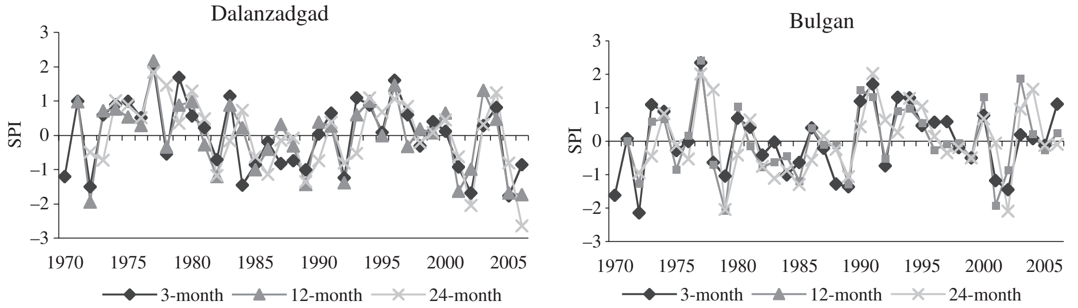

Figure 3 Comparison of SPI time series at 3, 12 and 24-month timescale from 1970 to 2006

Table II Drought events in Dalanzadgad and Bulgan, Mn. using 12-month SPI from 1970 to 2006. Includes droughts reaching moderate (≤ –1.0) severe (≤ –1.5) and extreme(≤ –2.0) intensity

Dalanzadgad							*Bulgan*					
Onset		*End*					*Onset*		*Completion*			
Year	*Month*	*Year*	*Month*	*Duration (months)*	*Intensity (peak)*	*Event index*	*Year*	*Month*	*Year*	*Month*	*Duration (months)*	*Intensity (peak)*
1971	4	1971	5	1	Moderate	*1*	1970	12	1970	12	6	Extreme
1972	8	1972	4	9	Severe	*2*	1972	8	1973	5	10	Extreme
1973	6	1973	7	2	Severe	*3*	1978	10	1980	3	18	Extreme
1978	10	1979	5	8	Severe	*4*	1982	7	1982	7	1	Moderate
1982	8	1983	2	7	Moderate	*5*	1982	11	1982	11	1	Moderate
1984	10	1985	8	11	Severe	*6*	1983	5	1983	6	2	Moderate
1988	7	1988	8	1	Moderate	*7*	1984	9	1985	8	12	Extreme
1989	1	1989	3	3	Moderate	*8*	1988	10	1989	9	12	Severe
1989	5	1989	6	2	Moderate	*9*	1993	5	1993	5	1	Moderate
1989	8	1990	2	7	Moderate	*10*	2001	8	2001	9	2	Severe
1992	8	1993	6	11	Severe	*11*	2002	6	2002	6	1	Moderate
1995	7	1995	8	1	Moderate	*12*	2002	10	2002	10	1	Moderate
2001	8	2001	9	2	Severe	*13*	2005	6	2005	6	1	Moderate
2002	8	2003	4	9	Severe	*14*	2006	5	2006	6	2	Moderate
2005	7	2006	9	15	Extreme	*15*						

Table III Number and percentage of months in drought by severity as measured by SPI. Total number of months = 444

	Months in drought					*% Time in drought by level*					
	3	*6*	*12*	*24*	*60*	*3*	*6*	*12*	*24*	*60*	*Cumulative probability %*
Dalanzadgad											
Moderate	32	53	62	34	50	7.2	11.9	14.0	7.7	11.3	9.2
Severe	23	17	19	23	29	5.2	3.8	4.3	5.2	6.5	4.4
Extreme	10	7	8	12	0	2.3	1.6	1.8	2.7	0	2.3
Total	65	77	89	69	79	14.6	17.3	20.0	15.5	17.8	15.9
Bulgan											
Moderate	32	37	41	38	37	7.2	8.3	9.2	8.6	8.3	9.2
Severe	23	25	21	29	31	5.2	5.6	4.7	6.5	7.0	4.4
Extreme	10	7	8	5	0	2.3	1.6	1.8	1.1	0	2.3
Total	65	69	70	72	68	14.6	15.5	15.8	16.2	15.3	15.9

