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RESEARCH

Grasshopper (Orthoptera: Acrididae) Community Composition in the Rangeland of the Northern Slopes of the Qilian Mountains in Northwestern China

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ABSTRACT. In order to describe grasshopper (Orthoptera: Acrididae) species composition, diversity, abundance, and density of four rangelands types, we compared the grasshopper community composition and dynamics in the rangeland of the northern slopes of the Qilian Mountains. In total, 55 grasshopper species were collected from 2007 to 2009, representing three families and six subfamilies. The subfamily Oedipodinae was dominant, followed by Gomphocerinae and Catantopinae. Species abundance varied among rangeland types (RTs). The greatest abundance of grasshoppers was found in mountain rangeland, while the lowest abundance of grasshoppers was caught in alpine shrublands. Three species (*Chorthippus cf. brunneus* (Thunberg) (Acrididae), *Chorthippus dubius* (Zubovskii), and *Gomphocerus licenti* (Chang) were broadly distributed in the four RTs and constituted 7.5% of all grasshoppers collected. *Ch. dubius* was very abundant in desert rangeland and alpine shrubland. *Bryodema dolichoptera* Yin et Feng *Eremippus qilianshanensis* Lian and Zheng, and *Filchnerella qilianshanensis* Xi and Zheng (Pamphagidae) were endemic to the region of the Qilian Mountains. Species similarity between RTs ranged from 17.8 to 51.6 based on the Renkonen index. Similarly, the Sørensen index indicated a wide separation in species composition among RTs. The abundance of the eight most common species showed obvious differences among RTs and years. On average, mountain rangeland had the highest density values in 2007 and 2008, and alpine shrubland supported the smallest density. The densities in desert and mountain rangeland in 2007 were significantly higher than in 2008, while alpine rangeland and shrublands did not present obvious differences among years.

Key Words: density, diversity, rangeland type, species composition

Grasshoppers (Orthoptera: Acrididae) are among the most important native herbivores in Northwestern China, causing large losses in pasture areas. In an average year, more than 20 million ha of rangeland suffer from grasshopper outbreaks in Northwest China, where grasshoppers annually consume an average of 1.6 billion kg of grass dry matter, equivalent to an estimated loss of \$80 million USD (Zhu 1999). Considerable manpower and material resources have been expended on the study of this problem. Previous studies of these insects have mostly focused on understanding the life-history strategies and diapause characteristics (Lockwood et al. 1994, Hao and Kang 2004a,b, Zhao et al. 2005), chemical and behavioral ecology (Chen and Kang 2000, Chen et al. 2003), livestock grazing and grasshopper population dynamics (Kang et al. 1989, Kang and Chen 1995), and grasshopper community structure (Li and Kang 1991, He et al. 1997). More recently, emphasis has been placed on the study of the complex ecological interactions between intraspecific and interspecific competition (Joern 1992, Belovsky 1997, Liu et al. 2007, Unsicker et al. 2010), climate conditions (Kemp and Cigliano 1994, Belovsky and Slode 1995, Cigliano et al. 2002, Weiss et al. 2013), vegetation structure (Morris 2000, Sirin et al. 2010, Hochkirch and Gröning 2012), and their host plants (Branson and Sword 2007, Franzke et al. 2010, Bazelet and Samways 2011).

The rangeland of the northern slopes of the Qilian Mountains is the main stockbreeding base of Gansu Province in Northwestern China, which plays an important role in servicing the ecological environment and socio-economics of the region (Wang et al. 2010). Various rangeland communities are used for raising yaks and sheep. However, grasshoppers, as the primary consumers and main component in rangeland ecosystems, affect rangeland productivity and compete with domestic animals for food resources (Hewitt and Onsager 1983). At various times in history, such as in the late 1980s and early 1990s, grasshoppers

