

Influence of Agricultural Activities on Grassland Arthropods in Inner Mongolia

Kiyan Sorgog¹, Masayuki Saito², Yutaka Hironaka¹, Yasutomo Higashiura³ & Hiroyuki Matsuda¹

¹ Graduate School of Environment and Information Sciences, Yokohama National University, Yokohama, Japan

² Graduate School of Arts and Sciences, The University of Tokyo, Tokyo, Japan

³ School of Life Sciences, Tokyo University of Pharmacy and Life Sciences, Hachioji, Tokyo, Japan

Correspondence: Kiyan Sorgog, Graduate School of Environment and Information Sciences, Yokohama National University, Japan. Tel: 81-045-339-4377. E-mail: suriguga-xj@ynu.ac.jp

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Abstract

Arthropod pest outbreaks are becoming more common in the grasslands of Inner Mongolia, China, most likely due to the expansion of agriculture. The area of cropland has increased from 43,300 km² in 1949 to 76,300 km² in 2005. To understand the effects of agricultural activities on arthropod distribution, sweep net sampling was conducted in a natural grassland. We collected 1287 individuals belonging to 23 families and 9 orders of arthropods from 41 sites. We divided these samples into two guild types (predator and herbivore) and analyzed six groups (grasshoppers, herbivorous Coleoptera, herbivorous Hemiptera, Cicadidae, Araneae, predatory Coleoptera) of them. Using a negative binomial regression analysis we analyzed the relationships between each group's sampled population size and measured environmental factors including pesticide application and mean temperature of the previous year, agricultural site, and vegetation condition. The best model for each group was determined using Akaike's information criterion. Grasshoppers showed a significant positive response to pesticide application and degraded vegetation, whereas spider (natural enemies of some insect pests) showed a negative response to these factors. The population of grasshoppers increased at sites where pesticides were applied, vegetation was degraded, and spider numbers were reduced. Other groups were not significantly correlated with pesticide application and degraded vegetation. Some of the environmental factors we studied promoted pests the following year. Our results also suggest that the current use of pesticides may not be effective for pest control and that alternative options should be considered in the grasslands of Inner Mongolia.

Keywords: Araneae, grasshopper, grazing land, insect pests, pesticides, regression analysis

1. Introduction

The grasslands of Inner Mongolia are found in the eastern region of the Eurasian continent. They cover 860,000 km² (Dong et al., 2012) and account for 75% of the region's land area. These grasslands are 10 times larger than the area of agriculture in Inner Mongolia (Zhang, Liu, Xin, Liu, & Gan, 2006). Livestock such as cattle and sheep historically grazed this area for several thousand years (Suzuki, 2003). However, due to anthropogenic and climatic effects, the desertification and degradation of natural grasslands have been rapidly progressing in Inner Mongolia since the 1970s, affecting the daily lives of local people. Pest outbreaks in particular (rodents and insects) have caused serious economic damage to local people. Since 1973, pests in Inner Mongolia have damaged an average 53,300 km² of grassland. By 2004, an area of 247,200 km² had been damaged by pests (Yang, 2010). The conservation and recovery of grassland ecosystems are urgent tasks, considering their important ecological and economical functions.

As a primary insect pest, grasshoppers have been studied extensively. Kang, Han, Zhang, and Sun (2007) reported the biogeography of 150 species of grasshopper in Inner Mongolia. However, the outbreak of other insect pests such as *Loxostege sticticalis* has also been observed in recent years (Wen, Wang, Qinggele, & Gao, 2011). Therefore, grassland pest management in Inner Mongolia requires a comprehensive understanding of insect population distribution and suppression (Kang et al., 2007).

Almost all species of herbivorous arthropod are considered potentially harmful species. In contrast, arthropod predators are considered beneficial species because they control grassland herbivores, and in Inner Mongolia

many grassland plants are used as medicinal herbs or livestock forage (Lockwood, Hong-Chang, Dodd, & Williams, 1994).

