2017 年度

博　士　論　文

酪農学園大学大学院

酪農学研究科　食生産利用科学専攻　博士課程

環境リモートセンシング研究室

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The Effects of Grazing Systems on Plant Communities in Steppe Lands—A Case Study From Mongolia's Pastoralists and Inner Mongolian Settlement Areas

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February, 2018

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Abstract

This study selected two adjacent soums (one on each side of the border) with basically the same natural conditions in the border region of typical steppe of Mongolia and China as the study area. We employed quadrats sampling method and remote sensing to set three perpendicular lines that dissect the two countries' boundary and seven lines parallel to the boundary to form a rectangle shape as a means to compare plant community response to different grazing systems under natural conditions. Then, we discussed the reasons for the degradation of Mongolian grassland together with the five periods of remote sensing NDVI data.

The results of the quadrat conditions survey and dynamic NDVI survey are as follows:

(1) The basic characteristics of plant communities: the values of average height, total coverage and total aboveground biomass reduce from forbidden grazing > rotational grazing > continuous grazing. There are significant differences in average height and total aboveground biomass among the three grazing systems ($p<0.05$). The total coverage for forbidden grazing and rotational grazing are significantly greater than continuous grazing ($p<0.05$) but no significant difference between rotational grazing and forbidden grazing.

(2) The responses of 10 species with dominance greater than 3% in the entire study area to different grazing systems are analyzed and found that the effects of different grazing systems on different species are significantly different. Though the grassland degradation and adverse succession are very obvious in the study area, the typical steppe is still maintaining the perennial grass-dominated plant communities that are resistant to grazing and drought. *S. grandis* and *L. chinensis* are at absolute advantage in forbidden grazing area but their dominance reduces in rotational grazing area where *A. frigida* and *C. duriuscula* are at an advantage. After *S. grandis* degenerated in continuous grazing area, *S. krylovii* is at advantage. Besides, the

dominance of other species that are resistant to grazing and drought such as *C. acuminatum*, *A. polyrhizum*, *A. tenuissimum* and *C. squarrosa* are obviously increasing in continuous grazing is the highest.

(3) There are no significant differences in species richness R, Shannon-Wiener index, Pielou evenness index among the three different grazing systems. This results explains that different grazing systems across the border between China and Mongolia have not had a significant impact on the species diversity of the community. From Simpson indexes of continuous grazing and forbidden grazing which are significantly greater than that of rotational grazing, it can be seen that the diversity is developing towards the direction of significant difference.

(4) In areas with different grazing system, the dominance of water-based functional groups and life-form functional groups are significantly different. The aridification phenomenon of continuous grazing and forbidden grazing is significantly greater than rotational grazing; the dominance of xerophytes in continuous grazing and forbidden grazing are significantly greater than rotational grazing ($p<0.05$); and the dominance of intermediate xerophytes in rotational grazing is significantly greater than that of forbidden grazing and continuous grazing ($p<0.05$). The dominance of perennial grass in forbidden grazing and continuous grazing are significantly greater than that of rotational grazing ($p<0.05$) but no significant difference between forbidden grazing and continuous grazing. The dominance of perennial weed in rotational grazing is significantly greater than both forbidden grazing and continuous grazing ($p<0.05$) but no significant difference between forbidden grazing and continuous grazing.

(5) Among the five periods NDVI data, the NDVI of rotational grazing in 1989, 2005, 2011 and 2016 are higher than those of continuous grazing, among which the NDVI of rotational grazing in 2011 and 2016 are significantly higher than those of continuous grazing ($p<0.05$). The results of forbidden grazing and grazing NDVI dynamics show that forbidden grazing plays a protective role on aboveground biomass and coverage.

(6) The calculated result of frequency of the M. Godron's community stability test shows that the stability reduces from continuous grazing > rotational grazing > forbidden grazing. The calculated result of coverage stability shows that the stability reduces from rotational grazing > continuous grazing > forbidden grazing.

Comprehensive analyses show that under the same natural conditions and grazing intensity, the effects of different grazing systems for typical steppe plant communities are significant and to a certain extent, rotational grazing system is better than continuous grazing system.

