# Community Richness, Height, Coverage, and Spatial Distribution Mediate Grasshopper Abundance in the Upper Reaches of Heihe River, China

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

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**Abstract:** Species interactions are often context-dependent and complex, such as the grasshopper community and phytoecommunity. The adaption of grasshopper abundance and plant community were 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. The geostatistical methods were used in natural grassland of the upper reaches of Heihe River to quantify the relationship of spatial correlation. A 5-years investigation shown that 3149 of grasshoppers was 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 follow ability of coverage, while the local following is consistent. Such as grasshopper abundance, the above 2750m sample with the opposite trend, the following areas were consistent. The grasshoppers exhibited the varieties on vegetation characters among all directions. On the different habits, the spatial distribution formed uniform trends; meanwhile, on the same, the trends diversified with altitude gradient, formed 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 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 was 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 relationship 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 high sensitive response and small home range requirements, grasshoppers were used as effective bio-indicators 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 elevation 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 communities. We hypothesized that: (1) the semi-variable 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) totally, the grasshoppers' diversity was driven on vegetation's, the grasshopper spatial pattern probability reliance on altitude as well.

## 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 is a highly variable typical continental climate consisting of wet summers and dry, cold winters (Fig. 1b). 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 is mainly composed of chestnut soil and chernozem. Vegetation is dominated by *Stipa krylovii, Agropyron cristatum* and *Poa pratensis*, with the coverage of 80% of community (Li, et al. 2011; Li, et al. 2013). Other common species 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 a non-grazing grassland area to carry out the composition study. During the year of 2009 to 2013 in mid-July, 36 sites were established on the grassland. The sites were located within a 3500 m ×900 m of area, ranged in elevation from 2300m to 2800 m, and were randomly chosen to include a range of grassland types (Fig. 1b).The 1: 50000 topographic map of the study area was digitized and the projection coordinate corrected. The plot was fixed on geometric center.

At each site, 3 plot with 100m × 100 m was delimited , all the investigations was taken on sunny days with low wind speed and cloud cover during the daytime of 09:00 -17:00. For each plot, we started at the center, then walked 30 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 sweep net. The grasshoppers were collected from each of the four directions, the population was averaged for the four directions; yet, the abundance was records for all presenting on the plot.

For each plot, the selecting and processing on plant was similar to the grasshoppers. Adapt to the grasshoppers habitat, three samples (1 m × 1 for plant was set around 10m for grasshoppers plots, randomly. On each sample, total plant species richness, proportional coverage of live vegetation, and plant diversity were calculated.The plant community of each plot was investigated following Cornelissen et al. (2003) and Perez-Harguindeguy et al. (2016) protocols.

### *Sampling preparation and identification*

Grasshoppers' specimens were stored in 70% ethanol and later dry mounted and sorted to morph-species 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. A 5 years investigation was shown that 3149 grasshoppers were collected, belonging to 3 families, 10 genera, and 13 species.

## *Statistical analyses*

### Estimation and modeling 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:

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

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. The 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 indexall showed aggregated distribution pattern (spherical and exponential) (Table 1). 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's were aggregation pattern, taking a certain spatial correlation and apparent structure. Moreover, the regularities of distribution on grasshoppers' were similar to the vegetation. All spatial patterns exhibited on vegetation and grasshopper relatively constant variation.

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

Based on the rule of principle of uniform distribution of projection points on perspective surface of sampling, the aspect of northeast-southwest and northwest-southeast was selected on vegetation and grasshoppers (Fig.2). The altitude is reducing from northwest to southeast.

The spatial trend of grasshopper abundance indicated that the direction of northeast-southwest was more intense than in northwest-southeast(Fig. 2a); the graphical representations inhibited an inverted "U" shape distribution. While the trends on northwest-southeast a Step-like transition was reflected. The region with the maximum abundance value was in the altitude of 2530m -2700m (Fig.2b), the grasshopper populations' assumed highly localized distributions on the middle elevation.

On the vegetation community, the spatial trend of vegetation height was confirmed in the direction of northeast-southwest, with a gradient across rows (Fig. 2b). The spatial trend of the vegetation coverage on northwest-southeast was identified shaped a ladder-like distribution (Fig. 2c); while on the northwest-southeast, the trend was obviously appeared an inverted "U" shape. The vegetation richness spatial trend exhibited a higher tendency in northeast-southwest than northwest-southeast (Fig. 2d), shaping a "U" distribution at northeast-southwest and an inverted "U" on northwest-southeast. Among the spatial distribution on vegetation, the high coverage consisted with lower height; however, the spatial distribution on height was similarity to abundance, centered in the area of middle elevation.