Pesticides are used for pest control in many countries including China (Willson & Tisdell, 2001) due to their instant effect and low cost (Metcalf & Luckman, 1982). However, pesticides can decrease the number of beneficial predators of pests (Willson & Tisdell, 2001; Matsuoka & Seno, 2008), which can bring about insect pest resurgence (Hardin et al., 1995). This is called the “paradox of the pesticides.” It remains unclear from field surveys of Inner Mongolia what the influence of pesticide application has been on non-target species, particularly when pesticides are used in the traditional management of grasshoppers.

Although pesticide application is a major pest-management strategy, there are several other methods that can also reduce agricultural damage by insect pests, including the introduction of natural enemies and specific scientific approaches to pesticide treatment (Lockwood, Sprecher, & Schell, 2002). An understanding of arthropod distribution in the context of community interactions will aid in the development of integrated pest-management strategies for Inner Mongolia.

Due to dramatic population growth in Inner Mongolia, natural grassland has recently become extensively cultivated for crop production. The land area undergoing agricultural cultivation increased from 43,300 km² in 1949 (Zhang et al., 2006) to 76,300 km² in 2005 (Dong et al., 2011). The impact of agriculture on grasslands has already been reported in Europe (Diekötter, Billeter, & Crist, 2008; Stoate et al., 2009) and the USA (Robertson, Porter, Landis, & Schemas, 2012), but has not yet been examined by field surveys in Inner Mongolia. Past studies of grassland ecosystems in China have focused on relatively small spatial scales. In the face of increasing demands for sustainable development, ecological studies between insect pests and their predators are required (Kang et al., 2007).

In the present study, we investigated the influence of agricultural activities on characteristics of arthropod distribution under field conditions using a combination of several covariates: pesticide application, landscape, climatic factors, and plant type, which are known determinants of arthropod populations.

2. Method

2.1 Study Area

The study was conducted in the Inner Mongolian Autonomous Region (Inner Mongolia) located at the northern border of China (Figure 1). For field sampling, we chose 13 sites at Xingan Meng, 4 sites at Chifeng city, 20 sites at Xilingol city, and 4 sites at Baotou city. The latitude and longitude of these study sites ranged from 41°08'18.2"N to 46°42'13.1"N and 111°12'58.4"E to 122°38'51.8"E, and their altitudes ranged from 206 m to 1701 m. The air temperature in Inner Mongolia varies throughout the year, with highs of 42°C and lows down to -52°C. The mean annual precipitation is approximately 200 mm.

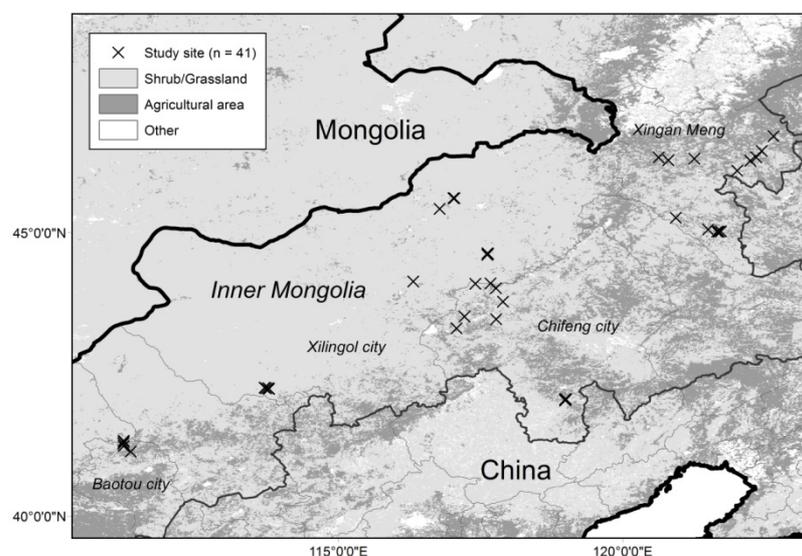


Figure 1. Location of the study area

Description: This map was drawn using the Global Map-Global Land Cover (GLCNMO) system.