ISSN 0020-2754

severe drought. Although both sites had limited extreme drought periods, overall Dalanzadgad experienced more extended episodes, with 20 per cent of the long-term period representing a 12-month drought. The six previously identified *dzud* years during the study period (Table I) were not concurrent with 12-month drought in South Gobi Province. The lack of a temporal link between the two hazards may reflect the fact that *dzud* identification cannot be generalised across Mongolia's large territory due to differing local conditions and the variability of *dzud* impacts.

Precipitation

Long-term (1970–2006) mean annual precipitation in South Gobi Province averaged 121 mm at both sites and ranged from 51.6 to 235.7 mm in Dalanzadgad and 57.1 to 216.5 in Bulgan. The inter-annual coefficient of variation (CV), equalling 33 per cent and 32 per cent respectively, crosses the 30 per cent threshold defining non-equilibrial ecosystem dynamics, a limiting threshold for stable plant and animal ecosystem interactions (Ellis and Galvin 1994). During June, July and August, potential drought intensification is indicated by CVs of 42 per cent and 52 per cent.

Examination of the decadal variability for long-term trends (Rouault and Richard 2003) shows a 17 per cent precipitation decline at Dalanzadgad between the first (1970–1979) and last (1997–2006) 10-year period (Figure 4). In the key summer growing season precipitation fell by 30 per cent, followed by a 45 per cent fall in June, reducing moisture availability for incipient grass growth. In contrast, Bulgan saw a 10 per cent increase in precipitation over the same time period, with a 6 per cent decline in summer. June rainfall decreased 30 per cent but was moderated by a large increase in May and a lesser gain in August. Annual days with precipitation (43.8) and average amount per event (2.75 mm) were the same at both sites, though distribution differed. Winter precipitation was minimal throughout the period, with precipitation correlating with human population in Bulgan (P = 0.05) (Table IV).

Temperature

Interdecadal comparison shows increasing average temperature at both locations. Dalanzadgad temperatures rose 1.5°C overall, with increases of 1.8°C in summer and 1.1°C in winter ($R^2 = 0.47$); similarly in Bulgan the increase was 1.05°C overall with summer 1.7°C higher ($R^2 = 0.25$). In this region changing temperature patterns may impact vegetation growth and winter weather extremes. The historic average January temperature was significantly negatively correlated, with SPI in Bulgan (3, 6 12 month P = 0.01; 24, 60 month P = 0.05), while in Dalanzadgad there was significance at 24 and 60 months (P = 0.05), whereas at 3, 6 and 12 months the mean July temperature was negatively correlated with SPI (P = 0.05) (Table IV). At both sites July temperature showed a significant relation (P = 0.05) with livestock numbers.

Normalised Difference Vegetation Index

South Gobi Province manifests limited precipitation in consistently low SPOT-4 derived annual values (–1 to 1.0 scale), 1998–2006, providing a historical perspective of land cover (Table V). Recent NDVI values fluctuated by 35 per cent at the sites with lowest values in 2002, 2005 and 2006. Inter-annual values varied from 28 per cent greater than average to 30 per cent less, whereas monthly values