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

According to the spatial distribution of vegetation community (height, coverage and abundance) and grasshopper richness, the relationship was found. 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 lower vegetation height; that is, most species of grasshoppers preferred to distribute on the low altitude (Fig. 3a). Totally, the spatial pattern on grasshopper abundance and vegetation coverage were distinct; despite of the altitude of 2700m-2750m were similar, such as the samples of 11, 12 and 13 (Fig. 3b). The relationship between grasshopper abundance and vegetation richness was highly depending on altitude; altitude below 2750m, diversity of grasshopper species was similar to vegetation's; while, the distributions were contrary above 2750m (Fig. 3c).

***Fuzzy neartude of grasshoppers' abundance and grassland community***

According to the uncertainty and dynamics of the community in nature, the fuzzy negritude similarity was used to analyze the intensity and structure of spatial variability between the grasshoppers' abundance and vegetation community (Kohout 1976; Morsi 1989). The inclusion measure of interval-valued fuzzy sets was [0, 1], means positive correlation, the value was the greater the better; if negative correlation, the smaller the better (Wang, et al. 2016; Zeng and Guo 2008).

The grasshopper habitat selection was prior on vegetation, relied the altitude as well (Table 2). The correlations between grasshopper and vegetation were complex. The grasshopper abundance and vegetation richness were positive correlation with high fuzzy nearness value (F=0.68) (Table 2), confirmed that the grasshoppers' diversity depends on vegetation's. Furthermore, grasshopper abundance and vegetation height appeared in an obvious negative correlation with high fuzzy nearness value (F=0.13) (Table 2), the result draw that the grasshopper's distribution extremely restricted by vegetation's height. The vegetation coverage influenced grasshopper spatial pattern probability reliance on altitude, such as a small fuzzy nearness value 0.32 presented in positive correlations (Table 2).

# 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 is critical factors that influenced by foraging selectivity and habitat heterogeneity. On the research, the results showed that grasshopper species were good at selecting a micro-environment to habitat. The semivariable function of grasshopper abundance and vegetation community was a nonlinear model in geo-statistics; the curves meant that the spatial distribution pattern was aggregated on ecology (Wang, et al. 2010; Zhong, et al. 2014). The grasshopper abundance typically produces special heterogeneity with larger range and nuggets than vegetation community (except the range of vegetation coverage in model). The range values were likely to be undetected spatial distance smaller than the 1.5m. Based on the spatial pattern, the grasshopper habitat selection was prior on vegetation community. Heterogeneity on grasshopper distribution was directly influenced by herbivore foraging decisions (Wiggins, et al. 2006; Zhu, et al. 2015), probability 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 confirmed that horizontal distribution of two communities presented a flaky and plaque distribution pattern, with obvious heterosexual structure (Huang, et al. 2017b; Yan and Chen 1998; Zhao, et al. 2012; Zhao, et al. 2009).

The exploratory analysis of ecological community data revealed that the trends were variable in a different method. According to the traditional biostatistics, correlation between grasshopper abundance and plant height presented negative, while the positive correlation exhibited in grasshopper abundance and plant coverage (Zhou, et al. 2011). However, on geostatistics, the relationships between two communities were much more complex, the altitude influenced distribution. Such as altitudinal support a positive relationship between two communities in total, but does 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). On the study area, the vegetation was dominant by perennial *Gramineae* and *Cyperaceae,* some vegetation exhibited strong attraction or indispensable to specific grasshoppers. Due to the influence of the altitude, the community was an appearance in the specific area, such as the altitude from 2500m-2700m was the species richness area (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. Lower height provided a wide view to defend predators, good transmittance to keep warm, high coverage and richness to compensate for grasshopper herbivore. Most of species prefer forest or jungles, most lived in dry, hard soil and open habitats with low vegetation height. Yet, the alpine meadow grassland and mountain shrubby-grassland lay above 2750m, with moisture, impermeability, and compactification soil, resulting massive layer of grass felt (Li, et al. 2011; Zhao, et al. 2012). It was difficult for grasshoppers to spawn in soil or keep eggs dry, 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 on the direction of northeast-southwest was more intense than in northwest-southeast. In vegetation communities, the strong trend of the distribution between height and abundance was consistent in northeast-southwest, while the coverage was on northwest-southeast. The results showed that the weather and season took an important part in determining the abundance of grasshopper

