# Vegetation richness, height, coverage and spatial distribution mediate grasshopper abundance in the upper reaches of Heihe River, China

**Lili Li** Corresp., [1, 2] , **Chengzhang Zhao** Corresp., [2] , **Tingjun Zhang** Corresp., [1] , **dawei wang** [3] , **yuxing li** [4] , **Feng Zhang** [1]

[1] College of Earth Environmental Science, Lanzhou University, Lanzhou, Gansu, China
[2] College of Geography and Environmental Sciences, The Northwest Normal University, Lanzhou, Gansu, China
[3] Northwest Regional Climate Center, Gan su Meteorological Bureau, lanzhou, gansu, China
[4] College of Earth Environmental Science, Lanzhou University, lanzhou, gansu, China

Corresponding Authors: Lili Li, Chengzhang Zhao, Tingjun Zhang
Email address: lill13@lzu.edu.cn, zhaocz@nwnu.edu.cn, tjzhang@lzu.edu.cn

Species interactions are often context-dependent and complex, such as the grasshopper community and phytoecommunity. The adoption of grasshopper abundance and vegetation community was determined by topographical heterogeneity. However, it remains vague about how vegetation community, such as coverage abundance and height, influence the spatial distribution pattern of grasshopper abundance at the altitude gradient. Using Geostatistical methods in natural grassland of the upper reaches of Heihe River to quantitatively study the relationship of spatial correlation. A 3 years investigation was shown that 3149 grasshoppers were collected, belonging to 3 families, 10 genera, and 13 species. The semivariable function of grasshopper abundance and vegetation community followed a nonlinear model. Meanwhile, horizontal distribution of two communities was a clear flaky and plaque distribution pattern, especially at the altitude gradient. The abundance of grasshoppers is opposite to the height and coverage of vegetation and the overall followability of coverage, while the local following is consistent. Such as grasshopper abundance, the above 2750m sample with the opposite trend, the following areas are consistent. Finally, grasshoppers have the different choice on different vegetation characteristics in different directions, formed of specific trend characteristics; and the spatial distribution trend is different even with the same community indicators, formed of embedded striped patches structure.

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# Vegetation richness, height, coverage, and spatial distribution mediate grasshopper abundance in the upper reaches of Heihe River，China

**Affiliations:**

LILI LI[1，2], CHENGZHANG ZHAO[2*], TINGJUN ZHANG[1*], DAWEI WANG[3], YUXING LI[1], ZHANG FENG[1]

[1] Key Laboratory of Western China's Environmental Systems（Ministry of Education), College of Earth and Environmental Sciences, Lanzhou University, Lanzhou, 730000, China

[2] College of Geography and Environmental Science, Northwest Normal University, Lanzhou, Gansu 730000, China

[3], Northwest Regional Climate Center, Gan Su Meteorological Bureau, Lanzhou, 730000, China

* Corresponding author, CHENGZHANG ZHAO, College of Geography and Environmental Science, Northwest Normal University, Lanzhou, China. (zhaocz@nwnu.edu.cn).

* Corresponding author, TINGJUN ZHANG, Key Laboratory of Western China's Environmental Systems（Ministry of Education), College of Earth and Environmental Sciences, Lanzhou University, Lanzhou, China. (tjzhang@lzu.edu.cn).

**Abstract:** Species interactions are often context-dependent and complex, such as the grasshopper community and phytoecommunity. The adoption of grasshopper abundance and vegetation community was determined by topographical heterogeneity. However, it remains vague about how vegetation community, such as coverage abundance and height, influence the spatial distribution pattern of grasshopper abundance at the altitude gradient. Using Geostatistical methods in natural grassland of the upper reaches of Heihe River to quantitatively study the relationship of spatial correlation. A 3 years investigation was shown that 3149 grasshoppers were collected, belonging to 3 families, 10 genera, and 13 species. The semivariable function of grasshopper abundance and vegetation community followed a nonlinear model. Meanwhile, horizontal distribution of two communities was a clear flaky and plaque distribution pattern, especially at the altitude gradient. The abundance of grasshoppers is opposite to the height and coverage of vegetation and the overall followability of coverage, while the local following is consistent. Such as grasshopper abundance, the above 2750m sample with the opposite trend, the following areas are consistent. Finally, grasshoppers have the different choice on different vegetation characteristics in different directions, formed of specific trend characteristics; and the spatial distribution trend is different even with the same community indicators, formed of embedded striped patches structure.