Acknowledgements

First of all, I sincerely give thanks to Professor Buho Hoshino, my supervisor for my doctoral degree. From dissertation topics, project design, field work, in-house experiment to the completion of this dissertation, Professor Buho has given many constructive and valuable opinions as well as fully supported me. I am deeply grateful to my supervisor for his hard work in assisting my studies and life during my PhD study in Japan.

I am grateful to my deputy examiners, namely Professor Hobara, S., Associate Professor Kenta Ogawa, Professor Kazuaki Araki and Professor Tuya Wulan for their valuable comments.

This dissertation field work, project design and other aspects had received great helps and supports from teacher Saixiyalt Bao and teacher Zhang Weiqing of College of Geographical Sciences, Inner Mongolia Normal University. Thank you. I would also like to express my sincere appreciation as the field work was successfully completed with the funding supported by the National Natural Science Foundation (No. 41561009), chair by teacher Saixiyalt Bao.

Thanks to the graduate students of teacher Saixiyalatu, ie. the team's four core members, including Sorgog, Qinggel, Has and Wuhant, for their supports in field work and data collection.

I would like to thank Basarhand and Alantanbater, the two teachers from Department of Geography, Mongolian National University of Education as well as teacher Tsedevdorj Serod and the graduate student, Yider, for their assistance in field work and facilitation of food, clothing and accommodation when we were in Mongolia.

Thanks to the drivers and friends for their hard work.

Thanks to the local pastoralists and leaders who had provided me with their selfless helps and assistance during the field work, so that we can successfully complete the collection of field data.

I would like to thank Rige Su, Hai Yong, Porbdorj, Hairihan, Ying Tian and Matsumoto from my laboratory for their valuable comments on the dissertation.

Sincerely thanks to teachers and students of Rakuno Gakuen University, members of the Rotary Foundation and other Japanese friends for their great helps and supports during my three years study in Japan.

Thanks to Ms. Khew Ee Hung for her great supports in English polishing.

Thanks to my family, especially my mother, though her body is rather weak due to old age, she was willing in helping to take care of my daughter. I also want to thank my wife, Ms. Fuying Qin, for not only finished her PhD with flying colors, but also took care of the household and supported my studies. Finally, I want to thank my five-year-old daughter, Saihan Sog.

I want to dedicate all my achievements and best wishes to the beautiful, lovely grasslands and kind, diligent pastoralists as well as to all my friends who care, support and help me.

Chapter 1 Introduction

1.1 Background of the study

Other than providing mankind with suitable living condition and resources, grassland plays an important role in soil and water conservation, climate regulation, biodiversity conservation and soil improvement. Therefore, its functions are important in maintaining the balance of global and regional ecosystems (Scarnecchia 1990). There are many names for grasslands around the world, examples are prairie in North America, pampas in South America, Veld and savanna in Africa, and steppe in Asia and Europe. Even though there are many definitions for grasslands but most refer to the definition proposed by UNESCO and Oxford Dictionary of Plant Sciences: grasslands include herbaceous vegetation growing in more arid environments (Suttie et al., 2005).

Mongolian grassland is actually a major part of temperate grassland in Eurasia (Bao et al. 2014a). Owing to its area mostly belongs to arid and semi-arid area with low precipitation throughout the year, its ecosystem is very fragile and sensitive to environmental changes. Mongolian grassland is mainly found in Mongolia and Inner Mongolia of China. In the past half century, Mongolian grassland experienced the most intense economic activities of mankind, hence, human disturbance together with global changes have worsen the degradation of Mongolian grassland. It has caused widespread concern among the scholars who study climate, hydrology, ecology etc (Angerer et al. 2008; Hoshino et al. 2009; John et al. 2013). Mongolia is one of the few countries relying on animal husbandry. Over the past half century, both human population and livestock are increasing rapidly in number and thus excessive grazing occur. However, comparing to the significant degradation of grassland in China, the grassland in Mongolia is still maintaining in a good condition to a certain extent (Conte and Tilt 2014b). A typical example is the famous Horqin Grassland in early 20th century which has now turned into Horqin Sandy Land after a century (Wulantuya 2000; Yintai et al. 2010).