caused severe damage to rangelands and influenced the local economy of these regions. The control of grasshoppers and locusts has been a very important part of the rangeland management, and many useful studies have been conducted to help individual herders and government agencies reduce the risk of outbreaks. Several studies have been undertaken of grasshopper community composition and species diversity in the Inner Mongolia Autonomous Region (Li and Kang 1991), Pampas of Argentina (Cigliano et al. 2000; Torrussio et al. 2002), Great Plains of North America (Lockwood et al. 1994), and southern Africa (Gebeyehu and Samways 2006). Geographical ranges (Schluter and Ricklefs 1993, Zhang and Jiang 1997) and spatial heterogeneity (Davidowitz and Rosenzweig 1998, Pandolfi 2002) play an important role in determining a community's composition, diversity, and other attributes of its organization. More spatially heterogeneous rangelands provide a greater range of micro-habitats, which can attract greater numbers of species able to co-exist within that ecosystem (Zhang and Jiang 1997, Davidowitz and Rosenzweig 1998). Thus, areas exhibiting greater floristic heterogeneity generally support more species of grasshoppers than less heterogeneous areas (Otte 1976). However, few attempts have been made to analyze the relative abundance and species composition of grasshopper communities in the rangeland of the northern slopes of the Qilian Mountains to help in developing management strategies for controlling grasshopper numbers. The objective of this article is to describe grasshopper species composition, richness, diversity, density, and abundance in different rangelands of this region and provide a rational basis for scientists, extension personnel, and rangeland managers when making decisions concerning research and management policies. Additional aims of the present study are to draw conclusions regarding grasshopper communities of the Qilian Mountains and to offer an alternative method to control grasshopper in this area.

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Table 1. Characteristics of the different RTs in the Qilian Mountains

| Characteristic | Desert rangeland | Mountain rangeland | Alpine rangeland | Alpine |
|--------------------------------|---|---|---|---|
| Altitude (m) | 1,400–2,300 | 1,400–3,000 | 3,000–3,800 | 2,900–3,800 |
| Mean annual precipitation (mm) | 173–220 | 260–491 | 200–280 | 300–500 |
| Yearly mean temperature (°C) | 3.6–6.0 | 0.2–2.1 | –3.1 | –5.4 to 0 |
| Dominant grass species | <i>Kalidium foliatum</i> , <i>Artemisia</i> spp. | <i>Stipa</i> spp., <i>Artemisia</i> spp. | <i>Stipa purpurea</i> , <i>Elymus nutans</i> | <i>Cyperus</i> spp., <i>Polygonum</i> spp. |
| Plant cover (%) | 35–47 | 45–75 | 50–80 | 75–90 |
| Height cm (cm) | 20–35 | 20–30 | 15–20 | 10–15 |

Materials and Methods

Study Area. The study area was located in the center of an area known as the Hexi (Gansu) Corridor and the northern slopes of the Qilian Mountains, in the northwest of China. Longitude and latitude are 37° 28′–39° 49′ N and 97° 20′–102° 13′ E, respectively, and the altitude ranges from 1,327 to 3,816 m. The climate is an extreme continental, desert, and plateau climate, with an annual average air temperature of 4°C. January is the coldest month, with temperatures reaching –24.9°C and a daily average of –10.9°C, while July is the warmest month, with an average daily temperature of 14.1°C. Total annual precipitation and evaporation averages 253 and 1,828 mm, respectively. The major soil type is the mountain chestnut soil, mountain chernozem soil. This region encompasses different available rangeland types (RTs) in the country. In total, 20 sites were selected and classified into four categories (desert rangeland, mountain rangeland, alpine rangeland, and alpine shrubland) according to the characteristics of vegetation and climate defined by The Office of Stockbreeding Regionalization of Sunan County (1985), and five sites were selected within each RT, representing a variety of natural plant communities and different biogeography. The precipitation, temperature, and dominant vegetation of the different RTs are summarized in Table 1.

Grasshopper Sampling. Adult grasshoppers were sampled along vegetation transects. Each site was sampled three times during the summer (late July, mid-August, and early September) from 2007 to 2009 to maximize chances of detecting species with different phenologies (Hochkirch and Adorf 2007). Grasshopper densities were assessed using a quadrat method (Stower and Greathead 1969), using square enclosures of 1 m² (1 × 1 m) with edges 0.4 m high. Grasshopper community composition was determined from 200 net sweeps per RT in each sampling period between 09:00 and 16:00 h under sunny conditions and light winds, with weather conditions consistent throughout the survey. Each sweep traversed an arc of 180° through the vegetation with a net, as reported in other studies (Evans et al. 1983, O’Neill et al. 2002). Grasshoppers collected using the sweep-net were placed in cages and taken to the laboratory for species identification based on Liu (1990) and confirmed at the Orthoptera collection of the Museum of Grasshoppers, Rangeland Station of Gansu Province. Grasshoppers were classified according to modern systematics as used in the Orthoptera species file (Eades et al. 2014).