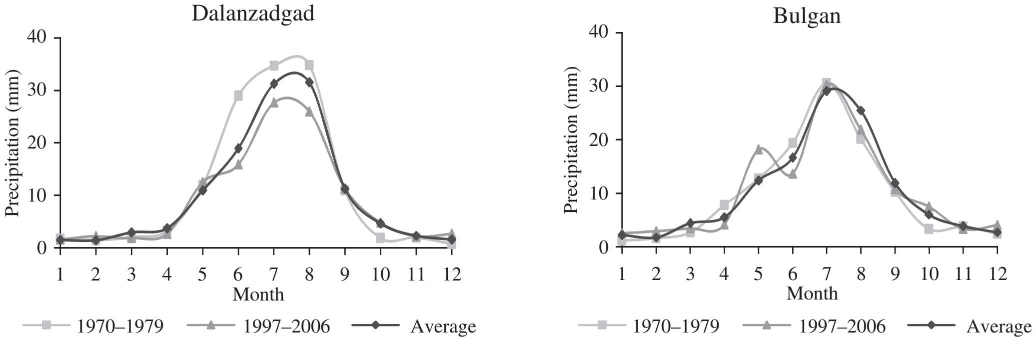

Figure 4 Long-term decadal precipitation average in South Gobi Province, 1970–2006

Table IV Pearson's correlation between SPI and site variables

BULGAN					*Temperature*			
SPI		*Livestock*	*Population*	*Precipitation*	*average*	*January*	*July*	*NDVI*
3-month	Pearsoris *r*	0.11	.593(**)	.854(**)	−0.16	.438(**)	0.22	0.21
	P value	0.60	0.00	0.00	0.33	0.01	0.20	0.59
6-month	Pearson's	0.10	.665(**)	.926(**)	−0.12	−.436(**)	−0.18	0.44
	r P value	0.62	0.00	0.00	0.48	0.01	0.29	0.24
12-month	Pearson's *r*	−0.04	.599(**)	.853(**)	−0.27	−.429(**)	−0.14	0.44
	P value	0.83	0.00	0.00	0.11	0.01	0.42	0.24
24-month	Pearson's *r*	0.21	.591(**)	.545(**)	−0.14	−.425(*)	−0.06	0.52
	P value	0.30	0.00	0.00	0.43	0.01	0.73	0.15
60-month	Pearson's *r*	0.38	.611(**)	.471(**)	0.07	−.401(*)	0.02	0.28
	P value	0.05	0.00	0.01	0.71	0.02	0.91	0.47

DALANZADGAD					*Temperature*			
SPI		*Livestock*	*Population*	*Precipitation*	*average*	*January*	*July*	*NDVI*
3-month	Pearson's *r*	0.09	.508(**)	.900(**)	−0.14	−0.13	−.372(*)	.721(*)
	P value	0.68	0.01	0.00	0.41	0.43	0.02	0.03
6-month	Pearson's *r*	−0.03	.554(**)	.928(**)	−0.16	−0.17	−.360(*)	0.65
	P value	0.89	0.00	0.00	0.34	0.30	0.03	0.06
12-month	Pearson's *r*	−0.04	.457(*)	.843(**)	−0.31	−0.32	−.332(*)	0.64
	P value	0.86	0.02	0.00	0.07	0.06	0.05	0.06
24-month	Pearson's *r*	0.17	.450(*)	.496(**)	−0.31	−.419(*)	−0.17	.756(*)
	P value	0.44	0.02	0.00	0.07	0.01	0.34	0.02
60-month	Pearson's *r*	.620(**)	0.27	.532(**)	−0.14	−.409(*)	−0.07	.889(**)
	P value	0.00	0.18	0.00	0.43	0.02	0.71	0.00

*Correlation significant at 0.0 5 **Correlation significant at 0.01

Table V Annual NDVI value by site, 1998–2006

	1998	*1999*	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*
Bulgan	0.11	0.12	0.13	0.09	0.07	0.12	0.10	0.07	0.07
Dalanzadgad	0.12	0.14	0.14	0.11	0.08	0.11	0.11	0.09	0.08

diverged from 25 per cent above to 31 per cent below average, with highest values in April and October and lowest values in July and August. Both areas have similar trends, though Bulgan shows slightly lower vegetation levels. NDVI correlated with SPI and with livestock numbers at 3, 24 (P = 0.05) and 60 (P = 0.01) months in Dalanzadgad, while showing no such significance in Bulgan (Table IV).

