Applied Geography 30 (2010) 639–649

Contents lists available at ScienceDirect

Applied Geography

journal homepage: www.elsevier.com/locate/apgeog

# Spatial analysis of time-series changes in livestock distribution by detection of local spatial associations in Mongolia

Izuru Saizen [a,*], Ai Maekawa [b], Norio Yamamura [b]

[a] Graduate School of Global Environmental Studies, Kyoto University, Yoshida Honmachi, Sakyo-ku, Kyoto 606-8501, Japan
[b] Research Institute for Humanity and Nature, 457-4 Motoyama, Kamigamo, Kita-ku Kyoto 603-8047, Japan

*Keywords:*
Livestock distribution in Mongolia
Spatial clusters
Local indicator of spatial associations
Grassland management

A B S T R A C T

The rapid change in the livestock population in Mongolia since the beginning of the 1990s has been a very important issue in terms of the sustainable management of grasslands. We investigated the spatial distribution and changes in the populations of Mongolian livestock for the years 1992, 1999, 2002, and 2006 using GIS datasets based on administrative units. Although the total livestock population had changed drastically owing to the shift from a planned economy to a free market economy from 1992 to 1999 and 2002 to 2006 – as well as the impact of the *dzud*, an adverse combination of summer drought followed by a harsh winter, between 1999 and 2002 – no significant change in the spatial association of any livestock other than goats was detected by the local indicators of spatial autocorrelation (LISA) statistics. Goats were the only animals to show a significant change in their spatial association, and the goat population is increasing in areas surrounded by a high density of livestock. Considering that of all Mongolian domestic animals, goats have the greatest impact on grasslands, policy makers should pay attention to these areas to ensure the sustainability of grasslands in the future. This could play a key role in the successful application of environmental management in Mongolia.



## Introduction

Uncontrolled changes in the domestic livestock population in Mongolia – a result of the country's shift from a planned economy to a market economy on switching to a capitalist economy in the early 1990s – is a very important topic of research (Nixson & Walters, 2006; Yoshihara, Chimeddorj, Buuveibaatar, Lhagvasuren, & Takatsuki, 2008; Zinsstag et al., 2005). Often unpredictable, this phenomenon raised some serious issues in terms of managing grasslands. Mongolia is located in the northeastern part of Asia where the climatic gradient from humid to arid conditions (forest–grassland–desert) causes the formation of ecotones. An ecotone is a transitional area between two adjacent ecological communities and is generally sensitive to any external disturbance of the environment, natural or human, such as climate change or human activities (Peters, 2002; Pogue & Schnell, 2001). Precipitation is concentrated in the summer months, whereas less than 10% of the annual total precipitation is observed during the cold season. Since the monthly temperature falls below 0 °C from November to March, most of the precipitation during this season is in solid form. January is the coldest month, and the monthly mean temperature ranges from −30 °C in the northern mountainous area to −15 °C in the southern Gobi region (Morinaga, Tian, & Shinoda, 2003). About 75% of the total area has been affected by the unrestrained grazing of animals, including cattle (cows,

*Abbreviations:* UB, Ulaanbaatar; SVC, The scale-variance component; LISA, Local indicator of spatial autocorrelation.

* Corresponding author. Tel.: +81 75 753 6369; fax: +81 75 753 6370.
*E-mail addresses:* saizen@kais.kyoto-u.ac.jp (I. Saizen), ai@chikyu.ac.jp (A. Maekawa), yamamura@chikyu.ac.jp (N. Yamamura).

0143-6228/$ – see front matter 
doi:10.1016/j.apgeog.2010.01.002

yaks, and cow-yak hybrids), camels, goats, horses, and sheep, following a nomadic pattern for thousands of years, and nomadism appears to be a hazardous enterprise (Fernandez-Gimenez & Allen-Diaz, 1999; Goldstein, Beall, & Cincotta, 1990). Accordingly, the severely cold climate, short and limited growing period, and especially grazing have led to sparse plant cover in the grasslands of Mongolia (Munkhtsetseg, Kimura, Wang, & Shinoda, 2007).

As an erstwhile socialist country, Mongolia transitioned to a free market economy in the beginning of the 1990s. As a result, all the livestock owned by herding cooperatives were transferred to herders as a result of privatization. No longer managed by the state, most herders were able to enlarge their nomadic activities, and hence, livestock population increased greatly (Chuluun & Ojima, 2001). However, the increase in livestock population under the free market economy may have affected the growth, density, and distribution of grassland plants (Chen, Lee, Lee, & Oikawa, 2007). Although livestock distribution is considered the only predictable and controllable factor compared to other factors affecting grasslands conservation, such as climate change and economic conditions, few studies have attempted to reveal the spatial distribution of livestock and demonstrated a time-series analysis from a macroscopic viewpoint. An understanding of the spatial and time-series distributions of livestock plays a key role in the successful application of environmental management.

In this study, we posit that particular spatial configurations of grazing animals in Mongolia are reflected in the presence of areas well suited for the different animals to live in and for herders to gain economic benefit from their nomadism. We try to detect the spatial clusters of each animal's distribution using an exploratory spatial data analysis. Although spatial autocorrelation was defined decades ago, its application has been limited by computation capacity, software availability, and platform limitation of spatial datasets. Previous studies with spatial autocorrelation for spatial dependence in global and local scales had primarily focused on spatial econometrics (Anselin, 1988, p. 284; Anselin and Rey, 1997; Pace, Barry, & Sirmans, 1998). Thus, there has been no report on the application of these statistics for understanding spatial livestock distribution in Mongolia.

The objectives of this study are (1) to identify and map the spatial patterns of livestock distribution and thus determine whether and where there are high (or low) spatial clusters of livestock distribution and (2) to observe whether these clusters shift geographically and have specific characteristics of their spatial distribution. We combine spatial analysis (GIS) with an empirical approach to clarify the characteristics of livestock distribution throughout Mongolia.

## Background

### *Transition of the Mongolian livestock population*

Until the early twentieth century, majority of the livestock in Mongolia was owned by the upper class and Tibetan Buddhist monasteries in a few large herds. As a result of the revolution in 1921, Mongolia became a socialist state in 1924 (Walters, Hall, Nixson, & Stubbs, 1999), and all livestock were allocated more evenly to small privately owned herds. In the late 1950s, the Mongolian government established livestock collectives throughout the country, and by 1960, all herders belonged to the collectives (Fernandez-Gimenez, 2002). The government owned almost all the Mongolian livestock and paid herders a regular salary to feed their livestock. The collective administration allocated pastures and regulated pasture use by forming medium- and large-sized herds that were moved on a seasonal basis (Fernandez-Gimenez, 2002). The Mongolian livestock population changed depending on the administrative structure, but not significantly, because the administrative structure had been designed and controlled by the state.