Data Analyses. Relative abundance of grasshopper species was calculated as the abundance of species relative to the total abundance of all species collected at each RT × 100. For each year, the mean value from July to September was considered. Species richness was quantified as the total number of species present in each habitat. Three of the most common indices have been calculated to describe and compare the grasshopper diversity of the various RTs among years: the Shannon-Weaver index (H'), Simpson’s diversity index (D), and species evenness. These indices are complementary and provide a good description of the similarity of communities. The similarity of grasshopper assemblages of different RTs was calculated using Renkonen index (Krebs 1999) and Sørensen index (Brower and Zar 1977). Density data from the three sample dates per site per year were averaged for analyses to estimate if the density of each was constant through time. The abundance of six common grasshopper species (*Chorthippus* cf. *brunneus*

(Thunberg) (Acrididae), *Chorthippus dubius* (Zubovskii), *Chorthippus fallax* (Zubovskii), *Gomphocerus licenti* (Chang), *Omocestus haemorrhoidalis* (Charpentier), *Angaracris rhodopa* (Fischer Walheim)) that were found in more than two RTs was compared among habitats and years.

Statistical analysis was conducted by ANOVA using SPSS with the GLM procedure (IBM, www.ibm.com). The model used for analyzing data of the experiment included the factor (with RT and year as factors). Probability values at the $P < 0.05$ value were accepted as statistically significant.

Results

Species Composition and Taxonomic Diversity. In total, 4,350 specimens of grasshoppers were collected during the 3 years, belonging to 55 species, three families, and six subfamilies (Table 2). Average species richness ranged from 10 to 23.7 species per category among the four RTs. Only 10 species were found in alpine shrubland, whereas greater species numbers were found in desert rangeland (34) and mountain rangeland (34). Mean species richness at the regional level (all sites, all years) was 10.

From a taxonomic perspective, the Oedipodinae and Gomphocerinae were the two most abundant and diverse subfamilies, with 20 and 19 species, respectively. Next in order of abundance and diversity was the Catantopinae (three species), followed by Thrinchinae. There were only two species within Acridinae and Tetriginae (Tables 2 and 3).

Diversity parameters for the different RTs among years are illustrated in Table 4. The mountain rangeland comprised the highest number of species in 2009, whereas the number of species in desert rangeland did not vary between the 2 years. The most diverse habitat considering diversity was the mountain. The alpine rangeland possessed the lowest species number and Shannon-Weaver index.

Faunal Comparison and β -diversity. Species similarity between RTs ranged from 17.8 to 51.6 based on the Renkonen index (Table 5). There was 51.6% overlap between desert rangeland and mountain rangeland, revealing more similarity in their respective grasshopper communities. Considering the Sørensen index, the faunal similarity of the studied areas decreased with an increase of altitude (Table 6). Comparing the desert rangeland with all other analyzed habitats, the faunal affinities decreased from nearly 50.0% (within mountain rangeland) to 13.6% (alpine shrubland). The highest similarity in faunal composition was found between the alpine rangeland and the alpine shrubland.