2.2 Data Collection

Sweep net sampling was conducted from June 14 to July 5, 2011, at 41 sites chosen to represent the diversity of natural grasslands in Inner Mongolia. A 5 m × 5 m square was set at each site and 50 sweeps were made. Samples were placed in plastic bags for later identification and counting. To avoid variability attributable to individual differences, the first author carried out all sweep net samplings. All collected arthropods except grasshoppers were counted and identified to the species or at least family level. All spiders were counted and identified to the order level, and grasshoppers were counted and identified to suborder. In addition, insects from each order were separated into guild groups based on Nonnaizab, Qi, and Li (1999) and Ma, Li, and Kang (1991) and then we determined whether they were herbivores or carnivores.

To illustrate the effects of vegetation on arthropod distributions, a detailed vegetation survey was performed at each sampling site. Vegetation coverage and plant height were observed and the dominant species at each site was identified taxonomically. In general, the presence of Cyperaceae and Asteraceae species were considered an indicator of the degradation of natural grassland in Inner Mongolia. Therefore, sites were separated by whether or not dominant species belonged to these two families (1 or 0).

To investigate the effects of agricultural activities on arthropod distribution, sampling sites were divided into agricultural (50-100 m from the edge of croplands) and non-agricultural (no cultivated area within 2 km) sites (1 or 0).

To examine the influence of pesticide application on arthropod distribution, pesticide application practices (1 = application, 0 = no application) of the previous year were determined for each site through interviews with local grassland managers. The pesticides mainly used in Inner Mongolia are Cypermethrin, Cyhalothrin, and Matrine. The monthly temperature of each site in 2010 was also recorded (Inner Mongolia Autonomous Regional Bureau of Statistics, 2011), because the previous year's temperature may influence the reproduction and survival of arthropods.

2.3 Statistical Analysis

Negative binomial distribution, which is appropriate for quantifying populations from field data (Anscombe, 1949), was used to analyze relationship between the numbers of different arthropod guild groups and environmental factors. This relationship was quantified using negative binomial regression analyses for Acrididae, Araneae, herbivorous Coleoptera, predatory Coleoptera, Cicadellidae of Hemiptera, and other herbivorous Hemiptera for in-depth statistical analysis. Other taxa such as Hymenoptera, Lepidoptera, Diptera, Neuroptera, and Odonata, were also identified to the order or family level and counted; however, considering the population size and limited effort to identify them, these taxa were not further analyzed.

The response variable used was the sampled population size for each group of arthropods and the explanatory variables of each model were the mean temperature of the previous year, pesticide application of the previous year, mean height of the plant, vegetation coverage, and dominant plant species. The best model for each group of arthropods was determined by comparing Akaike's information criterion (AIC) values using a stepwise procedure. All analyses were performed by R-2.11.1 (R development core team, 2010).

3. Results

We collected and identified 1287 individuals of arthropods belonging to 23 families and 9 orders. The largest population belonged to the order Hemiptera with 573 individuals, accounting for 44.5% of the total collected arthropods. The second largest order was Orthoptera with 476 individuals, and the third largest was Coleoptera with 94 individuals (Table 1).

The results from the negative binomial regression revealed that pesticide application, vegetation coverage, agricultural site, and dominant plants were the best model parameters for grasshoppers (Table 2). All selected parameters were positive. In other words, more grasshoppers were sampled at agricultural sites where pesticides were applied, vegetation coverage was relatively high, and the dominant plant species were those of the family Cyperaceae or Asteraceae. Pesticide application and dominant plants were selected as the best parameters for the model of Araneae, but these parameter values were negative. Additionally, the parameter of mean temperature was negative and the agricultural site parameter was positive. This implies that Araneae tended to occur at sites with low temperature, no pesticides applied, near agricultural land, and not dominated by either Cyperaceae or Asteraceae (Table 2).