**Keywords:** *grasshopper, vegetation, spatial pattern, spatial correlation, geostatistics, upriver area of Heihe*

## Introduction

Environment heterogeneity is the key influence on the dynamics and structure of ecological communities (Aranda and Olivier 2017; Pickett and Cadenasso 1995; Turner, et al. 1989; Viviansmith 1997), and reflect changes in functions and processes. Spatial heterogeneity in ecological systems maintains that all interactions between biotic and abiotic factors. All of them arose from the differential responses of organisms to these factors and the organisms themselves

(Milne 1991) and the organisms themselves(Huston 1994). The heterogeneity was a complexity and variability in the ecological system (Gustafson 1998; Li and Reynolds 1994; Wagner and Fortin 2005), especially after carved by topographic fragmentation. Quantifying spatial heterogeneity was a practical way to canvass the ecosystem structure and figure out the relationships among the ecological community in space. Therefore, evaluating the effect of topographical heterogeneity is the basis for recognizing the spatial correlation between the grasshopper abundance and vegetation.

Grasshopper was widely distributed in the world and an important component of temperate grassland (Branson, et al. 2006; Samways 1993). There was highly sensitive for grasshopper to change in environmental conditions (Samways and Sergeev 1997), such as grazing, fire, and land type conversion. Moreover, it also was the dominant native herbivore (Guo, et al. 2006) and cause extensive damage to grassland in Northwestern China(Yang, et al. 2014). Many grasshopper species have a specific area from different factors, including food selection of only plant species within a single family or a single genus in normal (Schoonhoven, et al. 2005), habitat fragmentation, and climate change. Grasshopper species and distribution benefited the local plant richness and community structure, hence it was critical to understanding the factors that drive grasshopper abundance and diversity. The influence of habitat loss and change on grasshopper community were important to global change. Grassland insect diversity is often linked to plant species composition and habitat structure (Joern 1979; Vandyke, et al. 2009). Plant community distributions, accepted as a driving factor of arthropod communities in grassland habitats (Ernoult, et al. 2013; Schaffers, et al. 2008), are structural complex and high diversity. Plant spatial pattern offers spatially and temporally more feeding and habitat niches for grasshopper.

Grasshopper and plants are generally predicted to show congruent patterns in species diversity due to ecological interactions(Kemp 1992), and their long history of mutual evolutionary(Kemp 1990). Understanding the relationships between grasshopper and plant is a theoretical basis for species distribution. All of which reflect the effects of varied minimum threshold temperatures and developmental rates between grasshopper species along a gradient in montane systems(Kemp 1990; Wachter 1998). Generally, the pattern of the grasshopper was influenced by plant species and characteristics of the vegetation (Joern 1979; Joern 1982), through affecting their feeding behavior and habitat environment (Ali, et al. 2012; Joern 1982).

On the other hand, grasshopper may change the inter-species competition pattern of the plant, even in the structure and diversity, by food selection of only plant species within a single family or a single genus in normal (Schoonhoven, et al. 2005). Combining hight sensitive response and small home range requirements, grasshoppers were used as effective bioindicators of habitat quality (Bazelet and Samways 2011). Many studies investigated relationships between grasshopper community and vegetation in grassland (Huang, et al. 2017a; Joern 2005; Kemp 1990; Torrusio, et al. 2002; Zhang, et al. 2012; Zhou, et al. 2011); however lots of results were based on the traditional spatial distribution type and ignore the spatial position(Kemp 1990; Torrusio, et al. 2002; Zhao, et al. 2009; Zhou, et al. 2011), causing the local variations masked. It assumed that any known data is independent and in the same distribution, ignoring the ecological relationship of adaptation and selection between plant grasshopper communities in the analysis of the spatial distribution of plant species and grasshoppers'.