Species Abundance. The average relative abundance of grasshopper species in the four RTs fluctuated between years. *Ch. dubius* were broadly distributed in the four RTs, and *Ch. dubius* exhibited very high population abundance, representing 13.3% of the total grasshopper relative abundance. *Ch. fallax* was broadly distributed in mountain and alpine rangelands, but was not found in desert rangeland. Some species were only distributed within specific RTs. For example, *Acrida cinerea* (Thunberg) and *Acrida oxycephala* (Pallas) occurred only in mountain rangeland, whereas the four *Sphingonotus* species were only caught in desert rangeland. The abundance of the six most common species also varied significantly among RTs and years (Table 7). Comparing the

Table 2. Mean relative abundance (individuals/200 sweeps) patterns of grasshopper species collected in four rangelands types in the Qilian Mountains

| Family | Sub-family | Species | Desert rangeland | | Mountain rangeland | | | Alpine rangeland | | | Alpine shrubland | |
|--|---|---|------------------|------|--------------------|------|------|------------------|------|------|------------------|------|
| | | | 2007 | 2008 | 2007 | 2008 | 2009 | 2007 | 2008 | 2009 | 2007 | 2008 |
| Acrididae | Acridinae | <i>A. cinerea</i> Thunb | | | 1.8 | | 1.3 | | | | | |
| | | <i>A. oxycephala</i> Pall | | | | | 1.1 | | | | | |
| | Catantopinae | <i>Dericorys annulata roseipennis</i> (Redt.) | | 2.4 | | | | | | | | |
| | | <i>Calliptamus abbreviatus</i> Ikonn | 13.2 | 16.8 | 6.6 | 6.2 | 7.1 | | | | | |
| Gomphocerinae | <i>Calliptamus barbarus cephalotes</i> Costa | 3.1 | | | | 2.1 | | | | | | |
| | <i>Chorthippus intermedius</i> (B.-Bienko) | | | 2.3 | | 2.5 | | 9.8 | 7.8 | | | |
| | <i>Chorthippus albonemus</i> Ceng et Tu | | | 3.7 | 4.2 | 4.6 | 12.8 | 15.2 | 11.1 | | | |
| | <i>Chorthippus biguttulus</i> (L.) | | | | | | | | 6.3 | | 9.6 | |
| | <i>Chorthippus brevicornis</i> (Wang et Zheng) | | | | | 6.2 | | 2.5 | | | | |
| | <i>Ch. cf. brunneus</i> (Thunb.) | | 4.2 | 6.7 | 8.5 | 6.4 | 5.5 | 7.7 | 7.3 | 10.9 | 8.6 | |
| | <i>Ch. brunneus huabeiensis</i> (Xia et Yin) | | | | | | | 2.1 | 4.9 | | | |
| | <i>Ch. dubius</i> (Zub.) | 15.1 | 16.2 | 15.1 | 10.2 | 9.3 | 9.7 | 7.5 | 9.6 | 14.7 | 12.3 | |
| | <i>Ch. fallax</i> (Zub.) | | | 8.6 | 7 | 6.1 | 17.6 | 12.4 | 12.8 | 20.1 | 15.1 | |
| | <i>Chorthippus hsiai</i> (Ceng et Tu) | | | 2.1 | | 5.2 | 4.3 | | 7.2 | | | |
| | <i>Chorthippus qingzangensis</i> (Yin) | | | | | | 5.3 | 7.6 | | | 8.5 | |
| | <i>Dasyhippus barbipes</i> (F.W) | | | | | 1.5 | 8.4 | | 3.4 | 10.3 | | |
| | <i>E. qilianshanensis</i> (Lian et Zheng) | | 1.2 | 1.2 | | | 2.3 | | | | | |
| | <i>Eremippus simplex maculatus</i> (Mistsh) | 3.1 | | | | | | | | | | |
| | <i>Euchorthippus unicolor</i> (Ikonn.) | | | | 1.7 | 1.3 | | | | | 12.5 | |