The best model parameters selected for herbivorous Coleopteran were mean temperature (negative) and agricultural site (positive). This means that herbivorous Coleoptera are more often found at sites with lower temperatures and near agriculture. The mean height of vegetation (positive) was the only parameter selected for

the best fit model of predatory Coleoptera. This means that predatory Coleoptera are more likely to occur in areas with taller vegetation. Mean height (positive), vegetation cover (positive), and agricultural landscape (negative) were selected as parameters for the best fit model of herbivorous Hemiptera, except for Cicadelidae. This means that herbivorous Hemiptera (excluding Cicadelidae) usually occur at sites with taller vegetation and a higher density of plants that are not in agricultural areas. Vegetation coverage (positive) and mean temperature of the previous year (positive) were selected as parameters for the best-fit model for Cicadelidae (Hemiptera), suggesting that this group of animals seemed to prefer areas with a higher coverage of vegetation and a lower temperature in the previous year. The only selected parameter for the best-fit model of predatory Coleoptera was the height of plants, implying that they prefer sites with taller plants (Table 2).

Grasshoppers are the dominant insect species and main insect pest in Inner Mongolia (Chen, 2007). The analysis of relationships between grasshopper populations and environmental factors showed that the sampled population size of grasshoppers was higher at agricultural sites and at sites with degraded vegetation (Table 2; Figure 2). Conversely, the spider population had a diametrically opposite response (Table 2; Figure 2). Few spiders were sampled at sites where pesticides were applied. Despite a lack of direct evidence, there appeared to be a negative correlation between the sampled population sizes of spiders and grasshoppers (Figure 3).

Table 1. List of sampled arthropods

Order	Family	No. of individuals	Guild type	Response variable
Orthoptera	Unknown (grasshopper)	464	Herbivore	Grasshopper
	Tettigoniidae	12	Predator	(not analyzed)
Araneae	Unknown	19	Predator	Araneae
Coleoptera	Chrysomelidae	9	Herbivore	Herbivorous Coleoptera
	Cryptophagidae	2	Herbivore	Herbivorous Coleoptera
	Curculionidae	19	Herbivore	Herbivorous Coleoptera
	Meloidae	13	Herbivore	Herbivorous Coleoptera
	Lampyridae	9	Herbivore	Herbivorous Coleoptera
	Coccinellidae	42	Predator	Predatory Coleoptera
Hemiptera	Pentatomidae	9	Herbivore	Herbivorous Hemiptera
	Miridae	54	Herbivore	Herbivorous Hemiptera
	Lygaeidae	1	Herbivore	Herbivorous Hemiptera
	Coreidae	16	Herbivore	Herbivorous Hemiptera
	Cicadelidae	488	Herbivore	Cicadelidae
	Nabidae	4	Predator	(not analyzed)
	Anthocoridae	1	Predator	(not analyzed)
Hymenoptera	Apidae	1	-	(not analyzed)
	Ichneumonidae	1	-	(not analyzed)
	Chalcididae	8	-	(not analyzed)
	Cepidae	2	-	(not analyzed)
	Formicidae	14	-	(not analyzed)
	Unknown	29	-	(not analyzed)
Lepidoptera	Nymphalidae	1	-	(not analyzed)
	Noctuidae	1	-	(not analyzed)
Diptera	Unknown	64	-	(not analyzed)
Neuroptera	Chrysopidae	3	-	(not analyzed)
Odonata	Lestidae	1	-	(not analyzed)