The Heihe River originates from the Qilian Mountains, scatters itself across the landscape in the middle reaches oasis region, and disappears into the desert lower reaches. The upper reaches of Heihe River occupy the Northwest of China. The area is an alpine system, characterized by isolated mixed grass-forb meadows and drought desert grasslands(Zhao, et al. 2011). In the elevational zone, the topography provides the necessary heterogeneity in habitat. In this study the objectives were to (1) quantify spatial heterogeneity on grasshopper and vegetation at altitude gradient; (2) identify the trend of grasshopper abundance and vegetation community; (3) find out the relationship of the two community, and predict the distribution pattern. We hypothesized that: (1) the semivariable function of grasshopper abundance and vegetation community followed a nonlinear model; (2) horizontal distribution of two communities have shown a clear flaky and plaque distribution pattern, especially under the altitude gradient; (3) the spatial distribution trend reflected that the spatial heterogeneity of vegetation communities and grasshopper appeared evident multiformity in different directions.

## Methods and Study Area

### *Study Area*

The study site is located in Baidaban grassland (38°48′0″-38°49′ 50″N, 99°37′15″-99°39′0″E) along the northern slope of Qilian Mountains in Gansu Province, northwestern China (Fig. 1a). The Mountains is a large mountainous area constituted by many northwest-southeast parallel mountains and flowed in Liyuan River, the tributary Heihe River. The region (Fig. 1b) is a highly variable typical continental climate consisting of wet summers and dry, cold winters. The annual average temperature of 1-2.5℃, July average temperature of 14℃, January average temperature -12.5℃, ≥0℃ accumulated temperature of 1400-1688℃, annual mean precipitation is 270-350mm, and precipitation mainly concentrated in the 6-8 months. The soil in this area is mainly composed of chestnut soil and chernozem. Vegetation at the study site is dominated by *Stipa krylovii, Agropyron cristatum* and *Poa pratensis*, with the coverage of 80% of the total community(Li, et al. 2011; Li, et al. 2013). Other common species found in this grassland include the *Artemisia frigida, Leymus secalinus, Therm opsislanceolata, Heteropappus altaicus, Potentilla acaulis, Taxaxacum mongolicum, Dracocephalum heterophllum, Lepidium alashanicum* and *Allium polyrhizum;* and the Noxious Weed *Melica przewalskyi, Pedicularis artselaeri* founded(Li, et al. 2011; Zhao, et al. 2012).

In this area, partially degeneration, bare ground covered 20-30% of the ground area. Thirteen grasshopper species have been recorded from this area, belonging to three families, ten genera. The dominant species were *oedaleus decorus asiaticus B.-Bienko, Gomphocerus licenti, Filchnerella sunanensis liu, Calliptamus abbreviatus Ikonnikov* and *Bryodema miramae miramae B.-Bienko,* each of them exceeded 10% of all grasshopper species(Li, et al. 2011; Zhao, et al. 2012). These vegetation types are important essence in Baidaban grassland ecosystem, providing heterogeneous habitats for survival and reproduction.

### *Sampling design*

The study area belongs to the middle of Qilian Mountains, including alpine desert, alpine steppe, and alpine meadow. We selected an area of 3500 m from east to west and 900 m from east to west for the composition study; combining the grassland types, 3-8 survey samples were setting in every single grassland type on mid-July from 2009 to 2011 between 09:00 and 17:00 on sunny days with low wind speed and cloud cover. The 1: 50000 topographic map of the study area was digitized and the projection coordinate corrected. The geometric center of the measured plot was designated as the marker of the grasshoppers' diversity survey. Each sample with the coverage of 100 m × 100 m, three 30 m × 30 m rectangular samples were extracted by the double diagonal method. In each plot, the plants within randomly selected a square sampling grid of 1 m × 1 m were used to record community coverage, height and above-ground biomass, and at last three replicate samples were taken.