In the 1990s, the livestock enterprise rapidly expanded, assisted by relatively good weather conditions and by many new entrants to the livestock economy (Lise, Hess, & Purev, 2006). The transition of the Mongolian livestock population is shown in Fig. 1. After the change to a free market economy in 1992, the total livestock population increased until 1999, which indicated the first peak. This was followed by a rapid and steady decline from 1999 to 2002, when it reached its lowest point, and then another increase to its highest level in 2006. In the present study, we focused our attention on these four time points to conduct a time-series analysis and detect the geographical shift of spatial clusters: (1) the livestock population at the beginning of the free market economy in 1992, (2) the first peak in livestock population in 1999, (3) the lowest population in 2002, and (4) the second peak in 2006.

In 1992, there were 25.694 million domestic livestock in Mongolia, as shown in Table 1. By 1999, this number had grown to 33.569 million, indicating an increase of 30.6%. The increase did not result from a growing number of sheep, despite sheep accounting for the highest number of livestock: the number of sheep increased only slightly from 14.657 million to 15.191 million. In addition, the number of camels decreased slightly. Instead, the growth was due to the increasing number of horses (from 2.2 million to 3.163 million), cattle (from 2.819 million to 3.825 million), and in particular, the number of goats almost doubling (from 5.603 million to 11.034 million). From 1992 to 2006, only the goat population increased dramatically and contributed to the increase in the total livestock population. The steep growth in the number of goats resulted from a strong demand for goat hair, or cashmere (Lise et al., 2006), which is the most important goat product. The yield, quantity, and quality of cashmere depend on the strain of goat, coat color, genetic potency, harvesting period, and technique of collection. Mongolian goat cashmere is considered to be one of the finest in the world, owing to its exquisitely soft, light, and durable texture.

Between 1999 and 2002, the deterioration of winter conditions caused an extreme *dzud*, a Mongolian term describing livestock loss directly induced by harsh winter conditions but often influenced by drought in the previous summer (Retzer &

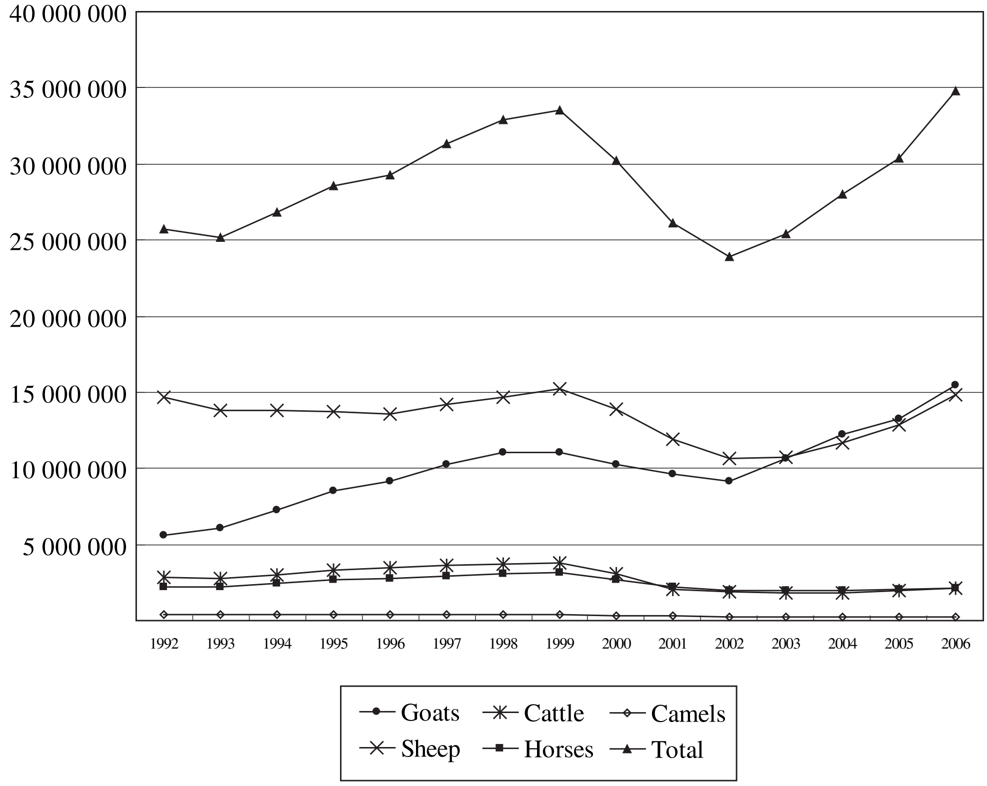


**Fig. 1.** Change in the livestock population of Mongolia (1992–2006).

Reudenbach, 2005). Accompanied by deterioration in spring-summer rainfall, the results were disastrous for Mongolian livestock, with 12 million animals dying nationwide. Of an estimated 190 thousand herding households in 1998, 11 thousand lost all their livestock (Lise et al., 2006). In 2002, the total livestock population had declined to about 23.898 million, back to the level of the late 1980s (Lise et al., 2006). Compared to 1999, the losses were the most severe among cattle (−50.7%) and horses (−37.1%) and least severe among goats (−17.2%), indicating that goats are resilient to cold and their survival rate was highest of all Mongolian domestic animals during this *dzud*.

## *Study area*

The present study covered all of Mongolia, which has a total area of about 1.56 million km$^2$. The Mongolian territory is landlocked and lies at relatively high altitudes, at an average height of 1580 m. The continental and dry climate in the country, where land area is categorized as 21.8% arid and 19.5% semiarid (Begzsuren, Ellis, Ojima, Coughenour, & Chuluun, 2004), is the result of this geographical location. The capital of Mongolia is its largest city, Ulaanbaatar (UB) – the political, economic, and scientific center of the country. More than one million inhabitants, that is, around one-third of the country's total population, live in UB, and the population has been increasing at a tremendous pace, primarily through migration of rural residents (Arguchintseva, Arguchintsev, & Ubonova, 2008). Consequently, many herders looking to do business by selling livestock products tend to move and gather near UB.

**Table 1**
Livestock numbers and their changes in Mongolia (1992, 1999, 2002, and 2006).

| | 1992 (thousand) | 1999 (thousand) | 2002 (thousand) | 2006 (thousand) | Change over 1992–1999 (%) | Change over 1999–2002 (%) | Change over 2002–2006 (%) |
|---|---|---|---|---|---|---|---|
| Goats | 5603 | 11 034 | 9135 | 15 452 | 96.9 | −17.2 | 69.2 |
| Sheep | 14 657 | 15 191 | 10 637 | 14 815 | 3.6 | −30.0 | 39.3 |
| Cattle | 2819 | 3825 | 1884 | 2168 | 35.7 | −50.7 | 15.1 |
| Horses | 2200 | 3163 | 1989 | 2115 | 43.8 | −37.1 | 6.3 |
| Camels | 415 | 356 | 253 | 254 | −14.3 | −28.8 | 0.2 |
| Households[a] | 143 | 189 | 175 | 170 | 32.2 | −7.4 | −2.9 |
| Total (livestock) | 25 694 | 33 569 | 23 898 | 34 803 | 30.6 | −28.8 | 45.6 |

[a] "Households" refers to households actually leading a nomadic existence. Source: National Statistical Office of Mongolia.