(Begon 1983; Pitt 2012; Wall and Begon 1987). On the warm condition, grasshoppers were assembled under the influence of direct insolation; otherwise, on high temperature, the insects were hiding in the shadow of the plant (Begon 2008; Pitt 2012). Thus, the trends in northeast-southwest were manifested, both in grasshopper and vegetation. With the increase of quantity and activity, grasshoppers became gregarious, reposing and crowing, shaping the hopping in the same direction (Begon 2008; Zhao, et al. 2011), aggregating distribution in northeast-southwest. Followed by the spatial distribution of plant community, grasshopper distribution formed embedded striped patches structure in the specific direction.

## Conclusions

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.

## Data availability

The raw/processed data required to reproduce these findings cannot be shared at this time as the data also forms part of an ongoing study.

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### *Contributions*

LL provided the idea of this study. CZ designed the experiments，LL XZ and YL performed the sample. LL and DW analyzed the data of this study.LL prepared the original draft. LL, CZ, XZ, DW, and YL reviewed and edited the draft. CZ was responsible for the project administration and funding acquisition. All authors read and approved the final manuscript.

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## Ethics declarations

***Ethical approval***

This manuscript is not submitted to any journal currently.

***Consent to participate***

All authors are agreed.

***Consent to publish***

All the authors agreed to published this paper

***Competing interests***

The authors declare that they have no competing interests.