Regarding the lack of quantitative information about mid-term to long-term relationship between Mongolian grassland and human population (50-300 years), Na and his colleagues (2017) utilized linear trend model and literature reviews to analyze the characteristics of Horqin human population change and their causes. Also, five remote sensing images from year 1977 to 2014 of the two selected regions were used to analyze the relationship between ratio of degraded areas and population density as well as quantify the effects of population changes to the grassland degradation. The results show that the main causes of increasing population at Horqin were the policy which encouraged immigration and the policy which encouraged the people to have more kids. However, the slow population growth after 1981 proved the efficiency of immigration policy and family planning policy the government later enforced. The analysis result of linear trend shows that each Banner (region) population density changes against time is not regular (The result of Q Test shows that 68% of R^2 value is significant $p<0.05$, $n=10$); the correlation of the ratio of the two selected regions' grassland degraded area and population density are 0.905

(p=0.035) and 0.503 (p=0.387) respectively. Therefore, they are positively correlated or in another word, the grassland degraded further when the population density increases (Na et al.2017).

With the population increasing, the need for agricultural resources including land, fresh water etc. is becoming the main pressure for our society. The land, forest, and grassland are over used in order to satisfy to human needs and desire, which leading to the grassland degradation (Curran and de Sherbinin 2004).

Several studies indicate that increased population is responsible for the worse ecological environment of grassland in Inner Mongolia. In 1994, John suggested that less rainfall, increased population, large scale graze make the grassland bear great pressure (John W. Longworth et al. 1994). The similar theory was raised by Bilige and Du (2016) that large number of immigrants in Inner Mongolia were encouraged to conduct agricultural activity, followed with grassland reclaim, finally, leading to degradation as well as the impaired ecological environment (Bi and Du 2016). According to Aorenqi and his colleague (2005), lifestyle change from nomadism to settlement, unreasonable fencing, and farming pattern contribute to the Inner Mongolia grassland regeneration as well. With noticeable, nomadism to settlement and agricultural farm is accessory to population increased (Ao and Da 2005).

Both Mongolia and Inner Mongolia of China share the main area of the Mongolian grassland. Mongolia represents the traditional animal husbandry country. The number of population and livestock of Mongolia is growing rapidly in the past half century. Although overgrazed, the Mongolia's grassland still maintains a good condition on some level. In contrast, degradation in Inner Mongolia of China is getting more serious, mainly due to the increase of population (Hoshino et al., 2009).

In early 90's, the Prairie overload of grassland in China was estimated around 84%, by using this detail as base plan, and considering the fact that human population growth was at peak in 20th century, even though the average population of nomads constitutes of 30% of the total population in the country. Based on the annual 2% increment in income of nomads, which obtained from farming or herding, grassland would be suffered from over-strong pressure up to 300% (Hou, 2001). Because of the over grazing in grassland and grassland vegetation degradation issues in the future, greater speed and magnitude of herding labor force transfer (immigration or premises transfer) will be demanded.

Grazing is the main utilization of the Mongolian grassland. Therefore, the study of grazing effects on the plant community of grasslands has become the focal point in grazing ecology (Conte and Tilt 2014a; Han et al. 2008; Milchunas et al. 1988).

Grazing system is a system in grazing management that is responsible to comprehensively organize and utilize the time and space for the use of pasture by livestock. It is a temporal and spatial constituent of science disciplines that utilize grassland grazing interval as well as adjust grazing intensity and grazing way to achieve a quantitative balance between the growth of pasture and livestock nutrition (Vera and Vera 1991).

Since 1950s, many countries such as United States, Netherlands, New Zealand, and Australia have developed various types of unique grazing systems, ie. deferredrotation, rest-rotation, season suitability, high intensity-low frequency (HILF), short-duration, best-pasture system etc. HILF rotational grazing system was widely used in 1960s and was known as the high intensity grazing and non-selective grazing. HILF grazing system, a short-duration grazing proposed in late 1960s, utilizing high stocking density and shorten grazing period so that the livestock can often feed on fresh pastures, hence, increasing the quality of forage fed during the day. If well managed, the stocking rate can be significantly higher than free-grazing and other grazing systems (Booysen 1967, 1969).