## Data and methods

### *Spatial variation of livestock distribution*

Mongolia comprises 21 administrative divisions known as *aimags* (provinces), which are hierarchically divided into 317 *soums* (municipalities). The National Statistical Office of Mongolia provides statistical data of the livestock population for the units of *soums*. The capital, UB, has provincial status but is administrated separately. In this study, we defined the following two types of administrative areas: (1) the 21 *aimags* and UB (AIMAG_U) and (2) the 317 *soums* and UB (SOUM_U), in order to cover all of Mongolia. Fig. 2 shows the map of the Mongolian administrative areas, AIMAG_U, and SOUM_U.

Before conducting the spatial analysis, it was necessary to determine whether AIMAG_U and SOUM_U were appropriate for the spatial analysis and which units reflected a more informative spatial variation for each domestic animal because the smaller spatial unit (SOUM_U) had high spatial accuracy but may have presented unreliable rates. The larger spatial unit (AIMAG_U) may have removed relevant geographical variation (Nakaya, 2000).

Once the variance has been decomposed into each scale of possible administrative areas as in spectrum analysis, Moellering and Tobler (1972) argued that the scale with the highest variance should be applied for mapping and presented the concept of the scale-variance component (SVC). While Curry (1972), Batty (1976), and Batty and Sammons (1979) employed spatial entropy as a similar theory, the SVC is a highly valuable approach to derive a great deal of information on spatial variation from geographical datasets (Okamoto & Himiyama, 1983). Further, the SVC requires hierarchical areal units, which are available in the present study. Although there is no formal criterion as to whether we should discard a low variance for the given scales, the SVC method is useful to compare AIMAG_U and SOUM_U in terms of choosing units that are more appropriate for the spatial analysis.

The SVC is defined by

$$SVC(1) = \frac{\sum_{i}^{I}(\overline{X}_{i.} - \overline{X}_{..})^2}{I-1} \tag{1}$$

$$SVC(2) = \frac{\sum_{i}^{I}\sum_{j}^{Ji}(\overline{X}_{ij} - \overline{X}_{i.})^2}{\sum_{i}^{I}(J_i - 1)} = \frac{\sum_{i}^{I}\sum_{j}^{Jj}(\overline{X}_{ij} - \overline{X}_{i.})^2}{J-1} \tag{2}$$

where $I$ and $J$ denote the numbers for AIMAG_U and SOUM_U, respectively; $\overline{X}_{..}$, the average livestock population in Mongolia; $\overline{X}_{i.}$, the average livestock population for $i$ AIMAG_U; and $\overline{X}_{ij}$, the livestock population for $j$ SOUM_U and $i$ AIMAG_U.

We applied the SVC to each domestic animal over every observed year; the results are shown in Table 2. As may be seen, a larger scale variation took place on SVC(2) (SOUM_U level) for cattle, sheep, and goats over the observed years. By contrast,

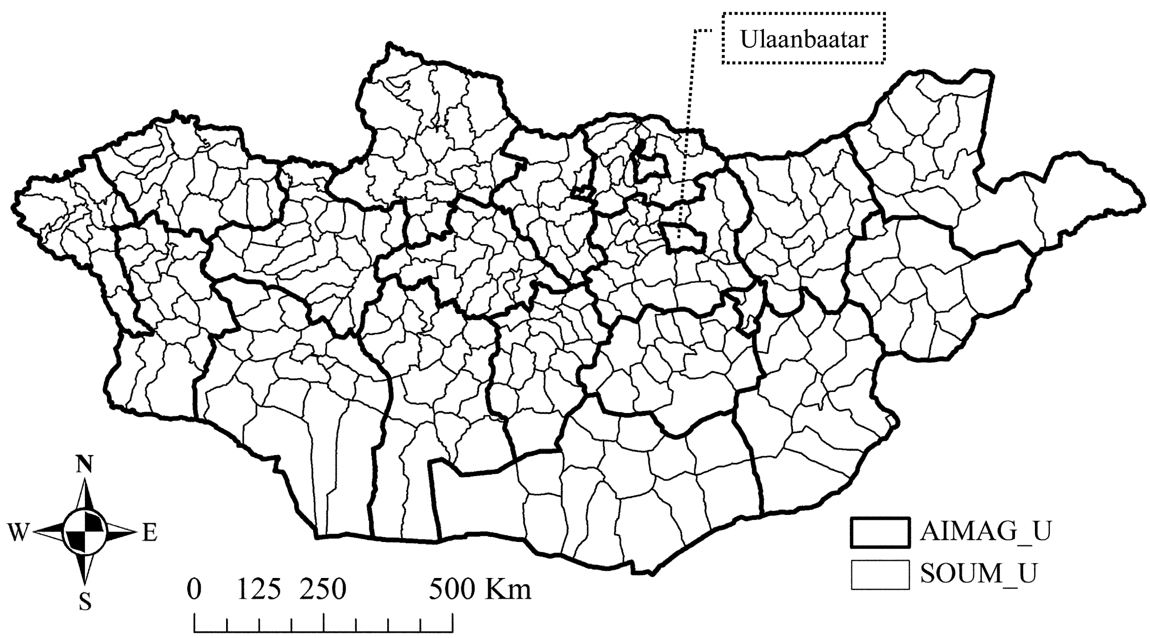


**Fig. 2.** Study area showing AIMAG_U and SOUM_U boundaries and the location of Ulaanbaatar.

**Table 2**
Scale variances of domestic animals (1992, 1996, 2002, and 2006).

| Domestic animals | Year | SVC (1) | Percent sum of squares | SVC (2) | Percent sum of squares |
|---|---|---|---|---|---|
| Camels | 1992 | 2816 | 52.2 | 2578 | 47.8 |
| | 1999 | 2370 | 59.1 | 1637 | 40.9 |
| | 2002 | 1257 | 56.8 | 957 | 43.2 |
| | 2006 | 1251 | 51.3 | 1186 | 48.7 |
| Horses | 1992 | 7854 | 39.7 | 11 933 | 60.3 |
| | 1999 | 19 333 | 43.6 | 24 981 | 56.4 |
| | 2002 | 13 057 | 54.1 | 11 090 | 45.9 |
| | 2006 | 11 759 | 46.5 | 13 511 | 53.5 |
| Cattle | 1992 | 13 511 | 30.6 | 30 703 | 69.4 |
| | 1999 | 33 570 | 41.0 | 48 320 | 59.0 |
| | 2002 | 13 784 | 40.8 | 20 039 | 59.2 |
| | 2006 | 13 392 | 33.3 | 26 784 | 66.7 |
| Sheep | 1992 | 229 965 | 33.8 | 450 037 | 66.2 |
| | 1999 | 264 260 | 34.7 | 497 182 | 65.3 |
| | 2002 | 174 853 | 36.5 | 303 627 | 63.5 |
| | 2006 | 310 323 | 34.9 | 577 584 | 65.1 |
| Goats | 1992 | 120 820 | 48.4 | 128 728 | 51.6 |
| | 1999 | 333 721 | 48.4 | 355 973 | 51.6 |
| | 2002 | 114 955 | 35.9 | 205 664 | 64.1 |
| | 2006 | 359 102 | 42.1 | 494 541 | 57.9 |

the scale variation on SVC(2) was less than that on SVC(1) for camels over the observed years and for horses in 2002. The results may be interpreted as denoting the existence of a more informative variation of cattle, sheep, and goats on the SOUM_U units as well as that of camels on AIMAG_U. Thus, we conducted an exploratory analysis for horse, cattle, sheep, and goats by SOUM_U and for camels by AIMAG_U. Although the SVC(1) was larger than the SVC(2) for horses in 2002, we chose the SOUM_U units to accomplish time-series analysis which would bring us fruitful findings about horses population changes over the observed periods.