| | <i>G. licenti</i> (Chang) | | 5.3 | 1.6 | 3.4 | 2.4 | 6.6 | 6.3 | 2.2 | 13.2 | 11 | |
| | <i>Gomphocerus sibiricus</i> (L.) | | | | | | | 4 | | 14.7 | 9.3 | |
| | <i>Myrmeleotettix palpalis</i> Zub | 19.4 | 7.6 | 10.3 | 8.1 | 7.3 | | | | | | |
| | <i>O. haemorrhoidalis</i> (Charp.) | | | 3.3 | 2.7 | 2.2 | 7.5 | 4.8 | 7.8 | 16.1 | 13.1 | |
| <i>Pararcyptera microptera meridionalis</i> (Ikonn.) | | | 2.3 | 1.4 | 1.5 | 5.9 | 7.6 | 7.3 | | | | |
| Oedipodinae | <i>A. nigripennis</i> Lian et Zheng | | 3.7 | | | 3.2 | | | | | | |
| | <i>A. rhodopa</i> (F.-W.) | 5.3 | 2.4 | 9.6 | 7.3 | 4.4 | 10.7 | 10.2 | 7.5 | | | |
| | <i>Bryodema uvarovi</i> B.-Bienko | | | | 1.3 | 1.1 | | | | | | |
| | <i>Bryodema dolichoptera</i> Yin et Feng | | | | 2.1 | | | | | | | |
| | <i>Bryodema holdereri holdereri</i> (Krauss) | | 3.3 | 1.2 | | 2.3 | | | | | | |
| | <i>Bryodema luctuosum luctuosum</i> Stoll | | | | 1.7 | 2.2 | | | | | | |
| | <i>Bryodema miramae miramae</i> B.-Bienko | | 3.2 | | | | | | | | | |
| | <i>Bryodema ochrooenna</i> Zheng et Xi | | | 1.8 | 1.4 | | 3.4 | 2.3 | 4.8 | | | |
| | <i>B. qilianshanensis</i> Lian et Zheng | 2.8 | | | | | | | | | | |
| | <i>Bryodema tuberculatum dilutum</i> (Stoll) | 3.7 | 4.5 | 3.2 | 2.6 | 1.7 | | | | | | |
| | <i>Compsorhipis davidiana</i> (Suass) | 2.3 | | | | | | | | | | |
| | <i>Epacromius coeruleipes</i> (Ivan.) | 3.4 | 1.8 | | | | | | | | | |
| | <i>Leptoptenis gracilis</i> EV. | | 4.2 | | | | | | | | | |
| | <i>Oedaleus infernalis</i> Sauss. | 1.8 | 2.3 | | | 1.2 | | | | | | |
| | <i>O. asiaticus</i> B.-Bienko | 2.3 | 6.2 | 11.3 | 13.7 | 5.9 | | | | | | |
| | <i>Otopharynx decorus</i> (germ.) | 2.5 | | | | | | | | | | |
| | <i>Sphingonotus elegans</i> Mistsh. | | 1.1 | | | | | | | | | |
| | <i>Scinax nebulosus</i> (E.-W) | 3.1 | | | | | | | | | | |
| | <i>Sphingonotus tzaidamicus</i> Mistsh. | 3.7 | | | | | | | | | | |
| <i>Sphingonotus yenchihensis</i> Zheng et Chiu | 4.2 | | | | | | | | | | | |
| Pamphagidae Thrinchinae | <i>Atrichotmethis cyanipes</i> Yin et Feng | 1 | | | | | | | | | | |
| | <i>Eoetotmethis longipennis</i> Zheng | 3.5 | | | | | | | | | | |
| | <i>Filchnerella beicki</i> Ramme | 2.3 | | | 6.2 | 2.2 | | | | | | |
| | <i>Filchnerella kukunris</i> B.-Bienko | | 5.2 | 2.5 | | 2.7 | | | | | | |
| | <i>Filchnerella qilianshanensis</i> Xi et Zheng | 1.1 | 2.1 | | 1.2 | 2.3 | | | | | | |
| | <i>Filchnerella sunanensis</i> Liu | 1.7 | 2.8 | 4.8 | 5.4 | 1.3 | | | | | | |
| | <i>Haplotropis brunneriana</i> Ssuss | 1.4 | | | | | | | | | | |
| | <i>Pseudotmethis</i> B.-Bienko | | 2.3 | | | | | | | | | |
| | <i>Sibotmethis amicus</i> B.-Bienko | | 1.1 | | | | | | | | | |
| Tetrigidae Tetriginae | <i>Tetrix japonica</i> (Bol.) | | | 2.6 | 1.4 | | | | | | | |
| | <i>Tetrix tartara</i> (Bol.) | | | 1.1 | | | | | | | | |
| | Total individuals/200 sweeps | 167 | 133 | 264 | 213 | 125 | 156 | 171 | 102 | 65 | 54 | |