Human population and livestock

Population trends in the two districts were similar from 1981 through 2006. Gradual 20-year population growth was followed by a 50 per cent drop in 2001 and an equal rebound in 2003 (Figure 5). This reflects pastoral migration motivated by perceived poor ecological conditions, concern for potential *dzud* impact and a lack of mitigating factors, such as emergency fodder in harsh circumstances. Herder population numbers were significantly

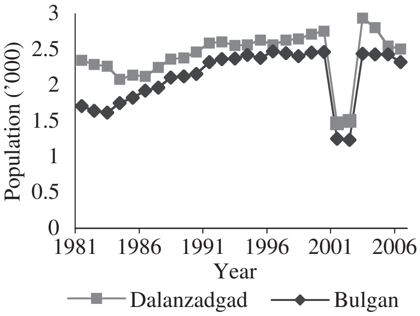

Figure 5 Population for Dalanzadgad and Bulgan, 1981–2006

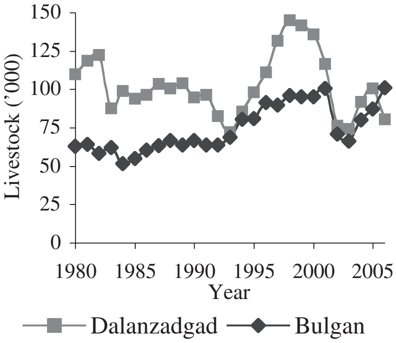

Figure 6 Livestock population in Dalanzadgad and Bulgan, 1980–2006

correlated (P = 0.01) with SPI at all time periods in Bulgan as well as 3 and 6 months in Dalanzadgad and at 12 and 24 months (P = 0.05) (Table IV). The strong tracking of population with SPI identifies herder-adaptive strategies to the drought conditions impacting their livelihood.

Following a period of political and socio-economic transition in the early 1990s, there was an increase in livestock numbers (Figure 6). There was a 200 per cent increase in livestock at Dalanzadgad from 1993 to 1998, followed by a 14 per cent drop in 2001 and a further 35 per cent fall in 2002. Bulgan livestock figures increased 71 per cent over the same period and maintained numbers until a 30 per cent decline in 2002. These decreases represent mortality as well as pastoralist out-migration to regions with greater forage potential. Environmental factors improved in 2003 as precipitation increased 123 per cent in Dalanzadgad and 97 per cent in Bulgan, and NDVI values rose 20 per cent and 29 per cent respectively. The livestock population increased in 2004, indicating rapid reproduction among dominant sheep and goat herds and animal in-migration (Bezsguren *et al.* 2004). However, changes in livestock numbers were not always matched by demographic patterns. In Dalanzadgad notable livestock declines occurred in 1982–3 (28%) and 1991–2 (15%) unrelated to human population shifts or identified *dzuds.*

Livestock numbers reflect drought at the 60-month interval (P = 0.01) in Dalanzadgad, whereas in Bulgan a link between livestock and temperature (P = 0.01) emerges. Population and livestock numbers in the same year showed little relationship, though population, with a 1-year delay in livestock figures, was significantly related throughout the study in both Dalanzadgad (P = 0.05) and Bulgan (P = 0.01). The 1-year delayed association between the two factors may reflect census timing in the country, as previously noted by Shinoda and Morinaga (2004).

Dzud of 1999–2001

Further investigation of the 1999–2001 drought–*dzud*, Mongolia's worst natural disaster in recorded history, focused on climate data for 1998 through 2003. The 1999 and 2000 SPI values for Dalanzadgad and Bulgan show neither site experienced drought at any timescale. The 1999 12-month SPI values were mild, changing in 2000 to wet conditions (Figure 7). In July and August 2001 both sites became drought-stricken at 12 months. Dalanzadgad reached drought status at all timescales in 2002, whereas drought at Bulgan only occurred at 3, 6 and 24 months. From August 2002 through April 2003, the two sites experienced a 24-month drought, reaching extreme intensity in August. In May 2003 both sites shifted to wet conditions.