From various studies on the effects of grazing on the characteristics of plant community quantity (Liang et al. 2009), more scholars believe that moderate grazing can increase the abundance and the complexity of resources, maintain the stability of plant community structure and improve the productivity of plant community (Liu et al. 2009). Overgrazing can lead to deterioration of grassland habitat, alters species composition, reduces species diversity and decreases productivity (Milchunas and Lauenroth 1993). Many evidences suggest that moderate grazing can sustains the survival of species threatening by human activities and thus, increasing the regional biodiversity. However, overgrazing that removes about 90% of the aboveground biomass will seriously decreases the biodiversity of grassland. Spence and his colleagues reported in 2007 that prolonged period of high intensity grazing significantly reduce the coverage, height, aboveground biomass and below-ground biomass (Spence 2007). The study of Bisigato and his colleagues in 2005 shows that the plant species spatial patterning change easier at heavy grazing areas than moderate grazing areas (Bisigato et al. 2005). Austrheim and Eriksson's study of plant diversity patterns in the Scandinavian mountains in 2002 have concluded that grazing is important in maintaining the biodiversity (Austrheim 2002). McIntyre and Lavorel (2001) also stated in their study that grazing changes species composition, species richness, vertical height, plant characteristics and many other grassland's characteristics (Mcintyre and Lavorel 2001). Alice Altestor and her colleagues reported in 2005 that species richness and species diversity are higher in grazing areas than forbidden grazing areas and that grazing leads to the replacement of some tussock grass by creeping-type grasses (Altesor et al. 2005). However, some studies found out that the vegetation at forbidden grazing region which are not impacted by feeding and trampling, grow rampantly, hence, the average height, total aboveground biomass and species richness are significantly greater than grazing region (Deak et al. 2016; Firincioglu et al. 2007). Near the end of 18th century, the theory of rotational grazing was composed by James Anderson in Scotland. It was supported by many other scholars who carried out studies at various locations and verified that rotational grazing can increase grass production and improve grassland utilization (Derner et al. 1994; Jacobo et al. 2006; Michael et al. 1990). Some studies also explain that rotational grazing can facilitate grassland recovery, increase vegetation coverage and pasture quality (Savory and Stanley 1980). Especially, choosing a suitable grazing system for different topography conditions can improve grassland utilization and prevent degradation as well as beneficial to livestock production (Hao et al. 2013). However, Bailey and Brown (2011) proposed that in arid and semi-arid shrublands, timely adjustments to animal numbers and practices that improve grazing distribution at regional and landscape scales are more likely to be effective in maintaining or improving rangeland health than fencing and rotational grazing (Bailey and Brown 2011). Martin and Severson (1998) explain that rotational grazing can facilitate grassland recovery when the grassland is unhealthy but such effect is minimum when the grassland is healthy (Martin and Severson 1988); Heitschmidt and his team (1987), who chose cow as target animal in his experiment at Texas, found out that the impacts of rotational grazing and continuous grazing on environment are basically similar and the differences are mainly caused by the difference in grazing intensity (Heitschmidt et al. 1987). In addition, Heitschmidt and his other team (1982) also found out that different grazing seasons and grazing systems affect vegetation differently (Heitschmidt et al. 1982).