# Figures

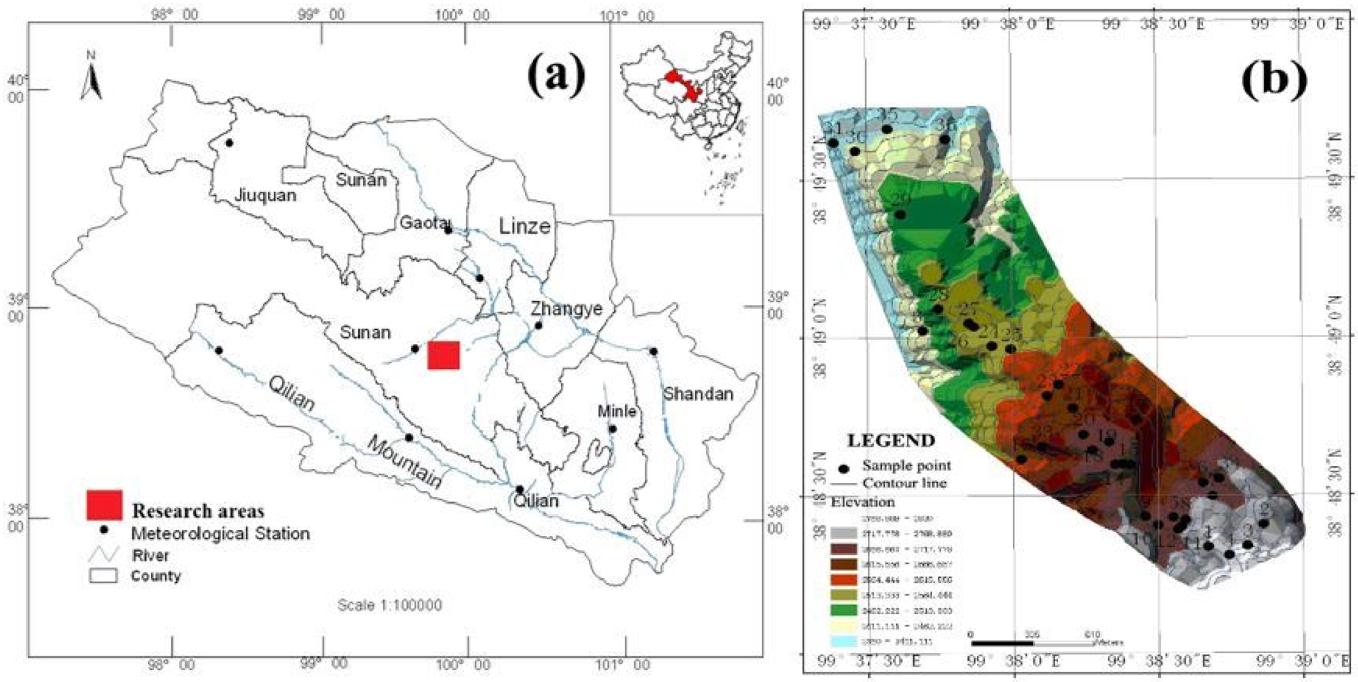
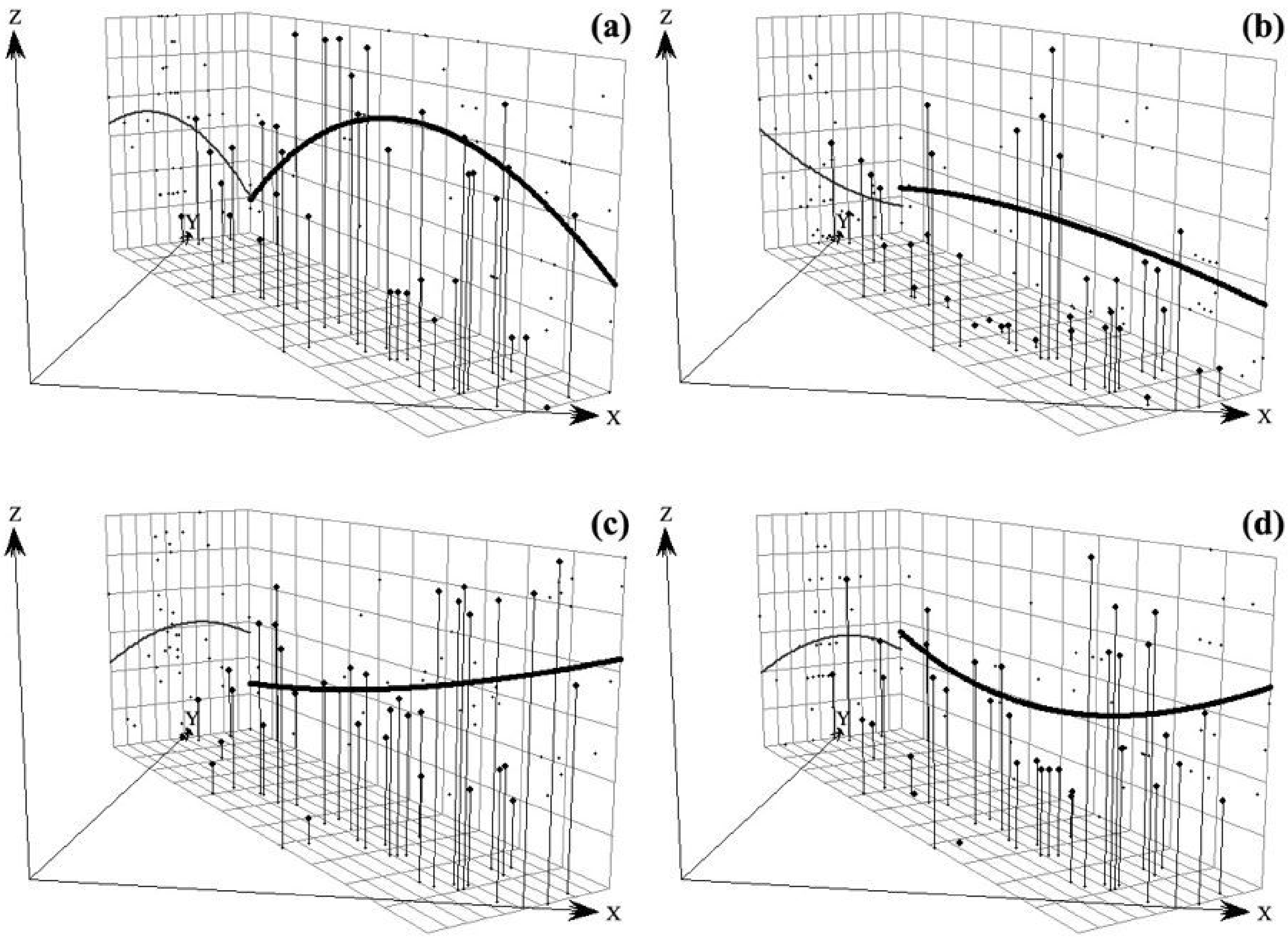