Table 2. Parameter estimate of the best models

	Intercept	Mean height	Coverage	Dominant plant	Agricultural site	Pesticide treatment	Mean temperature
Grasshopper							
Coefficient	-0.704		0.017	1.981	1.189	2.105	
(± SE)	(±0.793)		(±0.01)	(±0.481)	(±0.481)	(±0.494)	
<i>P</i> value	0.379		0.08	< 0.01	< 0.05	< 0.01	
Herbivorous Coleoptera							
Coefficient	1.467				0.961		-0.43
(± SE)	(±0.647)				(±0.578)		(±0.17)
<i>P</i> value	< 0.05				0.105		< 0.05
Herbivorous Hemiptera (except Cicadelidae)							
Coefficient	-3.201	0.08	0.037		-1.188		
(± SE)	(±1.06)	(±0.031)	(±0.016)		(±0.724)		
<i>P</i> value	< 0.01	< 0.01	< 0.05		0.101		
Cicadelidae							
Coefficient	3.039		0.049				-0.891
(± SE)	(±1.379)		(±0.019)				(±0.244)
<i>P</i> value	< 0.05		< 0.05				< 0.01
Araneae							
Coefficient	6.189			-4.686	1.822	-4.682	-1.427
(± SE)	(±2.449)			(±1.82)	(±0.986)	(±0.511)	(±0.533)
<i>P</i> value	< 0.05			< 0.05	0.065	< 0.01	< 0.01
Predatory Coleoptera							
Coefficient	-2.49	0.12					
(± SE)	(±0.799)	(±0.036)					
<i>P</i> value	< 0.01	< 0.01					

4. Discussion

Vegetation has a key influence on grasshopper populations (Kang et al., 2007), and the degradation of grasslands can cause outbreaks of some locust species in the Eurasian steppe system (Cease et al., 2012). Agricultural activities may be responsible for an increase in the density of grasshoppers in Europe (Badenhausser & Cordeau, 2012). This suggests that the damage caused by grasshoppers will increase in Inner Mongolia as agricultural activities become intensified.

Our results indicate that grasshopper populations will likely increase at sites where pesticides are applied in the previous year. Although pesticides are effective for controlling insect populations shortly after application, in the long-term, the effects wear off and may in fact promote the occurrence of insect pests by killing off natural predators (Matsuoka & Seno, 2008).

In general, spider populations are significantly lower in areas where pesticides are applied than in untreated areas (Wick & Freier, 2000). It is possible that the effects of pesticides remain the year following application and consequently influence spider populations. In the present study, spiders did not occur at sites where either pesticides were applied or where vegetation was degraded. Therefore, pesticide application and the degradation of vegetation are considered to be reasons for the decline in spider populations.

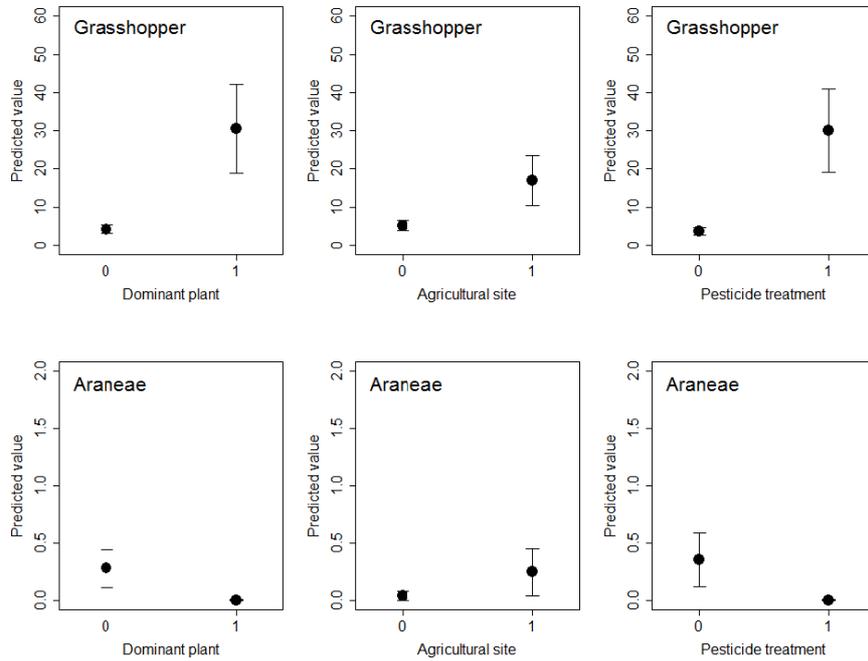


Figure 2. The effects of dominant plant species, agricultural site, and pesticide application on the population of grasshoppers and Araneae based on the best-fit model

Description: Values were calculated keeping other environmental variables at their mean sample values. Error bar is SE.