*Exploratory spatial data analysis*

Spatial autocorrelation can be defined as the coincidence of value similarity and locational similarity (Premo, 2004). Therefore, positive spatial autocorrelation occurs when high or low values of a random variable tend to be spatially clustered, and negative spatial autocorrelation occurs when areal units tend to be surrounded by neighbors with very dissimilar values. Analyzing the geographic dimension of the spatial patterns of livestock should help us understand the characteristics of its distribution and transition, and enable us to derive meaningful information for managing grasslands in Mongolia. Hence, we applied the techniques of an exploratory spatial data analysis. These techniques serve to describe spatial distribution (clusters or dispersions) in terms of spatial association patterns such as global spatial association and local spatial association (Goovaerts & Jacquez, 2004; Jacquez & Greiling, 2003). Moran's I statistic is a representative measure of global spatial autocorrelation (Anselin, 1988, p. 284; Moran, 1948). Moran's I is useful as a global test that may suggest randomness or non-randomness in the overall spatial pattern of livestock over the observed years in Mongolia but does not indicate where the clusters are located or what type of spatial autocorrelation is occurring spatially. Therefore, the local indicator of spatial autocorrelation (LISA) was applied as an indicator of local spatial association. The LISA, the so-called Local Moran Index, was developed based on Moran's I and was applied in multiple fields (Andresen, 2009; Hare & Barcus, 2007). These patterns are associated with a spatial weight matrix, where each unit is connected to a set of neighboring units. In other words, spatial connectivity is incorporated by means of a spatial weight matrix (Anselin, 1995). In this study, a matrix of distances between the gravity points of each AIMAG_U/SOUM_U was used to model the relations between spatial units. The results presented are those obtained with a matrix of the 10 nearest neighbor administrative units from which meaningful outputs were detected.

In this analysis, a Monte Carlo permutation approach is applied to verify the significance of the LISA. This permutation approach assumes that data are equally likely to be observed at any location. The observed values were randomly shuffled over all locations, and the LISA was recalculated for each permutation. Then, the significance of the LISA was determined by generating a reference distribution by using 999 random permutations. Finally, the LISA significance map was created by incorporating information about the significance of the local spatial patterns. Specifically, the LISA map shows the types of spatial relations between a unit of place and its neighboring units, which allows us to visualize five types of local spatial associations between the observed units and their neighbors, each being located in a quadrant of the scatter plot. Therefore, in the present analysis, each neighborhood can be characterized by one of the following associations: (1) high–high (HH), indicating a clustering of a high livestock population density in an AIMAG_U/SOUM_U (positive spatial autocorrelation); (2) high–low (HL), indicating that low values are adjacent to high values of livestock population density in an AIMAG_U/SOUM_U (negative association); (3) low–low (LL), indicating clustering of low values of livestock population density in an AIMAG_U/

SOUM_U (positive association); (4) low–high (LH), indicating that high values are adjacent to low values of livestock population density in an AIMAG_U/SOUM_U (negative association); and (5) not-significant (NS), indicating no spatial autocorrelation was detected by the LISA statistics.

The LISA was defined by Anselin (1995) and is given by

$$I_i = \frac{x_i - \bar{x}}{\sum_i^n (x_i - \bar{x})^2} \sum_j^n w_{ij}(x_j - \bar{x}) \tag{3}$$

where $n$ equals the number of observed AIMAG_U/SOUM_U units; $w_{ij}$ denotes the weight between locations $i$ and $j$; $x_i$ and $x_j$, the values at locations $i$ and $j$; and $\bar{x}$, the average over all locations of the variables.

The analyses were conducted using GeoDa (Anselin, Syabri, & Kho, 2006), a stand-alone software package that provides exploratory spatial data analysis techniques for areal data. GeoDa has been applied and proven to be an efficient method in multiple fields such as epidemiology, biology, geography, and so forth (Charreire & Combier, 2009; Goldberg & Waits, 2009; Scarborough, Allender, Rayner, & Goldacre, 2009; Wang & Arnold, 2008).

## Results

### *Local spatial association of livestock distribution*

Camels are ideal for the desert as a draft animal because they are extremely undemanding and well adapted to the extreme surroundings of the Gobi and other desert zones (Moser, 2007, p. 130; Retzer, Nadrowski, & Miehe, 2006). As shown in Fig. 3, in 1992, 80.3% of camels were concentrated in eight *aimags* – Bayankhongor, Govi-Altai, Dornogovi, Dundgovi, Övörkhangai, Ömnögovi, Sükhbaatar, and Khovd – located in the south of Mongolia. By 2006, camels in the above eight *aimags* still constituted 82.0% of the total camel population. While the camel population had decreased since 1992 owing to the widespread use of trucks among herders (Oniki & Konagaya, 2006), their distribution pattern had scarcely changed, and no spatial cluster in the observed years was detected with the LISA statistics based on the AIMAG_U units. Although camels display a voracious appetite for pasture plants, it seems reasonable to suppose that the camel's impact on pastures in Mongolia was decreasing in accordance with the decline in their population and that their distribution was affected not by the free market economy but by natural conditions.

Livestock population densities and the results of the LISA statistics for other animals are shown in Fig. 4. The distribution of their population density do not necessarily correspond with the LISA statistics. LISA statistics, as an exploratory spatial data analysis, should focus explicitly on the spatial aspects of the datasets in terms of spatial association and heterogeneity. In other words, this technique can describe spatial distributions, discover patterns of spatial association (spatial clustering), suggest different spatial regimes or other forms of spatial instability (non-stationarity), and identify atypical observations (Anselin, 1996). In this case, LISA statistics can reveal local pockets of non-stationarity or hot spots that cannot be found on population density maps.