During 1999–2002 mean January temperature was generally warmer at both sites than the long-term averages; 2000–1 was about 3°C colder

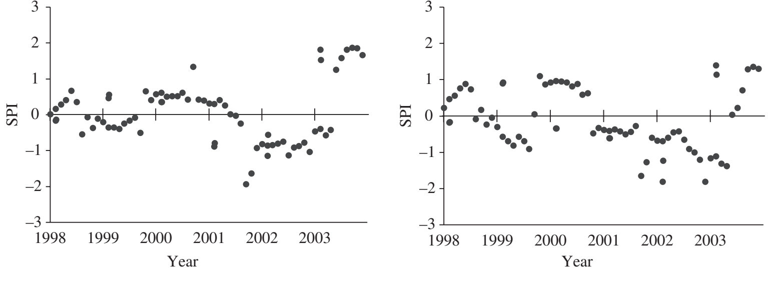

Figure 7 Twelve-month SPI records, 1998–2003

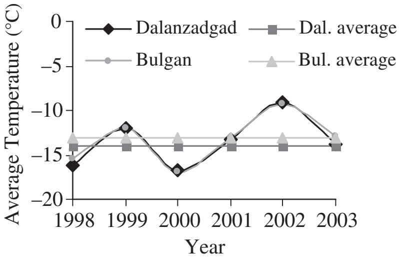

Figure 8 Average January temperature, 1998–2003

(Figure 8), whereas 2002 was 4.8°C and 3.8°C warmer than historic norms at the two sites. Winter precipitation (December, January, February) in 1999–2001 was normal or slightly low at both sites (Figure 8). High precipitation in December 2001 was followed by above-average temperatures (Figure 9) and preceded livestock losses in 2002 (Figure 10). The human population fell by 50 per cent in both districts in 2001 (Figure 10); recovery for human populations started in 2003 with livestock numbers rebounding in 2004 as vegetation cover increased.

Dzud and drought; non-drought years

Examination of other historic *dzuds* (1987–8, 1994–4, 1997–8) at both sites showed that drought was not present during these years. Five of the six *dzud* periods (three Bulgan, three Dalanzadgad) had above-average rainfall with, in all cases, precipitation decline the year after the *dzud*. Livestock numbers increased five of the six years, human populations increased during four years and decreased slightly (2%) in two years. In brief, an analysis of *dzuds* found there were no significant correlations between *dzud* years and livestock, precipitation or January average temperatures.

Time series analysis was used to investigate the relation of non-drought years to livestock, precipitation, NDVI, and January and July temperatures since 1981 at the 12-month timescale (through August). Results showed that livestock numbers and July temperatures were significantly related (P = 0.01) at both sites and that NDVI was correlated with livestock in Dalanzadgad (P = 0.05), whereas other factors were uncorrelated. Non-drought years showed less correlation with environmental factors than drought years.