Sweep-net sampling was used to estimate the relative density of the grasshopper species. For each plot, we started at the center, then walked 15 m in each of the four cardinal directions, without replacement for 3 times, and conducted a standard sample of parallel sweeping 200 nets with a 30 cm diameter. Recording and averaging all grasshoppers collected from each of the four directions to derive a relative grasshopper density (number of individuals per 200 nets).

***Sampling preparation and identification***

Grasshoppers' specimens were stored in 70% ethanol and later dry mounted and sorted to morphospecies based on external characters and general appearance. Genus and/or species were identified according to the *Insect Mathematic Ecology (Ding 1994)*. The abundance of grasshoppers in each plot was calculated according to mean of three replicates of each plot.

***Statistical analyses***

**Estimation and modelling of spatial autocorrelation**. Semivariograms was selected to evaluate the spatial variation (E. Rossi, et al. 1992; Sciarretta and Trematerra 2014) , after analyzing correlation coefficient, covariance (in covariance functions) and variance (in semivariograms).

Semivariograms function expresses the variation of two regionalized variables $z(x_i)$ and $z(x_i+h)$ of points $x_i$ and $x_i+h$ which separation distance is $h$, showing the Semivariograms of sample pairs against the distance between sampling points(Kemp, et al. 1989; Zurbrügg and Frank 2006). The formula is:

$$r(h)=\frac{1}{2N(h)}\sum_{i=1}^{k}\{z(x_i)-z(x_i+h)\}^2$$

Where $N(h)$ is the number of the binate sample points which interval is $h$, $z(x_i)$ and $z(x_i+h)$ are measurements at the point $x_i$ and $x_i+h$. Semivariograms has three most significant parameters: Nugget constant ( $C_0$ ), Sill ( $C_0+C_1$ ) and Range ( $a$ ).

Nugget constant reflects the extent of the randomness of the regionalization variable; Sill reflects the change rate of the variable, and Range reflects the reach of the regionalization variable.

**Spatial trend analysis.** A trend-surface analysis was set on spatial sampling data to fit a mathematical surface and used to reflect the change of spatial distribution. It can be divided into two parts: the trend surface and the deviation. The trend surface reflects the trend of the spatial data, which is influenced by the whole situation and the wide range of factors (Cane, et al. 2017; E. Rossi, et al. 1992). Each vertical bar in the trend analysis graph represents the value and position of a data point. These points are projected onto an east-west and a north-south orthogonal plane. An optimal fitting line can be obtained through these projection points, which can be made to simulate the trend in a particular direction. If the line is straight, it is indicated that no trend exists.

## Results and Analysis

### *Semivariograms and Spatial structure of Ecological Community*

Spatial analysis of grasshopper abundance index (Table 1) showed good model and (67.05% variance attributable to spatial autocorrelation) spatial structure. As above spherical model was selected to describe the semivariograms for grasshopper. The parameter " $a$ " in grasshopper was 9.32m (Table 1), meant the range over the distance of 931.74m was statistically correlated; " $c_0$ "was nugget with the value of 153.12, concluded the minimum variability was 153.12 (estimating the variability of repeated sampling at the same site); " $c_0+c_1$ " was still with the value of 228.37, consider the overall variance at distances was greater than the value of " $a$ ". Spatial variability of vegetation height and coverage fitted the spherical model from 0.18 to 0.90 (Table 1); it was clear the spatial structure of the height and coverage were not regularly or randomly distributed at the sampling areas. The vegetation richness was a good fit for the exponential model with the spatial variability of 98.72.The vegetation community index (Table 1) all showed aggregated distribution pattern (spherical and exponential) and strong spatial structure. The distance of spatial autocorrelation was detected for the vegetation community and ranged from 1.55 to 24.59 m. The spatial distribution types of vegetation and grasshoppers were both aggregation pattern, taking a certain spatial correlation and apparent structure. All above include that the potential to impose spatial structure on the individual of the vegetation and grasshopper was existent.