As shown in Fig. 4, LL clusters are mainly observed in the Gobi regions in the southeast of Mongolia. As mentioned above, these regions are arid areas where annual precipitation is limited, making them an unsuitable habitat for these domestic


**Fig. 3.** The distribution of camel population density (km$^2$) in 1992.

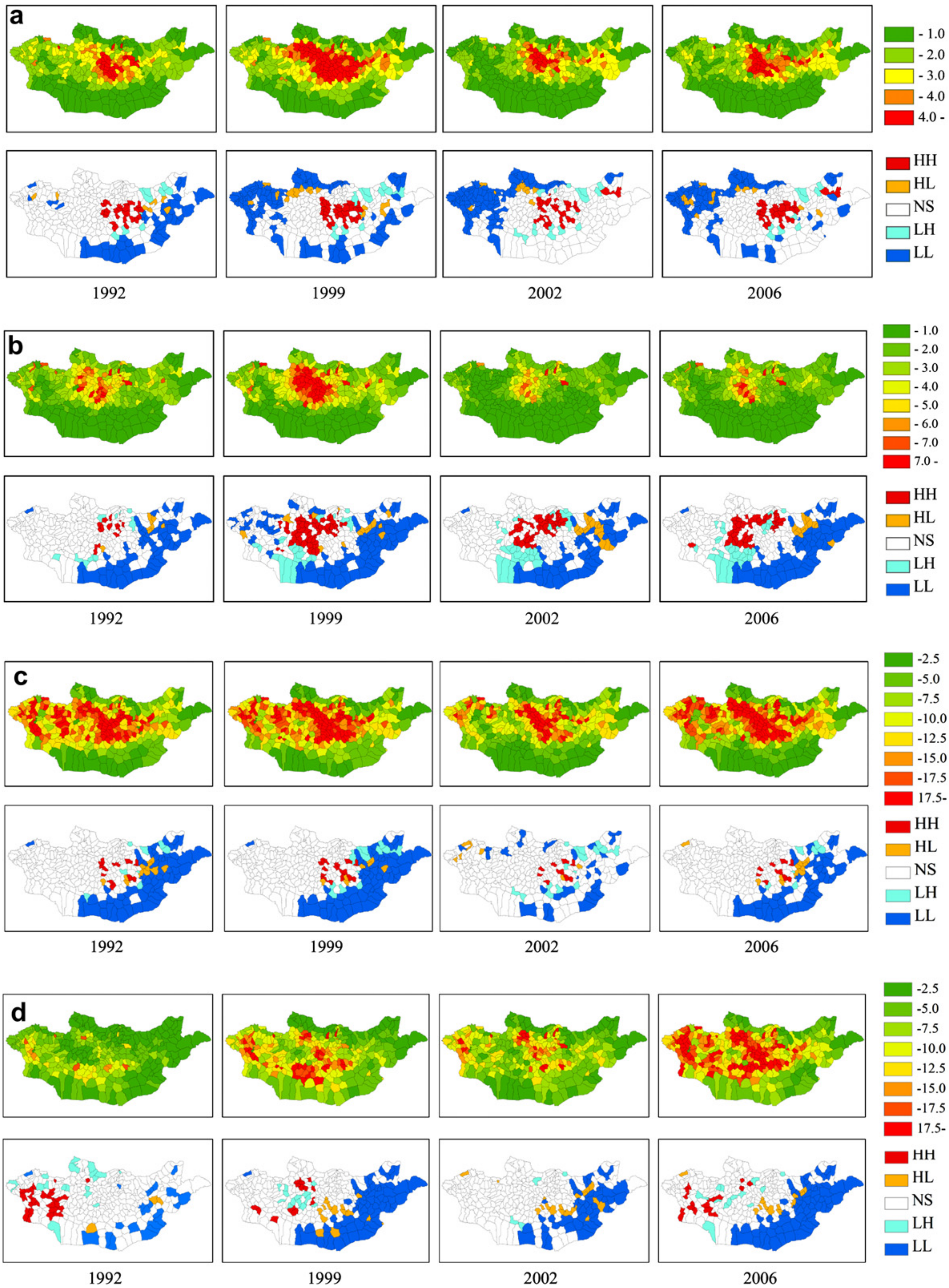


**Fig. 4.** The maps of livestock population density ($km^2$) and LISA cluster maps (1992, 1999, 2002, and 2006). (a) Top row: Horse population density; bottom row: Horse LISA statistics. (b) Top row: Cattle population density; bottom row: Cattle LISA statistics. (c) Top row: Sheep population density; bottom row: Sheep LISA statistics. (d) Top row: Goat population density; bottom row: Goat LISA statistics.

animals. Since a detailed discussion of LL and LH clusters would carry us too far from the purpose of the present paper, only the HH and HL clusters for each animal are examined closely.

Herders breed horses primarily for the purposes of riding, traveling, and racing and for horsemeat and *airag* (fermented mare's milk), a beverage commonly consumed during the summer (Degen, 2007). The herders do not always consume the horsemeat and *airag* themselves but also sell them for profit. Fig. 4(a) shows high values in the horse population density widely distributed in the central parts of Mongolia for every observed year, with a peak observed in 1999; however, the LISA cluster maps show that the distribution of HH clusters was locally concentrated south of UB during the period 1992–2006. There are possibly two main reasons for this distinctive distribution of HH types. First, horses used for horsemeat and *airag* would tend to be bred near UB because both goods spoil rapidly in summer. Most herders who live far from UB do not need cashable goods made from horses, using them mostly for traveling, riding, and sometimes racing. Second, livestock collectives specialized to breed horses used to be found in these areas, south of UB. The severe climate and sparse plant life in these areas is also suited to horses because horses have a higher tolerance for the cold in normal precipitation in Mongolia and are able to eat plants by pushing aside snow with their hooves (Kanaoka, 2000, pp. 48–51). Historically, there have been more horses in these areas; moreover, this distribution still remains and was detected by the LISA statistics.

As far as cattle are concerned, an ecological adaptation of the Mongolian cattle, which helps reduce heat loss during the cold seasons, is coat color (Badarch, Zilinskas, & Balint, 2003, pp. 69–113). The coats are generally red, brownish-red, and black which absorb more heat than light colors. Another well-developed adaptation specific to Mongolian cattle is their ability to choose particular types of pasture hay and to wrap the grass around their tongues to tear it off (Badarch et al., 2003) and, compared to other cattle, Mongolian cattle are well adapted to high mountain. A map of cattle population density for all the observed years is presented in Fig. 4(b). The high level of cattle population density is distributed from the west of UB to around the *Hangai* mountainous regions, which constitute the largest area of the so-called Mongolian Plateau to be covered with rich vegetation (Petit, Déverchère, Calais, San'kov, & Fairhead, 2002). LISA statistics also show similar characteristics in all the observed years, except in 1992. Meat is the principal product of Mongolian cattle (Badarch et al., 2003); therefore, HH clusters are observed around UB and in the *Hangai* mountain regions, which are physically accessible from the capital. For the same reason, the distribution of the HH clusters was unchanged, even after the rapid decrease in cattle population following its peak in 1999.

The distribution of sheep population density was largely spread from west to east in Mongolia (Fig. 4(c)). By contrast, HH and HL clusters were observed around or in the south of UB to a limited extent. The high values around UB reflect the city inhabitants' demand for mutton. Recently, the price of wool has been falling rapidly, but the demand for mutton, which is relatively difficult to transport to long distances due to its weight, still remains; therefore, HH clusters around UB would be observed and detected by LISA statistics as well.