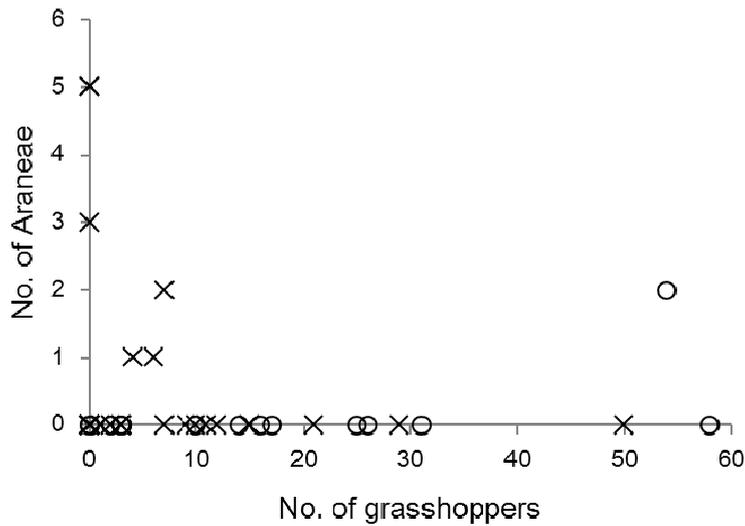


Figure 3. The scatter plot of the sampled numbers of grasshoppers and araneae

Description: Circle and cross indicate sites treated with and without pesticides, respectively.

Spiders are natural enemies of grasshoppers, and they can feed on grasshoppers that are larger than themselves (Parks, Stoecker, & Kristensen, 2006). Spiders can effectively control a population of grasshoppers (Williams, Zhu, Snodgrass, & Manrique, 2012). In the present study, at sites with no or few spiders, the population of grasshoppers was relatively high (Figure 3). However, a maximum of only five spiders were found at any one

site, a thus a more extensive field survey is required to illustrate the contribution of spiders to insect dynamics in the grasslands of Inner Mongolia.

The dominant plant species is a driving factor in the distribution of grassland arthropods. In Inner Mongolia, both vegetation cover and plant height increased the sampled population size of herbivorous Coleoptera, herbivorous Hemiptera, Cicadellidae, and predatory Coleoptera. We did not detect any effects of pesticide application and vegetation degradation on any of these groups (Table 2). Compared to grasshoppers and spiders, these arthropods may be resistant to pesticide application and vegetation degradation. However, the details of this resistance remain unclear.

Because the agricultural utilization of grasslands in Inner Mongolia is being intensified, conservation of the grassland ecosystem is important. Our results suggest that grasshopper populations may increase over time while spider populations may decrease as ecosystems are further degraded by agricultural activities. The concept of integrated pest management, as propounded by Smith and Reynolds (1966), may prove important in conserving these ecosystems. However, due to many limitations, such management strategies have not been well developed or practiced in the grasslands of Inner Mongolia.

Traditionally, pest management strategies have focused on pesticide application. However, the adverse effects of pesticides on beneficial arthropod populations are widely known (Geiger et al., 2010), and pesticide application can lead to the extermination of spiders (Chatterjee, Isaia, & Venturino, 2009). To balance the risks and benefits of pesticide application, scientific methods such as reduced-area or reduced-agent treatment (Lockwood et al., 2002) should be introduced to Inner Mongolia. Recently introduced methods of biological control, although facing some difficulties, should be encouraged in the future agricultural activities in the grasslands of Inner Mongolia.