***Spatial trends in grasshopper abundance and vegetation community***

The rule to identify a trend of grasshopper abundance and vegetation community was looking for an irregular curve on the projected plane. In the study, northeast-southwest and northwest-southeast were determined by the grasshoppers' trend direction (Fig. 2a). The spatial trend of grasshopper abundance (Fig. 2a) indicates that the direction of northeast-southwest was more intense than in northwest-southeast; the graphical representations in the northwest-southeast shows an inverted "U" shape distribution; on the contrary, it reflected a Step-like transition from northeast to southwest. The region with the maximum abundance value was in the altitude of 2530m -2700m (Fig.1b), and the grasshopper populations assumed highly localized distributions within the middle elevation.

In the vegetation community, the spatial trend of vegetation height (Fig. 2b) was confirmed in the direction of northeast-southwest, with a gradient across rows; while on the direction of northwest-southeast was no spatial trend. The direction of northwest-southeast was identified as the spatial trend of the vegetation coverage (Fig. 2c), with a ladder-like distribution; and on the opposite, the trend was obviously appeared an inverted "U" shape. According to the spatial trend of vegetation richness (Fig. 2d) exhibited a higher tendency in northeast-southwest than northwest-southeast; in the graphical representation, northwest-southeast was shown to manifest shape of inverted "U"; in contrast, the spatial trend at northeast-southwest was presented "U"-shaped distribution. The trend of the distribution between height and abundance was consistent, which was centered in the area of middle elevation; but the coverage was opposite trend of distribution to the others.

***The relationship between Grasshopper abundance and Vegetation Community.***

According to the uncertainty and dynamics of the community in nature (Lv and Guo 2010; Selvachandran, et al. 2017; Zegeye, et al. 2006) , the fuzzy negritude similarity was used to analyze the intensity and structure of spatial variability between the grasshoppers' abundance and vegetation community (height, coverage, and richness of grassland).The properties of grasshopper abundance must be affected by vegetation community and sample location (altitude). The effects of sample altitude on grasshopper abundance and vegetation community were shown in fig.3. Basically, grasshopper abundance decreased with an increase of vegetation height; in other words, most species of grasshoppers preferred to distribute in areas with low vegetation height (Fig. 3a). The effects of sample location (altitude) on grasshopper abundance and vegetation coverage were distinct, despite the altitude of 2700m-2750m were similar, including the samples of 11、 12 and 13 (Fig. 3b). The trend curves between grasshopper abundance and vegetation richness were contrary above the altitude of 2750m; when the altitude decreased, the trends of grasshopper abundance followed with vegetation richness' (Fig. 3c).

In order to know the similar degree of grasshopper abundance and vegetation community on numerically expressing, two objects by means of the distance of the corresponding fuzzy sets were loaded(Kohout 1976; Morsi 1989). The inclusion measure of interval-valued fuzzy sets is [0, 1], which was means in positive correlation, the value was the greater the better; if negative correlation, the smaller the better (Wang, et al. 2016; Zeng and Guo 2008). It concluded that (Table 2) grasshopper abundance were positively associate with plant height and coverage, and the height was more correlated with grasshoppers abundance.The value of a similar degree in grasshopper abundance and vegetation richness was hight, meaning that plant diversity affected grasshopper abundance (Table 2).