As previously suggested, goats are the only animal species whose population increased during the observed period 1992–2006 owing to the strong demand for cashmere. The distribution maps of goat population density and spatial clusters are shown in Fig. 4(d). In 1992, the goat population density was less than 10 per $km^2$ for almost all of Mongolia. In 1999, the figure had increased considerably, especially in the central areas, by up to more than 17.5 per $km^2$. Furthermore, with the impact of the *dzud*, population densities of more than 17.5 per $km^2$ were widely observed in 2006, exceeding that of the first peak in 1999. Comparing the LISA cluster maps for the period 1992–2006, the HH cluster was observed in western Mongolia in 1992, and its distribution had shifted to the east in 1999. In 2002, the HH cluster had disappeared and was once again distributed in western Mongolia in 2006. These changes do not seem to be associated with the change in population density. Instead, it was shown that the HH goat cluster was shifting, and its distribution was different from those of other animals' HH clusters.

*Relation between goat population change and sheep units*

To clarify the spatial characteristics of changes in the goat population, we calculated the LISA statistics of sheep units, which represent the degree of total domestic animal population, for a comparison with changes in the goat population. Table 3 shows the relation between the changes in goat population during the period 1992–1999 and sheep units in 1992 as well as the relation between these changes for the period 2002–2006 and sheep units in 2002. In 1992, the LISA statistics produced the following sheep units: 57 HH type, 1 HL type, 15 LH type, 73 LL type, and 172 NS type. Table 3 shows the characteristics of the different types obtained from these calculations by each type of spatial grouping. On the whole, for both the periods, areas with low livestock density showed a high increase rate of goat density as shown in LH and LL, whereas the second highest rate is observed in HH during the period 2002–2006. It should be noted that the highest rate of goat population change from 1992 to 1999 was observed in the LH type of sheep unit (178% increase), while the lowest rate was seen in the HL type of sheep unit (31% increase). In addition, in 2002, 49 HH, 6 HL, 17 LH, 73 LL, and 173 NS types of sheep units were obtained, and the highest rate of goat population change from 2002 to 2006 also occurred in the LH type of sheep unit (97.2% increase). Given that the LH type is the cluster with low values surrounded by high values of sheep units, this fact indicates that the goat population tended to increase in areas with relatively low sheep units and especially surrounded by high sheep units; in other words, goats were moving into these areas. We also observed the relation between the LISA statistics of sheep units and other domestic animals; however, any significant aspect observed in case of goats was not detected. Compared to other domestic animals, goats are not required to be bred in specific conditions such as physical nearness to UB or near rich vegetation owing to the characteristics of their main product – cashmere – and their survival ability, and accordingly, the LISA statistics reflect this aspect in the case of the sheep units.

**Table 3**
Relations between goat population change and type of sheep unit (SU) local spatial associations during 1992–1999 and 2002–2006.

| LISA statistic level types | HH | HL | NS | LH | LL | Total |
|---|---|---|---|---|---|---|
| Number of SOUM_U of sheep units in 1992 | 57 | 1 | 172 | 15 | 73 | 318 |
| Rate of change (1992–1999) | 123.3% | 31.1% | 89.3% | 177.6% | 95.6% | 96.9% |
| Goat population in 1992 (thousand) | 752 | 21 | 3192 | 99 | 1539 | 5603 |
| Goat population in 1999 (thousand) | 1679 | 27 | 6041 | 275 | 3011 | 11 034 |
| Gross area (km$^2$) | 144 607.8 | 3608.9 | 703 982.7 | 51 371.2 | 659 311.7 | 1 562 882.3 |
| SU in 1992 (thousand) | 11 317 | 190 | 30 164 | 1820 | 10 600 | 54 090 |
| SU in 1999 (thousand) | 15 777 | 131 | 39 579 | 2756 | 13 749 | 71 992 |
| Number of SOUM_U of sheep units in 2002 | 49 | 6 | 173 | 17 | 73 | 318 |
| Rate of change (2002–2006) | 54.0% | 58.6% | 65.9% | 97.2% | 83.2% | 69.2% |
| Goat population in 2002 (thousand) | 1343 | 209 | 5060 | 260 | 2263 | 9135 |
| Goat population in 2006 (thousand) | 2068 | 332 | 8393 | 513 | 4145 | 15 452 |
| Gross area (km$^2$) | 178 697.4 | 10 866.4 | 578 795.2 | 63 431 | 731 092.3 | 1 562 882.3 |
| SU in 2002 (thousand) | 8509 | 872 | 26 387 | 1872 | 7712 | 45 351 |
| SU in 2006 (thousand) | 9521 | 996 | 33 956 | 2574 | 10 753 | 57 800 |

## Discussion and conclusion

A herder's mobility is a key factor in ensuring the sustainability of a livestock production system in semiarid and arid landscapes (Ellis & Swift, 1988; Sneath, 1998). This system was suitable in Mongolia until the 1990s, when the goat population and its spatial distribution were most influenced by the shift to a free market economy. After 1992 and excluding the period between 1999 and 2002, livestock density maps of horses, cattle, and sheep show geographical shifts depending on the changes in their population throughout Mongolia, and on the contrary, the LISA statistics corresponding to these animals do not represent any significant change of their spatial distribution while only goats have the characteristic of moving to the areas with LH clusters. As mentioned above, cashmere can be easily transported from any location, near or far, from UB and maintained in good condition even in summer, as compared to the perishable products of other animals, such as meat and milk. Therefore, herders are not limited by geographic conditions when choosing locations for breeding goats. In addition, the highly attractive prospect of cash income from cashmere accelerates this tendency. Meanwhile, herders do not tend to expand the number of livestock other than goats in areas far from UB due to poor profits and limitations of their suitability to natural condition; accordingly, the HH and HL clusters of these animals did not change significantly during the observed years, as per the results of the LISA statistics.

During the period 1999–2002, with the occurrence of several record-breaking disastrous *dzud*, livestock mortality was associated with the low normalized difference vegetation index (NDVI) in summer, high snow water equivalent (an index calculated by multiplying snow depth by its density) in winter, a high previous year's mortality, and high previous year's livestock population (Tachiiri, Shinoda, Klinkenberg, & Morinaga, 2008). Templer, Swift, and Payne (1993) identified the *dzud* risk and clarified that the eastern region had the lowest risk by summarizing the historical frequency of the *dzud*, whereas *aimags* in the other regions had medium and high levels of risk based on *aimags* units. During this study, a rapid decrease of livestock was also observed mainly in these areas. By using more detailed units, namely, *soums* where geographic variance is higher, it was possible to clarify that the characteristics of spatial distribution for camels, horses, cattle, and sheep had not changed before and after the *dzud*; however, their populations had changed in accordance with the impact of the *dzud*. The high spatial clusters of these animals depended mostly on their suitability for the severe natural environment of Mongolia and their historical backgrounds.