Table 3. Relative abundance (%) of families and subfamilies collected in four RTs in the Qilian Mountains

| Family | Subfamily | Desert rangeland | Mountain rangeland | Alpine rangeland | Alpine shrubland | Mean |
|-------------|---------------|------------------|--------------------|------------------|------------------|-------|
| Tetrigidae | Tetriginae | | 1.62 | | | 0.41 |
| Pamphagidae | Thrinchinae | 12.22 | 9.53 | | | 5.43 |
| Acrididae | Catantopinae | 17.75 | 7.32 | | | 6.27 |
| | Oedipodinae | 33.9 | 26.4 | 12.97 | | 18.32 |
| | Gomphocerinae | 31.46 | 53.63 | 87.03 | 100 | 69.2 |
| | Acridinae | | 1.42 | | | 0.35 |

Table 4. Diversity parameters for the four RTs among years in the Qilian Mountains

| Index | Desert rangeland | | Mountain rangeland | | | Alpine rangeland | | | Alpine shrubland | |
|-----------------------------|------------------|------|--------------------|------|------|------------------|------|------|------------------|------|
| | 2007 | 2008 | 2007 | 2008 | 2009 | 2007 | 2008 | 2009 | 2007 | 2008 |
| Species number ^a | 22 | 22 | 22 | 21 | 29 | 13 | 14 | 14 | 7 | 9 |
| H' | 2.71 | 2.78 | 2.86 | 2.75 | 3.13 | 2.44 | 2.5 | 2.56 | 1.92 | 2.18 |
| D | 0.91 | 0.92 | 0.92 | 0.93 | 0.95 | 0.9 | 0.91 | 0.92 | 0.85 | 0.88 |
| J | 0.88 | 0.9 | 0.93 | 0.9 | 0.93 | 0.95 | 0.95 | 0.97 | 0.99 | 0.99 |

H', Shannon-Weaver index; D, Simpson index; J, evenness.

^aSpecies number is the total number of grasshoppers sampled of in each RT.

Table 5. Renkonen similarity index of grasshopper species between RTs

| | Desert rangeland | Mountain rangeland | Alpine rangeland | Alpine shrubland |
|--------------------|------------------|--------------------|------------------|------------------|
| Desert rangeland | | | | |
| Mountain rangeland | 51.6 | | | |
| Alpine rangeland | 17.6 | 48.6 | | |
| Alpine shrubland | 17.8 | 33.4 | 48.9 | |

Table 6. Sørensen similarity index and number of shared species between RTs

| | Desert rangeland | Mountain rangeland | Alpine rangeland | Alpine shrubland |
|--------------------|------------------|--------------------|------------------|------------------|
| Desert rangeland | | | | |
| Mountain rangeland | 50 | | | |
| Alpine rangeland | 19.3 | 54.9 | | |
| Alpine shrubland | 13.6 | 31.8 | 57.5 | |

Table 7. The abundance (number of species per 200 sweeps) of common grasshoppers among different RTs and years (Y)^a