## Conclusions and Discussion

Spatial heterogeneity was a key point to influence the patterns and changing the relationship on spatial space (Huang, et al. 2017b; Kemp, et al. 1989; Laws and Joern 2017). It was a big challenge to predict that the heterogeneity of grasshopper patches are critical factors that influenced by foraging selectivity and habitat heterogeneity.This study finds that grasshopper population was good at selecting a micro-environment to a dwelling. The semivariable function of grasshopper abundance and vegetation community were a nonlinear model in geostatistics; while in ecology, the curves meant that the spatial distribution pattern was aggregated (Wang, et al. 2010; Zhong, et al. 2014).The grasshopper abundance typically produces spacial heterogeneity with larger range and nuggets than vegetation community (except the range of vegetation coverage in model). Firstly, it was likely to be undetected spatial distance smaller than the 1.5m. Secondly, the structures were indicated that the spatial pattern of the grasshopper species population were influenced by vegetation community distribution. Finally, the distribution of grasshopper heterogeneity was directly influenced by herbivore foraging decisions (Wiggins, et al. 2006; Zhu, et al. 2015), and radically determined by the topography of Qilan mountains(Li, et al. 2011; Li, et al. 2013; Zhao, et al. 2012), micro-climate and soil condition. The result much the same as others (Huang, et al. 2017b; Yan and Chen 1998; Zhao, et al. 2012; Zhao, et al. 2009), was that horizontal distribution of two communities presented a flaky and plaque distribution pattern, with obvious heterosexual structure.

The exploratory analysis of ecological community data revealed that the trends were variable in a different method. In this study area, grasshopper abundance and plant height was a negative correlation, while between grasshopper abundance and plant height was positive; all of which were confirmed (Zhou, et al. 2011) by using traditional biostatistics. When dealing with geostatistics method, the relationship between two communities was not merely positive or negative correlation but changing with the change of elevational gradient. Such as altitudinal support a positive relationship between two communities in total, but does not exist at every stage of elevation. The result testified that alpine grasshoppers were an important adaptation to the mountain environment(Vandyke, et al. 2009; Wachter 1995).

Grasshopper needs adequate food resources and habitat to support their survival, development, and reproduction(Levy and Nufio 2015; Wachter 1995). In the study area, the vegetation was dominant by perennial *Gramineae* and *Cyperaceae,* and some species have taken strong attraction or indispensable to specific grasshoppers; combining with the influence of the altitude, the community was an appearance in the specific area, such as the altitude from 2500m-2700m was an area of species richness (Fig.1b, Fig.3). Furthermore, the plant was not only food resources, but also habitat environment for grasshopper. The zone of 2500m-2700m, a transition zone between desert steppe and mountain steppe, with good coverage and richness of plant, was high grasshopper abundance; with the low height, there was a wide view to defend predators, good transmittance to keep warm, high coverage and richness to compensate for grasshopper herbivory. Though some species prefer forest or jungles, most lived in dry, hard soil and open habitats with low vegetation height. On the contrary, the alpine meadow grassland and mountain shrubby-grassland lay above 2750m, and the soil was moisture, impermeability, and compactification for the massive layer of grass felt(Li, et al. 2011; Zhao, et al. 2012). So it was difficult for grasshoppers to spawn in soil or keep eggs dry, and forming a plaque heterogeneity structure between vegetation and grasshopper with different elevation gradients.

The spatial distribution trend reflected that the spatial heterogeneity of vegetation communities and grasshopper appeared evident multiformity in different directions. The trend of grasshopper abundance in the direction of northeast-southwest was more intense than in northwest-southeast; in vegetation community, the strong trend of the distribution between height and abundance was consistent in northeast-southwest, while the coverage was opposite. That was because the weather and season took an important part in determining the abundance of grasshopper (Begon 1983; Pitt 2012; Wall and Begon 1987). In warm it was found under the influence of direct insolation; however, in high temperature, it was hiding in the shadow of the plant (Begon 2008; Pitt 2012). Thus, the trends in northeast-southwest were manifested, including grasshopper and vegetation. With the increase of quantity and activity, grasshopper became gregarious, reposing and crowing, causing hopping in the same direction(Begon 2008; Zhao, et al. 2011) and aggregated distribution in northeast-southwest. Followed by the spatial distribution of plant community, grasshopper distribution formed embedded striped patches structure in the specific direction.