The forage preferences of these domestic animals are well known to be substantially different. These preferences result from differences in the body size; reticulorumen capacity; anatomy of teeth, lips, and mouth structures; grazing ability; agility; and digestive systems of the different species (Vallentine, 2001). The grazing animals in this study can be divided into three groups based on their forage preferences: (1) grazers, (2) intermediate feeders, and (3) browsers. Grazers primarily consume graminoids and strongly avoid woody species. Occasionally, they consume locally available forbs and woody species when graminoids are not available. Horses and cattle are grazers (Vallentine, 2001). Horses mostly consume graminoids and occasionally eat forbs and woody species. Cattle prefer grasses and eat forbs and woody species seasonally and can switch to woody species or forbs if grasses are not available. Intermediate feeders eat large amounts of graminoids, forbs, and woody species and are known for their ability to adjust their feeding habits to whatever is locally available. Sheep are intermediate feeders and are known to be highly selective foragers. Sheep consume large amounts of forbs and grasses and smaller amounts of woody species. Their diets also consist of a large proportion of grasses compared to that of goats (Gordon & Illius, 1992). Browsers primarily consume forbs and woody species. They commonly consume green grass during growing seasons, but avoid dry, mature grass (Vallentine, 2001). Most studies agree that goats are browsers. Goats prefer the leaves and tender twigs of woody species and consume the young growth of many woody species that are less palatable to other species (Vallentine, 2001). They have the ability to consume forage of lower quality and can consume needle leaves of conifer trees up to 220 cm tall by bending the trees to reach the leaves on higher branches (Child, Byington, & Hansen, 1985). Goats are not recommended to be used to maintain tree and shrub in rangelands, and goat grazing is often restricted in tree plantations where tree seedlings are short or thin enough for goats to bend over (Child et al., 1985). In addition, goats consume grasses and forbs (Gordon & Illius, 1992) and are less sensible to the *dzud* effect because of their browsing grazing habit, which is woody plants having usually deep roots that make them less sensible to the effect of summer drought. Therefore, of all Mongolian livestock, goats can be considered to have the greatest effect on vegetation even after severe natural disasters, such as the *dzud*.

We tried the spatial analysis by administrative units, that is, *soums*. Nomadic people in Mongolia are eligible to various public services such as education, medical treatment, suffrage, etc., from the *soum* in which they are registered as residents. They normally do not move far away without changing their resident registration. In case they decide to move and change the pasture area for their livestock for whatever reason, be it to make money by selling livestock products or to seek a better place for nomadic life far away from the *soum* they have lived in so far, they will register their residency in the *soum* they intend to move to. Further, they are required to pay a tax based on their livestock population so that the livestock population datasets provided by the *soum*, which we used in this study, reflect the exact number of livestock and can partly explain social aspect of Mongolia (Yoshino & Ganbat, 2006).

Although livestock distribution is changeable depending on natural conditions such as precipitation, vegetation, temperature, altitude, and water availability, this study revealed that the characteristics of livestock distribution could be partly explained by the demand for products made from each type of animal. Generally speaking, it is difficult for us to obtain time-series statistical datasets of natural conditions spatially throughout Mongolia, which affect the livestock distribution. On the contrary, datasets of livestock population are easily available for this kind of spatial analysis. Our procedure designated in this study would contribute a macroscopic spatial analysis in Mongolia.

These results should be considered in maintaining a sustainable nomadic enterprise. We detected the local spatial associations of cattle, horses, sheep, and goats by LISA statistics, clarifying that the LH type of local spatial associations are areas where the goat population will potentially increase in the near future and severe land degradation will occur owing to overgrazing. LISA statistics may prove to be a useful method for predicting areas of grazing impact and will be increasingly helpful in managing sustainable nomadic enterprises in Mongolia.

## Acknowledgement

This research was supported by the Research Institute for Humanity and Nature (project number D-04) and the Grant-in-Aid for Young Scientists (B) (20780172).

## References

Andresen, M. A. (2009). Testing for similarity in area-based spatial patterns: a nonparametric Monte Carlo approach. *Applied Geography, 29*, 333–345.
Anselin, L. (1988). *Spatial econometrics: Methods and models*. Dordrecht, The Netherlands: Kluwer Academic Publishers.
Anselin, L. (1995). Local indicators of spatial association-LISA. *Geographical Analysis, 27*, 93–115.
Anselin, L. (1996). The Moran scatterplot as an ESDA tool to assess local instability in spatial association. In M. Fischer, H. Scholten, & D. Unwin (Eds.), *Spatial analytical perspectives on GIS* (pp. 111–125). London: Taylor and Francis.
Anselin, L., & Rey, S. J. (1997). Introduction to the special issue on spatial econometrics. *International Regional Science Review, 20*, 1–7.
Anselin, L., Syabri, I., & Kho, Y. (2006). GeoDa: introduction to spatial data analysis. *Geographical Analysis, 38*, 5–22.
Arguchintseva, A. V., Arguchintsev, V. K., & Ubonova, L. V. (2008). Modeling of the distribution of anthropogenic pollutants in the atmospheric boundary layer of the city of Ulan Bator. *Geography and Natural Resources, 29*, 146–149.
Badarch, D., Zilinskas, R. A., & Balint, P. J. (2003). *Mongolia today*. London: RoutledgeCurzon.
Batty, M. (1976). Entropy in spatial aggregation. *Geographical Analysis, 8*, 1–21.
Batty, M., & Sammons, R. (1979). A conjecture on the use of Shannon's formula for measuring spatial information. *Geographical Analysis, 11*, 304–310.
Begzsuren, S., Ellis, J. E., Ojima, D. S., Coughenour, M. B., & Chuluun, T. (2004). Livestock responses to droughts and severe winter weather in the Gobi Three Beauty National Park, Mongolia. *Journal of Arid Environments, 59*, 785–796.
Charreire, H., & Combier, E. (2009). Poor prenatal care in an urban area: a geographic analysis. *Health and Place, 15*, 412–419.
Chen, Y., Lee, G., Lee, P., & Oikawa, T. (2007). Model analysis of grazing effect on above-ground biomass and above-ground net primary production of a Mongolian grassland ecosystem. *Journal of Hydrology, 333*, 155–164.
Child, D. R., Byington, E. K., & Hansen, H. H. (1985). Goats in the mixed hardwoods in the southeastern United States. In F. H. Baker, & R. K. Jones (Eds.), *Multispecies grazing* (pp. 149–158). Morrilton, AK: Winrock International Institute for Agricultural Development.
Chuluun, T., & Ojima, D. (2001). Sustainability of pastoral systems in Mongolia. Ulaanbaatar, Mongolia. *Abstracts of open symposium on change and sustainability of pastoral land use systems in temperate and central Asia* (pp. 75).
Curry, L. (1972). A spatial analysis of gravity flows. *Regional Studies, 6*, 131–147.
Degen, A. A. (2007). Sheep and goat milk in pastoral societies. *Small Ruminant Research, 68*, 7–19.
Ellis, J. E., & Swift, D. M. (1988). Stability of African pastoral ecosystems: alternate paradigms and implications for development. *Journal of Range Management, 41*, 450–459.
Fernandez-Gimenez, M. E. (2002). Spatial and social boundaries and the paradox of pastoral land tenure: a case study from post-socialist Mongolia. *Human Ecology, 30*(1), 49–78.
Fernandez-Gimenez, M. E., & Allen-Diaz, B. (1999). Testing a non-equilibrium model of rangeland vegetation dynamics in Mongolia. *Journal of Applied Ecology, 36*, 871–885.
Goldberg, C. S., & Waits, L. P. (2009). Using habitat models to determine conservation priorities for pond-breeding amphibians in a privately-owned landscape of northern Idaho, USA. *Biological Conservation, 142*, 1096–1104.
Goldstein, M. C., Beall, C. M., & Cincotta, R. P. (1990). Traditional conservation on Tibet's northern plateau. *National Geographic Research, 6*(2), 139–156.
Goovaerts, P., & Jacquez, G. M. (2004). Accounting for regional background and population size in the detection of spatial clusters and outliers using geostatistical filtering and spatial neutral models: the case of lung cancer in Long Island, New York. *International Journal of Health Geographics, 3*, 14.
Gordon, I. J., & Illius, A. W. (1992). Foraging strategy: from monoculture to mosaic. In A. W. Speedy (Ed.), *Progress in sheep and goat research* (pp. 153–177). Wallingford: CAB International.
Hare, T. S., & Barcus, H. R. (2007). Geographical accessibility and Kentucky's heart-related hospital services. *Applied Geography, 27*, 181–205.
Jacquez, G. M., & Greiling, D. A. (2003). Local clustering in breast, lung and colorectal cancer in Long Island, New York. *International Journal of Health Geographics, 2*, 3.