| Species | Years | Desert rangeland | Mountain rangeland | Alpine rangeland | Alpine shrubland | P values (RT) |
|---------------------------|-------|--------------------|---------------------|---------------------|-------------------|---------------|
| <i>Ch. cf. brunneus</i> | 2007 | – | 17.6 ^{b,g} | 8.6 ^{c,g} | 7 ^c | ** |
| | 2008 | 5.3 ^d | 39.6 ^{c,f} | 14 ^{c,f} | 6 ^d | * |
| | 2009 | – | 8.3 ^h | 7.3 ^g | – | NS |
| P values (Y) | | | ** | ** | NS | NS |
| <i>Ch. dubius</i> | 2007 | 25.3 ^c | 39.0 ^{b,f} | 15.6 ^d | 7.0 ^e | ** |
| | 2008 | 21.6 ^b | 21.6 ^{c,g} | 13 ^c | 5.6 ^d | ** |
| | 2009 | – | 11.3 ^h | 9.6 | – | NS |
| P values (Y) | | NS | | NS | NS | |
| <i>Ch. fallax</i> | 2007 | – | 22.6 ^{b,f} | 27.3 ^{b,f} | 13.0 ^c | * |
| | 2008 | – | 15.0 ^{c,g} | 21.3 ^{b,f} | 9.7 ^d | * |
| | 2009 | – | 7.6 ^{b,h} | 13.0 ^{b,g} | – | * |
| P values (Y) | | | ** | ** | NS | |
| <i>G. licenti</i> | 2007 | – | 4.3 ^{c,g} | 10.3 ^{b,f} | 8.6 ^b | ** |
| | 2008 | 7.0 ^c | 7.3 ^{c,f} | 10.6 ^{b,f} | 7.0 ^c | * |
| | 2009 | – | 3.0 ^g | 2.3 ^g | – | NS |
| P values (Y) | | | * | * | NS | |
| <i>O. haemorrhoidalis</i> | 2007 | – | 8.6 ^{c,f} | 11.6 ^{b,f} | 10.3 ^b | * |
| | 2008 | – | 5.6 ^{c,g} | 8.3 ^{b,g} | 8.6 ^b | * |
| | 2009 | – | 2.6 ^{c,g} | 8.0 ^{b,g} | – | ** |
| P values (Y) | | | ** | * | NS | |
| <i>A. rhodopa</i> | 2007 | 8.6 ^{c,f} | 25.3 ^{b,f} | 16.6 ^{b,f} | – | ** |
| | 2008 | 3.0 ^{c,g} | 15.6 ^{b,g} | 17.3 ^{b,f} | – | * |
| | 2009 | – | 5.6 ^h | 7.6 ^f | – | NS |
| P values (Y) | | * | ** | ** | | |

^aData are means of three sample periods.

^{b–e}Means in columns with no common superscript differ significantly.

^{f–g}Means in rows with no common superscript differ significantly.

*P < 0.05; **P < 0.01.

mountain rangeland with all other rangelands, the numbers of *Ch. cf. brunneus* and *Ch. dubius* were the highest in 2007 and 2008. Nevertheless, *G. licenti* and *O. haemorrhoidalis* had the lowest numbers. Some species were not caught in certain years in the same habitat, such as *G. licenti*, *Angaracris nigripennis* (Lian et Zheng), and *Bryodema dolichoptera* (Yin et Feng).

Population Density. The analysis of the mean grasshopper density by year revealed that the population density changed among habitats and years (Table 8). Mountain rangeland had the highest density values compared with all other habitats in both 2007 and 2008, and alpine shrubland supported the smallest density. There were great differences among years, as the densities in desert rangeland and mountain

Table 8. Mean values of grasshopper populations in RTs and years (Y) in the Qilian Mountains^a

| Years | Desert rangeland | Mountain rangeland | Alpine rangeland | Alpine shrubland | P values (RT) |
|--------------|---------------------|----------------------|-------------------|------------------|---------------|
| 2007 | 4.56 ^{c,f} | 13.45 ^{b,f} | 4.61 ^c | 1.5 ^d | *** |
| 2008 | 2.82 ^{d,g} | 9.51 ^{b,g} | 4.02 ^c | 1.3 ^e | ** |
| 2009 | — | 6.72 ^h | 4.13 | — | NS |
| P values (Y) | ** | * | NS | NS | |

^aData are means of 50 samples, and all samples were conducted in mid-August each year.

^{b–e}Means in columns with no common superscript differ significantly.

^{f–h}Means in rows with no common superscript differ significantly.

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

rangeland in 2007 were significantly higher than in 2008, while alpine rangeland and shrubland did not present obvious differences among years.

Discussion

When the results of this study are compared with grasshopper community composition from the Inner Mongolian rangeland, the latter consists of 150 grasshopper species (Li and Kang 1991), compared with only 55 species of grasshopper found in our study area. This can be explained by the spatial heterogeneity hypothesis, which suggests that because of the large area and lower altitudes of the Inner Mongolian rangeland, there is a wider range of habitats available, allowing more species with narrower microhabitat preferences to co-exist. Although Inner Mongolian rangelands appear to have greater species diversity, the dominant grasshopper species (e.g., *Ch. dubius*, *Oedaleus asiaticus*, and *A. rhodopa*) are similar in both regions. These species are also widely distributed in other regions of North China, such as Qinhai Lake (Ni et al. 2000) and the Ganjia high-mountain rangelands (Liu and Fen 2000).