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References

- Anscombe, F. J. (1949). The statistical analysis of insect counts based on the negative binomial distribution. *Biometrics*, 5, 165-173. <http://dx.doi.org/10.2307/3001918>
- Badenhausser, L., & Cordeau, S. (2012). Sown grass strip-A stable habitat for grasshoppers (Orthoptera: Acrididae) in dynamic agricultural landscapes. *Agriculture, Ecosystems and Environment*, 159, 105-111. <http://dx.doi.org/10.1016/j.agee.2012.06.017>
- Cease, A. J., Elser, J. J., Ford, C. E., Hao, S., Kang, L., & Harrison, J. F. (2012). Heavy livestock grazing promotes locust outbreaks by lowering plant nitrogen content. *Science*, 335, 467-469. <http://dx.doi.org/10.1126/science.1214433>
- Chatterjee, S., Isaia, M., & Venturino, E. (2009). Spiders as biological controllers in the agroecosystem. *Journal of Theoretical Biology*, 258, 352-362. <http://dx.doi.org/10.1016/j.jtbi.2008.11.029>
- Chen, Y. (2007). *The main Acridoids and ecological management of locust plagues in China* (1st ed.). Beijing: Science Press (in Chinese).
- Diekötter, T., Billeter, R., & Crist, T. O. (2008). Effects of landscape connectivity on the spatial distribution of insect diversity in agricultural mosaic landscapes. *Basic and Applied Ecology*, 9, 298-307. <http://dx.doi.org/10.1016/j.baae.2007.03.003>
- Dong, J., Liu, J., Yan, H., Tao, F., & Kuang, W. (2011). Spatiotemporal pattern and rationality of land reclamation and cropland abandonment in mid-eastern Inner Mongolia of China in 1990-2005. *Environmental Monitoring and Assessment*, 179, 137-153. <http://dx.doi.org/10.1111/10.1007/s10661-010-1724-9>
- Dong, X., Brown, M. T., Pfahler, D., Ingwersen, W. W., Kang, M., Jin, Y., ... Ulgiati, S. (2012). Carbon modeling and emergy evaluation of grassland management schemes in Inner Mongolia. *Agriculture, Ecosystems and Environment*, 158, 49-57. <http://dx.doi.org/10.1016/j.agee.2012.04.027>