Kanaoka, H. (2000). *The sixty chapters to understanding Mongolia*. Tokyo: Akashi-Shoten. (in Japanese).
Lise, W., Hess, S., & Purev, B. (2006). Pastureland degradation and poverty among herders in Mongolia: data analysis and game estimation. *Ecological Economics, 58*, 350–364.
Moellering, H., & Tobler, W. (1972). Geographical variances. *Geographical Analysis, 4*, 34–50.
Moran, P. (1948). The interpretation of statistical maps. *Journal of the Royal Statistical Society B, 10*, 243–251.
Morinaga, Y., Tian, S., & Shinoda, M. (2003). Winter snow anomaly and atmospheric circulation in Mongolia. *International Journal of Climatology, 23*, 1627–1636.
Moser, A. (2007). *Mongolia: Land of Genghis Khan*. Bucher.
Munkhtsetseg, E., Kimura, R., Wang, J., & Shinoda, M. (2007). Pasture yield response to precipitation and high temperature in Mongolia. *Journal of Arid Environments, 70*, 94–110.
Nakaya, T. (2000). An information statistical approach to the modifiable areal unit problem in incidence rate maps. *Environment and Planning A, 32*, 91–109.
Nixson, F., & Walters, B. (2006). Privatization, income distribution, and poverty: the Mongolian experience. *World Development, 34*(9), 1557–1579.
Okamoto, G., & Himiyama, Y. (1983). Application of scale-variance to agricultural geography. *The Tohoku Geography, 35*(3), 116–117, (in Japanese).
Oniki, T., & Konagaya, Y. (2006). The policies for sustainable development of animal husbandry in Mongolia. In Y. Konagaya (Ed.), *Mongolian environment conservation handbook* (pp. 17–26). Kenbunsya, (in Japanese, with English abstract).
Pace, R. K., Barry, R., & Sirmans, C. F. (1998). Spatial statistics and real estate. *Journal of Real Estate Finance and Economics, 17*(1), 5–13.
Peters, D. P. C. (2002). Plant species dominance at a grassland – shrubland ecotone: an individual-based gap dynamics model of herbaceous and woody species. *Ecological Modelling, 152*, 5–32.
Petit, C., Déverchère, J., Calais, E., San'kov, V., & Fairhead, D. (2002). Deep structure and mechanical behavior of the lithosphere in the Hangai–Hövsgöl region, Mongolia: new constraints from gravity modeling. *Earth and Planetary Science, 197*, 133–149.
Pogue, D. W., & Schnell, G. D. (2001). Effects of agriculture on habitat complexity in a prairie-forest ecotone in the Southern Great Plains of North America. *Agriculture, Ecosystems and Environment, 87*, 287–298.
Premo, L. S. (2004). Local spatial autocorrelation statistics quantify multi-scale patterns in distributional data: an example from the Maya Lowlands. *Journal of Archaeological Science, 31*, 855–866.
Retzer, V., Nadrowski, K., & Miehe, G. (2006). Variation of precipitation and its effect on phytomass production and consumption by livestock and large wild herbivores along an altitudinal gradient during a drought, South Gobi, Mongolia. *Journal of Arid Environments, 66*, 135–150.
Retzer, V., & Reudenbach, C. (2005). Modelling the carrying capacity and coexistence of pika and livestock in the mountain steppe of the South Gobi, Mongolia. *Ecological Modelling, 189*, 89–104.
Scarborough, P., Allender, S., Rayner, M., & Goldacre, M. (2009). Validation of model-based estimates (synthetic estimates) of the prevalence of risk factors for coronary heart disease for wards in England. *Health and Place, 15*, 596–605.
Sneath, D. (1998). State policy and pasture degradation in Inner Asia. *Science, 281*, 1147–1148.
Tachiiri, K., Shinoda, M., Klinkenberg, B., & Morinaga, Y. (2008). Assessing Mongolian snow disaster risk using livestock and satellite data. *Journal of Arid Environments, 72*, 2251–2263.
Templer, G., Swift, J., & Payne, P. (1993). The changing significance of risk in the Mongolian pastoral economy. *Nomadic Peoples, 33*, 105–122.
Vallentine, J. F. (2001). *Grazing management*. San Diego: Academic Press.
Walters, B., Hall, D., Nixson, F., & Stubbs, P. (1999). Institutional change in a transitional economy: the reform of economics higher education in Mongolia. *International Journal of Educational Development, 19*, 423–439.
Wang, F., & Arnold, M. T. (2008). Localized income inequality, concentrated disadvantage and homicide. *Applied Geography, 28*, 259–270.
Yoshihara, Y., Chimeddorj, B., Buuveibaatar, B., Lhagvasuren, B., & Takatsuki, S. (2008). Effects of livestock grazing on pollination on a steppe in eastern Mongolia. *Biological Conservation, 141*(9), 2376–2386.
Yoshino, E., & Ganbat, J. (2006). Mongolian income tax system and estimates of its gross domestic product. *Keizaigaku Kenkyu, 55*(4), 31–42, (in Japanese).
Zinsstag, J., Roth, F., Orkhon, D., Chimed-Ochir, G., Nansalmaa, M., Kolar, J., et al. (2005). A model of animal–human brucellosis transmission in Mongolia. *Preventive Veterinary Medicine, 69*, 77–95.