In conclusion, the semivariable function of grasshopper abundance and vegetation community followed a nonlinear model in the study area. The trend of grasshopper and vegetation in the direction of northeast-southwest was more intense than in northwest-southeast, besides coverage. The two community distribution formed embedded striped patches structure in the specific direction of northeast-southwest. The insights into the relationship between grasshopper abundance and vegetation community with the mountainous environment, provide a theoretical basis for potential distribution prediction.

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## Table 1 (on next page)

Tab. 1 Spatial pattern for different index of community

Spatial analysis of grasshopper abundance index showed good model and spatial structure .

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**Tab. 1** Spatial pattern for different index of community

| Community Index | model | Nugget( $c_0$ ) | Sill( $c_0+c_1$ ) | Range(a) (m) | Variance (%) $c_0$/ ( $c_0+c_1$ ) |
|---|---|---|---|---|---|
| Grasshopper abundance | exponential | 153.12 | 228.37 | 9.32 | 67.05 |
| Vegetation height | Spherical | 24.52 | 137.80 | 1.55 | 18.11 |
| Vegetation coverage | Spherical | 0.04 | 0.044 | 24.59 | 90.69 |
| Vegetation abundance | Exponential | 1.51 | 1.53 | 5.64 | 98.72 |

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## Table 2 (on next page)

Table 2 Fuzzy neartude of the experimental semivariogram of grasshopper abundance and grassland community

similar degree of grasshopper abundance and vegetation community on numerically

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**Table 2** Fuzzy neartude of the experimental semivariogram of grasshopper abundance and grassland community

| | Plant | | |
|---|---|---|---|
| | Height | Coverage | Abundance |
| grasshopper abundance Fuzzy neartude | 0.13 | 0.32 | 0.68 |

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## Figure 1(on next page)

Fig. 1 (a) Location map of the study area, (b) the geographic map for grasshopper and vegetation sampling

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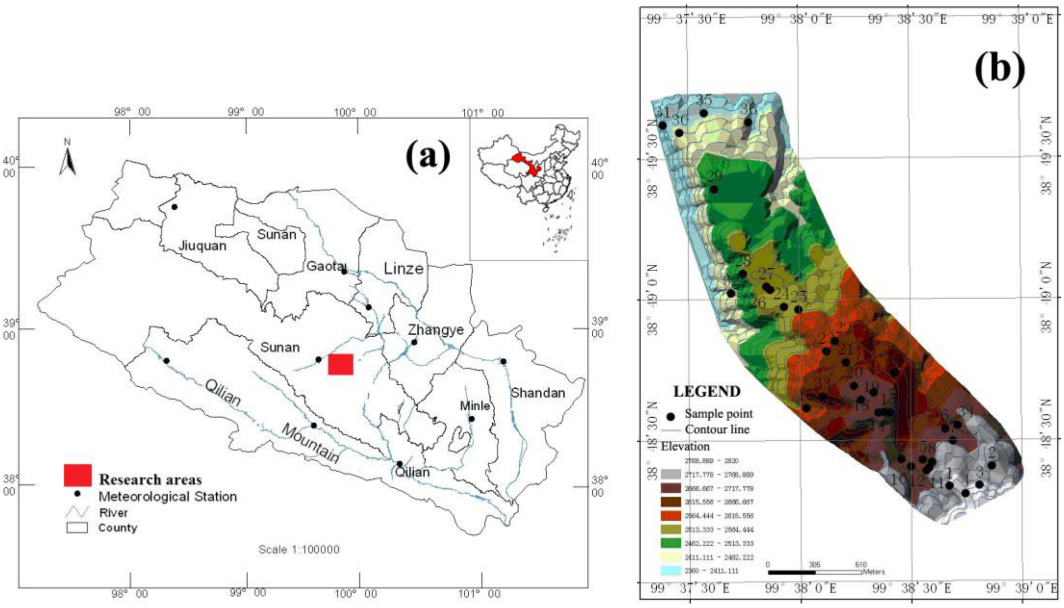