A previous study found that grasshopper species richness was generally greater in the alpine rangelands than any other RT (Li et al. 2001). Their results indicated that the Acridoidea exhibited greater species richness in areas providing diverse food resources and climatic conditions than in areas with simple vegetation types and a less variable climate, which was confirmed by our study. We found evidence of wide annual variation in grasshopper species abundance in the very same RTs. Some species were collected in 1 year, but disappeared in following years (e.g., *Bryodema qilianshanensis* Lian and Zheng). The reasons for this remain unclear, but one possibility is that the incubation and development of these species' eggs were limited by the special humidity and temperature condition (Hao and Kang 2004a, Chen et al. 2007). Other factors, such as host plant availability and nutritional value, have also been reported to affect grasshopper abundance and distribution (Kang and Chen 1994b, Wu et al. 2005, Gebeyehu and Samways 2006).

The long-term adaptive process of co-evolution between grasshoppers and rangeland ecosystems also influences grasshopper biodiversity (Kang et al. 1989, Zhong et al. 2006). Most grasshoppers are not strongly specialized on different food plants, and they often differ in their choice of suitable microhabitats for ovipositing, habitation, and refuge sites (Jonas and Anders 2006). Grasshopper subfamilies vary in their habitat and dietary preferences, e.g., members of the subfamily Gomphocerinae mainly feed on grasses (Otte 1981), which may explain, why we found only a few Gomphocerinae species in desert rangeland compared with other RTs. Members of Oedipodinae and Thrinchinae subfamilies, preferring warm, dry habitats with sparse grass cover, were only found in desert rangeland and mountain rangeland in this study, similar to the findings of (Otte 1984). Species such as *Bryodema miramae miramae* (B.-Bienko) and *B. qilianshanensis*, however, were endemic to regions possessing unique vegetation, climate, and topography, and were only occasionally found in desert rangeland in our study. In contrast, species with broad ecological amplitude

concerning habitat and diet (e.g., *Ch. dubius*, *O. asiaticus*, and *A. rhodopa*) were more widely distributed than the habitat and dietary specialists (Kang and Cheng 1994a). However, some grasshoppers found in the region were endemic, such as *B. dolichoptera*, *E. qilianshanensis* Lian and Zheng, and *F. qilianshanensis* Xi and Zheng (Pamphagidae), which all are only found in the Qilian Mountains.

The diversity of spatially heterogeneous habitats and geographical ranges, as well as grasshoppers' various evolutionary strategies, have caused the occurrence of numerous representatives of the superfamily Acridoidea, representing three families, six subfamilies, and 55 species. A lot of research has been conducted in order to understand what determines grasshopper diversity at a given site. Kang et al. (2007) proposed that physical habitats and food sources are the main determinants for grasshoppers' ecological ranges, which is also the most likely explanation of the differences in grasshopper communities found among the four RTs, despite their close proximity. Li et al. (2011) reported that elevation is the most important topographical factor influencing grasshopper diversity, and under the impact of topography, redistribution of water and heat lead to diversification of grasshopper distributions. In western North Dakota (USA), Branson (2011) found that plant species richness is too coarse-grained as a measure to accurately predict grasshopper species richness. The mechanism causing variation of grasshopper distribution in the Qilian Mountains still needs further research in the future.

It can be concluded that the control of grasshoppers in this area should pay more attention on the population dynamics of the six most common species. It is not necessary to treat the entire area, but control measures should be concentrated in the mountain rangeland and alpine rangeland, the areas most frequented by these insects. The main difficulty in the application of chemical control of grasshoppers in the Qilian Mountains is the high cost and the varied topography, which limits machine applications. Therefore, a method of 'controlling grasshoppers and rearing birds' was introduced in this region (Sun 2010). This method not only provides an efficient means of reducing grasshopper populations, but provides the consumer with chicken products (Sun et al. 2012). Furthermore, it is probably more sustainable and avoids the extinction of non-target species, such as endemic or threatened species.

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