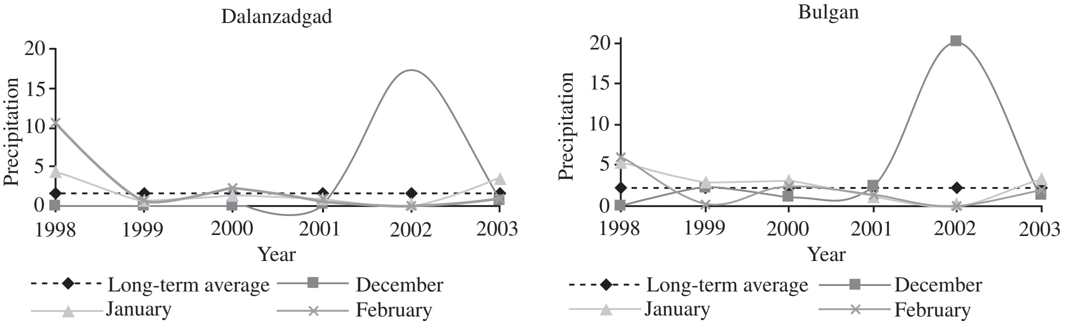

Figure 9 Average winter precipitation, 1998–2003

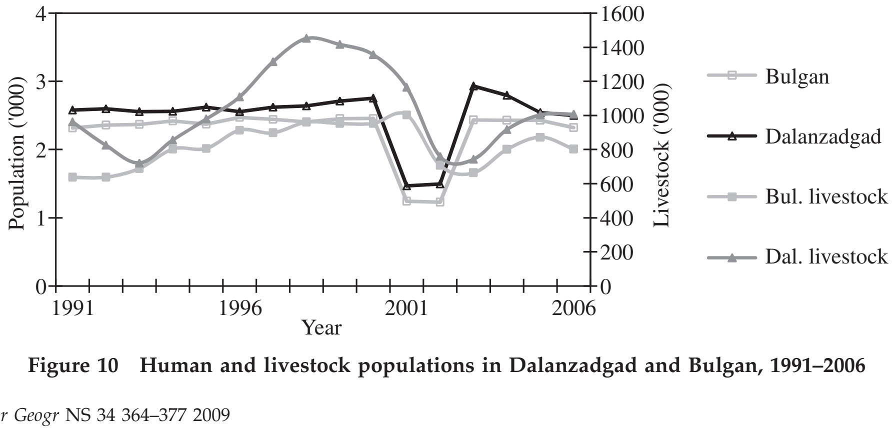

Figure 10 Human and livestock populations in Dalanzadgad and Bulgan, 1991–2006

Discussion

Drought is a recurrent natural hazard in the South Gobi Province environment. The conventional understanding of drought and *dzud* is that drought precedes or intensifies a *dzud* (World Bank 2004). This study suggests that drought and *dzud* are de-coupled in South Gobi Province; thus the prevailing concept needs more thorough examination, particularly when *dzud* is defined by stock losses rather than meteorological data alone (Suttie 2006).

The SPI was used to identify site-specific meteorological droughts across five timescales in South Gobi Province. Over the 12-month period, 93 per cent of droughts occurred during the May to September peak precipitation and vegetation growth seasons. Drought was widespread, re-occurring on average every third year, with the duration of moderate, severe or extreme states varying from 1 to 18 months. By contrast, *dzuds* are not preceded or concurrent with 12-month droughts, nor are years of extreme drought (1970, 1972 and 1978 in Bulgan and 2005–6 in Dalanzadgad) followed by identified *dzud* conditions. Similarly, in South Gobi Province the *dzuds* of 1987, 1994, 1997, 1999–2000 and 2000–2001 are also uncorrelated with drought. Unassociated, between-site SPI values explain divergent findings such as a link between vegetation and drought in Dalanzadgad, yet none in Bulgan. The observed climate differences between the two sites were not readily explained by elevation, physical environment or location.

The long-term record in this survey shows South Gobi Province experienced *dzud* conditions in 2002. Out-migration of half the population in 2001 was followed by livestock decreases of ≥30 per cent in 2002. July and August drought in 2001 may have impacted the *dzud*, yet a more extended drought in 2002 saw human and livestock populations stabilise. As precipitation and vegetation conditions improved, pastoralists returned in 2003 with a corresponding >20 per cent rise in livestock in 2004. During this period the greatest climatic variant was a multi-fold increase in winter 2001–2 precipitation providing sufficient moisture as snow or ice to create *dzud* conditions. Precipitation, together with higher than average temperature, may have impacted environmental events, with warmer temperatures creating more freeze–thaw cycles, contributing to the *dzud* (Batima *et al.* 2005).

The most notable climate factor was a warming temperature trend, with mean decadal temperature (1970–1979 and 1996–2005) rising by 1.5°C in Dalanzadgad and 1.05°C in Bulgan. Summer temperature increases of 1.8°C and 1.7°C respectively over the same two periods had implications for moisture availability, growth patterns, future ecological productivity and related livelihood issues. Precipitation varied throughout, with decreases in June and declining precipitation, particularly in summer, in Dalanzadgad. Yet drought episodes did not logically mirror changing precipitation patterns: overall decadal increases in Bulgan saw more drought events whereas, although there was a fall in Dalanzadgad's precipitation, there were fewer droughts.