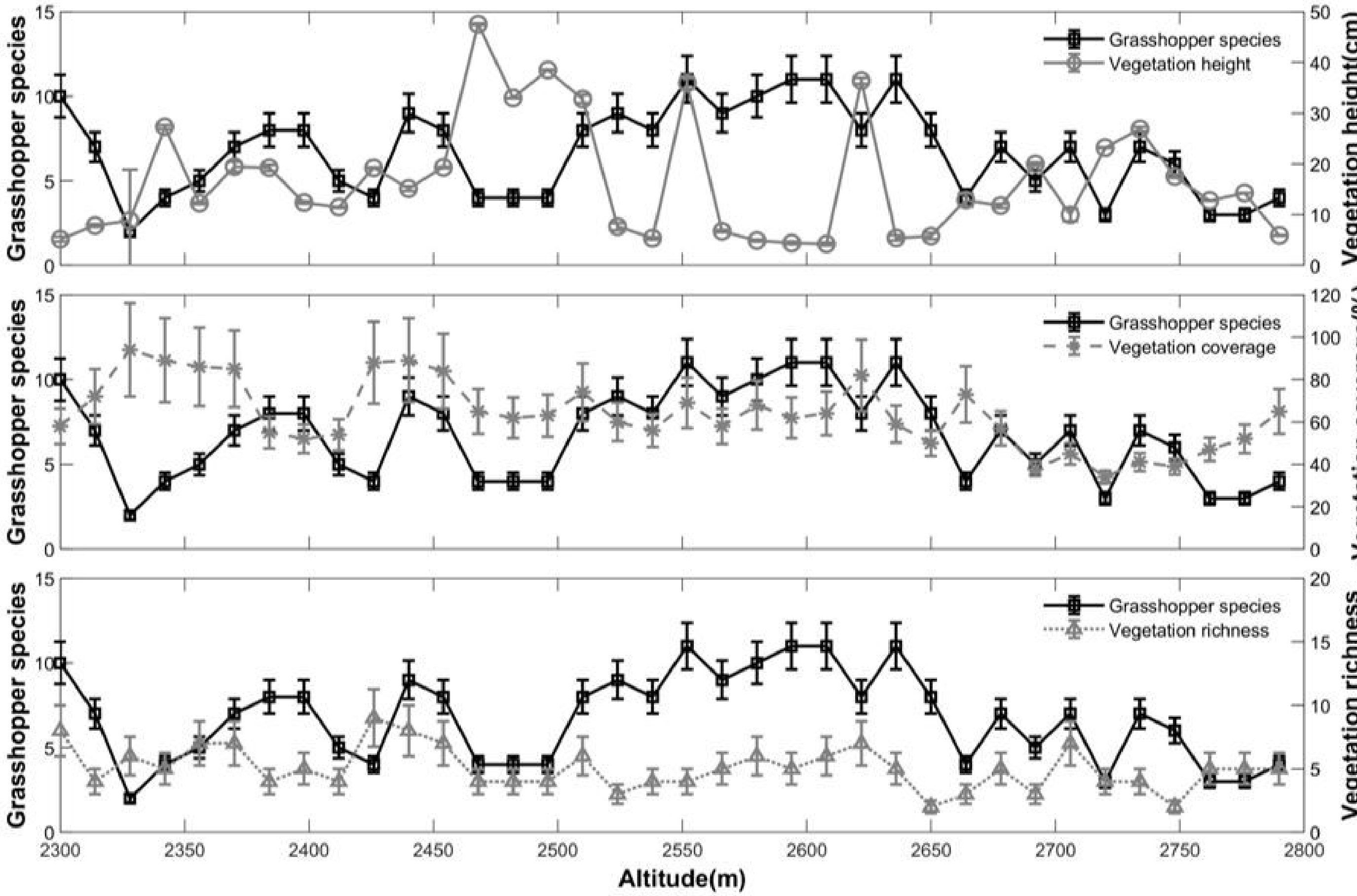

**Figure 1**

(a) Location map of the study area, (b) the geographic map for grasshopper and vegetation sampling Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.




## Figure 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 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




## Figure 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 grasshopper 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.