## Figure 2(on next page)

Fig.2 Special trends of community for index in different direction

The X axis is the line that indicates the North and South, the Y axis is the line indicates that the East and West , the Z axis is the line that indicates the index of the grasshopper, The lighter-line is the trend that is the Northeast-Southwest, the harder-line is the trend that is the Northwest-Southeast. a, the trend of spatial distribution for the index of abundance; b, the trend of spatial distribution for the index of height; c , the trend of spatial distribution for the index of coverage; d, the trend of spatial distribution for the index of abundance

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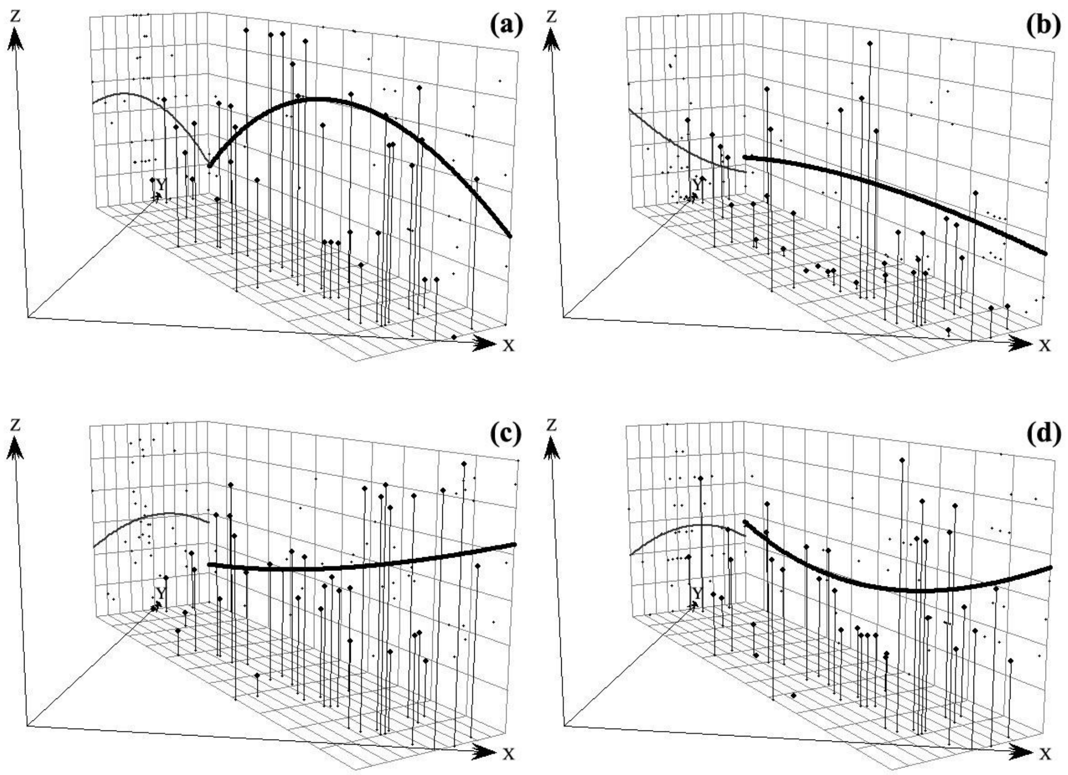

## Figure 3(on next page)

Fig. 3 Effects of different samples between grasshopper abundance and grassland community

The X axis is the sample location, the Y axis is the line indicates that the characteristics of vegetation and grasshoppher abundance. a, the correlation between grasshopper abundance and vegetation height; b, the correlation between grasshopper abundance and vegetation coverage; c,the correlation between grasshopper abundance and vegetation richness.

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