Rather than climatic or ecological variables, the strongest long-term correlation of drought is with pastoralist movements, with populations adapting to drought stress through mobility. However, livestock numbers display independence, implying association with economic motivators rather than environmental factors.

Reactions to perceived random environmental events have in the past reflected a poorly targeted approach to disaster alleviation. For example, international *dzud* aid was directed to the province in 2000–1 (UN 2001; IFRC 2001), although there was no identifiable natural disaster. An understanding of the impact of winter hazards, extreme or otherwise, involves acknowledging anthropogenic as well as environmental causes. Myriad herder-related issues influence livelihoods in this pastoral environment with these including high livestock numbers, resource competition, herder preparedness, lack of fodder or adequate shelter, emergency relief and land degradation (Suttie 2006). Addressing these challenges requires planning, organisation and governmental or private support. Human agency and natural factors need to be separated when considering hazard mitigation at the same time as pastoralist motivations and broader development and sustainability themes.

Our study findings question the oft-cited detrimental effect of drought (Adiyasuren 1998; UNCCD 2002; World Bank 2002; FAO 2006). Drought is a commonplace event and only one of several environmental challenges affecting this arid region. Its frequency and intensity here showed a moderate link with natural factors with little influence on livestock numbers. Pastoralists have adapted and evolved mechanisms to reduce drought impact on their livelihoods.

Conclusion

The paper looks at climatic extremes on the steppe and relates these to IPCC forecasts for an increasing incidence and severity of drought. Established methodology (SPI) is applied together with climate, NDVI, and human and livestock population records in a little-studied area that presents the unusual pastoral dynamic of a cold dryland region with a high annual temperature range where the greatest natural disasters are extreme winter events. Although SPI has been used globally to assess drought, it has seldom been applied in East Asia nor has it been employed to investigate how droughts interact with other extreme physical conditions such as *dzud* in the region.

We find that drought and localised extreme weather events in Mongolia are unassociated, although drought is perceived to have a direct influence on the occurrence and intensity of *dzuds,* as exemplified by government and international organisations continuing to group the two together. We propose that development design and relief-aid efforts would be more productive if it were recognised that these hazards can be unconnected. Further, by acknowledging pastoralists' traditional ability to accommodate drought through migration, their need for external support when dealing with *dzuds* that threaten livestock survival would be decoupled from drought aid *per se*. Establishment of adequate risk management strategies could then improve herders' ability to cope with drought and *dzuds*.

Our results, indicating that droughts are commonly site-specific events, show that these events are relatively independent of other natural factors and neither magnify nor act as indicators of extreme winter conditions in the region. Pastoral movements clearly recognise, and are motivated by droughts. Although drought is widely cited as a cause of negative environmental conditions in Mongolia, we found no strong correlation between drought and other natural forces in South Gobi Province.

Addressing environmental issues on the Mongolian plateau, an area shared with China, adds to the understanding of a region that receives much attention politically and economically but where documentation of physical processes has received less attention. Our work presents a point of comparison with other pastoral areas and provides a factual basis for regional development and policy debate.

Further work is urgently needed to improve understanding of drought dynamics, in particular the initiation, intensity and duration of droughts, and its interaction with NDVI data. More research is required to aid the identification of drought risks and the degree of pastoralist vulnerability to precipitation deficiency over multiple time intervals in this arid region.

Acknowledgements

The authors thank the Royal Geographical Society's Slawson Fellowship for funding the research. The support of Professor Tsolmon of Mongolian National University's UNESCO Remote Sensing Lab and Dr Batbuyan of the Mongolian Institute of Geography was greatly appreciated. Perceptive comments from three anonymous referees enhanced the paper.

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ISSN 0020-2754