As for the research on the impact of grazing system on grassland vegetation in Mongolia, Wei et al. (2000) and Yan et al. (2008) studied the effects of different grazing systems on plant community dynamics in Mongolian desert grassland. The results show that the density, height, coverage and the important value of dominant species in rotational grazing area are higher than free-grazing area while the height, coverage and density of degraded plants, annual grass and weeds in continuous grazing area increased (Wei and Han 2000; Yan et al. 2008). Yang et al. (2001) analyzed and compared the reproductive characteristics of the main plant population, *Stipa breviflora*, in rotational grazing area and continuous grazing area located in desert grassland (Yang 2001). The results how that the rotational grazing area is more favorable for *Stipa breviflora* to shoot, grow and produce more seeds than continuous grazing area. Li et al. (2002) also prove that rotational grazing system has little effect on grassland communities through their study on the effects of rotational grazing system and continuous grazing system in desert grassland plant communities (Li et al. 2002). Han et al. (2004) studied the effects of rotational grazing and continuous grazing on sheep food intake and weight (Han et al. 2004). They concluded that continuous grazing system is unfavorable to the uniform utilization of forage due to the significant fluctuation forage nutrient content and sheep weight. Meanwhile, rotational grazing can maintain a constant growth of sheep weight and increase stocking rate. Zhu et al. (2002) carried out a comparative study on the effects of different grazing systems on the aboveground biomass of three main plant populations in desert grassland: *Stipa breviflora*, *Cleistogenes songorica* and *Allium polyrhizum*. The results show that forbidden grazing can increase the aboveground biomass while rotational grazing is more beneficial to the restoration and improvement of aboveground biomass than continuous grazing. She also found out that the plants in rotational grazing area and forbidden grazing area grow faster than continuous grazing area (Zhu et al. 2002). Bao et al., (2008) carried out a comparative study on *Stipa grandis* community's characteristics under different grazing systems and found out that rotational grazing has higher species richness and diversity than free grazing. Besides, rotational grazing has a more complex population structure and the species evenness decline lesser than free grazing (Bao et al. 2008). Peng and Wang (2005) studied the impacts of grazing systems on the degenerated grassland vegetation and found out that with same stocking rate, rotational grazing which rationally utilizing the pasture, has higher frequency, coverage, important values and biomass than continuous grazing (Peng and Wang 2005). Forbidden grazing area has the same recovery effects as rotational grazing area too. Oesterheld and McNaughton (1990) studied the effects of different grazing systems on the dynamic plant changes and plant compensatory growth at household pasture in meadow grassland and found out that rotational grazing area's biomass, growth and productivity are higher than free-grazing area (Oesterheld and McNaughton 1990). Xin et al. (2006) studied the influence of different grazing systems on vegetation characteristics in Ningxia steppe and suggested that the best way to use the steppe for grazing is by dividing the steppe into six areas and carried out rotational grazing, which also can increase the pasture productivity (Xin et al. 2006).

Recently, precision grazing management systems have become a hot research topic for grazing ecologists throughout the world. Both rotational grazing and continuous grazing have also become the focal point whereby their pros and cons are discussed through controlled experiments (Derner et al. 1994; Heitschmidt et al. 1987; Jacobo et al. 2006). Though controlled experiments are very maneuverable, they have a few problems: (1) Controlled experiments are usually done during growing season and seldom consider the effects of grazing throughout the year; (2) Experiments usually involve only one type of livestock, lack the consideration of the combined effect of several livestock species; (3) Limited study area and short time span; (4) Only a simple control of gazing and rest-grazing time without taking into account the effective control of pastoralists according to climatic conditions and grassland conditions.

Both Mongolia and Inner Mongolia of China share the main area of the Mongolian grasslands. In earlier times the same grazing system was employed on the whole Mongolian grassland, but following the development of a two state system, different grazing systems were developed on each side of the border, ie. rotational grazing (RG) in Mongolia, continuous grazing (CG) in Inner Mongolia of China and forbidden grazing (FG) near the boundary region, which have changed or disturbed the plant community of the grassland in different ways. Therefore, the boundary region of China and Mongolia is the best location to study the differences between the effects of the different types of grazing systems towards the same grassland ecosystem (Wang et al. 2013). Yet, due to the fact that the region is large and managed by two different countries, communication issues, difficult accessibility etc., the studies on Mongolian Plateau's resources and environment are not very thorough for the time being. Systematic and comprehensive scientific investigation, data collection, spatial distribution pattern and differentiation of different scales, as well as in-depth drive-response research are especially lacking. Besides, most studies are mainly carried out in Inner Mongolia, China instead of Mongolia. Hot topics are the atmospheric circulation, historical climate change, dust storm, certain plant species distribution, micromorphology of plant physiology, species evolution etc. In addition, there are some other studies on the distribution pattern of vegetation and health status at the plateau, response of long-term vegetation parameters to climate change, measurement of local wind erosion rate and the risk assessment of regional wind erosion (Tian et al. 2015). Botanists often do not analyze the overall spatial differentiation patterns of Mongolian plateau while the large-scale analysis of geologists provided somehow imperfect primary data. Secondly, in recent studies on the characteristics of grassland vegetation, because of the hierarchy and complexity of the ecosystem, researchers do not have a synchronized understanding of the relationship between grassland's total plant species, biomass and environmental factors in different regions and scales (Batunacun et al. 2015). The typical steppe is most widely distributed in Mongolian grassland, and thus is the most representative grasslands type. It has unique ecology and species composition, community type, structure and functionality and has proven its vulnerability and fragility of the ecosystem. Because of both natural and anthropogenic factors, grassland degradation rate of typical steppe for grazing accelerates. Therefore, the study of typical steppe vegetation is beneficial to the conservation of Mongolian grassland resources and to maintain a stable development of grassland-based animal husbandry.