- Geiger, F., Bengtsson, J., Berendse, F., Weisser, W. W., Emmerson, M., Morales, M. B., ... Inchausti, P. (2010). Persistent negative effects of pesticides on biodiversity and biological control potential on European farmland. *Basic and Applied Ecology*, *11*, 97-105. <http://dx.doi.org/10.1016/j.baae.2009.12.001>
- Hardin, M. R., Benrey, B., Colt, M., Lamp, W. O., Roderick, G. K., & Barbosa, P. (1995). Arthropodpest resurgence: an overview of potential mechanisms. *Crop Protection*, *14*, 3-18. [http://dx.doi.org/10.1016/0261-2194\(95\)91106-P](http://dx.doi.org/10.1016/0261-2194(95)91106-P)
- Inner Mongolia Autonomous Regional Bureau of Statistics. (2011). *Inner Mongolia statistical yearbook 2011*. Beijing: China Statistics Press (in Chinese).
- Kang, L., Han, X., Zhang, Z., & Sun, O. J. (2007). Grassland ecosystems in China: review of current knowledge and research advancement. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *362*, 997-1008. <http://dx.doi.org/10.1098/rstb.2007.2029>
- Lockwood, J. A., Hong-Chang, L., Dodd, J. L., & Williams, S. E. (1994). Comparison of grasshopper (Orthoptera: Acrididae) ecology on the grasslands of the Asian steppe in Inner Mongolia and the Great Plains of North America. *Journal of Orthoptera Research*, *2*, 4-14. <http://dx.doi.org/10.2307/3503601>
- Lockwood, J. A., Sprecher, R. A., & Schell, S. P. (2002). When less is more: optimization of reduced agent-area treatments (RAATs) for management of rangeland grasshoppers. *Crop Protection*, *21*, 551-562. [http://dx.doi.org/10.1016/S0261-2194\(01\)00145-4](http://dx.doi.org/10.1016/S0261-2194(01)00145-4)
- Ma, Y., Li, H., & Kang, L. (1991). *The grassland insects of Inner Mongolia* (1st ed.). Shanxi: Tianze Eldonejo. (in Chinese).
- Matsuoka, T., & Seno, H. (2008). Ecological balance in the native population dynamics may cause the paradox of pest control with harvesting. *Journal of Theoretical Biology*, *252*, 87-97. <http://dx.doi.org/10.1016/j.jtbi.2008.01.024>
- Metcalf, R. L., & Luckman, W. H. (1982). *Introduction to insect pest management* (2nd ed.). New York: John Wiley Inc.
- Nonnaizab, Qi, B., & Li, Y. B. (1999). *Insects of Inner Mongolia China* (1st ed.). Inner Mongolia: Inner Mongolian Public Press (in Chinese).
- Parks, J., Stoecker, W. V., & Kristensen, C. (2006). Observations on *Loxosceles reclusa* (Araneae, Sicariidae) feeding on short-horned grasshoppers. *Journal of Arachnology*, *34*, 221-226. <http://dx.doi.org/10.1636/S04-32.1>
- R Development Core Team. (2010). *R: A language and environment for statistical computing*. Vienna: R Foundation for Statistical Computing. Retrieved from <http://www.R-project.org/>
- Robertson, B. A., Porter, C., Landis, D. A., & Schemaske, D. W. (2012). Agroenergy crops influence the diversity, biomass, and guild structure of terrestrial arthropod communities. *BioEnergy Research*, *5*, 179-188. <http://dx.doi.org/10.1007/s12155-011-9161-3>
- Smith, R. F., & Reynolds, H. T. (1966). Principles, definition and scope of Integrated Pest Control. *Proceedings FAO Symposium on Integrated Pest Control*, *1*, 11-17.
- Stoate, C., Báldi, A., Beja, P., Boatman, N. D., Herzon, I., van Doorn, A., ... Ramwell, C. (2009). Ecological impacts of early 21st century agricultural change in Europe-A review. *Journal of Environmental Management*, *91*, 22-46. <http://dx.doi.org/10.1016/j.jenvman.2009.07.005>
- Suzuki, Y. (2003). The present conditions of agriculture and livestock farming in Mongolia. *Kagaku*, *73*, 549-553 (in Japanese).
- Wen, S., Wang, Y., Qinggele, & Gao, Q. (2011). Key technologies for integrated control of meadow moth. *Animal Husbandry and Feed Science*, *32*, 7-9 (in Chinese).
- Wick, M., & Freier, B. (2000). Long-term effects of an pesticide application on non-target arthropods in winter wheat-A field study over 2 seasons. *Anzeiger für Schädlingskunde*, *73*, 61-69. <http://dx.doi.org/10.1046/j.1439-0280.2000.00061.x>
- Williams, L., Zhu, Y., Snodgrass, G. L., & Manrique, V. (2012). Plant-mediated decisions by an herbivore affect oviposition pattern and subsequent egg parasitism. *Arthropod-Plant Interactions*, *6*, 159-169. <http://dx.doi.org/10.1007/s11829-011-9165-0>
- Wilson, C., & Tisdell, C. (2001). Why farmers continue to use pesticides despite environmental, health and

- sustainability costs. *Ecological Economics*, 39, 449-462. [http://dx.doi.org/10.1016/S0921-8009\(01\)00238-5](http://dx.doi.org/10.1016/S0921-8009(01)00238-5)
- Yang, Y. (2010). Development of sustainable animal husbandry in Inner Mongolia. Chinese Academy of Agricultural Sciences. Ph.D dissertation.
- Zhang, L., Liu, A., Xin, Q., Liu, D., & Gan, W. (2006). Trend and analysis of vegetation variation in typical rangeland in Inner Mongolia-A case study of typical rangeland of Xilinguole. *Journal of Arid Land Resources and Environment*, 20, 185-190.
- Zhao, H. -L., Cui, J. -H., Zhou, R. -L., Zhang, T. -H., Zhao, X. -Y., & Drake, S. (2007). Soilproperties, crop productivity and irrigation effects on five croplands of Inner Mongolia. *Soil and Tillage Research*, 93, 346-355. <http://dx.doi.org/10.1016/j.still.2006.05.009>