Inner Mongolia of China mainly studies the changes of plant communities under different grazing intensities (Dianlin et al. 2006; Li et al. 2016; Li and Chen 1998; Liu et al. 2017; Lumushanburenbayier et al. 2013) while only a few comprehensive studies on the impact of different grazing systems on plant diversity in typical steppe, especially the cross-border study in Mongolian grassland. Most scholars only carried out experimental studies of a smaller area to study the differences between the effects of different grazing systems towards the plant community instead of carrying out the study directly on-site within a larger area (Yan et al. 2008; Yang 2001; Zheng et al. 2011; Zhu et al. 2002). In addition, few studies have integrated multiple methods such as remote sensing, quadrat sampling method, belt transect sampling method, plant community and regional geography, which also represent heaven, earth, nature and society in realizing the quantitative analysis.

With the grassland ecosystem development law as foundation as well as a holistic scientific management of ecological protection and economic development as pursuing target, grassland degradation and ecosystem destruction can be minimized. Therefore, carrying out scientific researches that are in line with the characteristics of grassland geography are indeed imminent.

1.2 Study objectives

(1) To compared the differences between the effects of different grazing systems on plant communities under relatively natural conditions;

(2) To discuss the causes of degradation on Mongolian grassland in order to ensure a sustainable grassland ecosystem based on the scientific basis in the future.

(3) To promote multidisciplinary research on grassland environment, which includes grassland ecology, geography, economic management, remote sensing and spatial science.

Chapter 2 Study Area

2.1 Introduction to Mongolian Plateau

Mongolian plateau is located at the Central Asian Plateau with a latitude and longitude range of 37º24'-53º23'N; 88º43'-126º04'E. The plateau is enormous with an area of about 2 million square kilometers as it has a large width from Sayan mountain range and Yablonoi mountain range in the north to Yin mountain range in the south and extends from Greater Khingan Range in the east to Altai mountain range in the west. The plateau is politically included the whole country of Mongolia; Tuva Republic and Republic of Buryatia in the southern part of Russia; and the entire territory of Inner Mongolia Autonomous Region at the northwest and parts of Xinjiang Uygur Autonomous Region in China. This study selected the core of the Mongolian plateau located in Mongolia and Inner Mongolia Autonomous Region as the study area (Figure 1).

Most parts of Mongolian plateau are ancient platform with an average altitude of 1,580 meters. Its topography altitude decreases gradually from west to east, has an average annual precipitation of about 200 mm and has many lakes and rivers. As the temperature could drop to -45 degrees Celsius during winter, it is one of the cold sources in Asia. Meanwhile, the highest temperature during summer could go up to 30 to 35 degrees Celsius. It is also known as "the Mongolian region" because Mongolian has been utilizing the plateau region since ancient times.

The climate types of Mongolian plateau change from humid and semi-humid alpine climate in the northern mountainous zone to semi-humid and semi-arid temperate climate in the central zone to temperate mountainous area and semi-humid, semi-arid and arid climate in the southern zone. The rain water of northern Mongolian plateau (Mongolia) are mainly sourced from the Arctic Ocean and the precipitation decreases from 300 to 400 mm in the north to about 100 mm in the south. Meanwhile, the rain water of the southern Mongolian plateau (Inner Mongolia) are mainly sourced from the Pacific Ocean and the precipitation decreases from 300 – 400 mm in the south and southeast to 100 – 200 mm in the north and northwest. As for the border of two countries, the precipitation is about 200 mm. Because of the climate, especially precipitation changes, the vegetation cover changes from north to south in the following order: forests, forest grasslands, typical steppe, desert grasslands, Gobi Desert, typical steppe and farming and pastoral areas (unnatural).

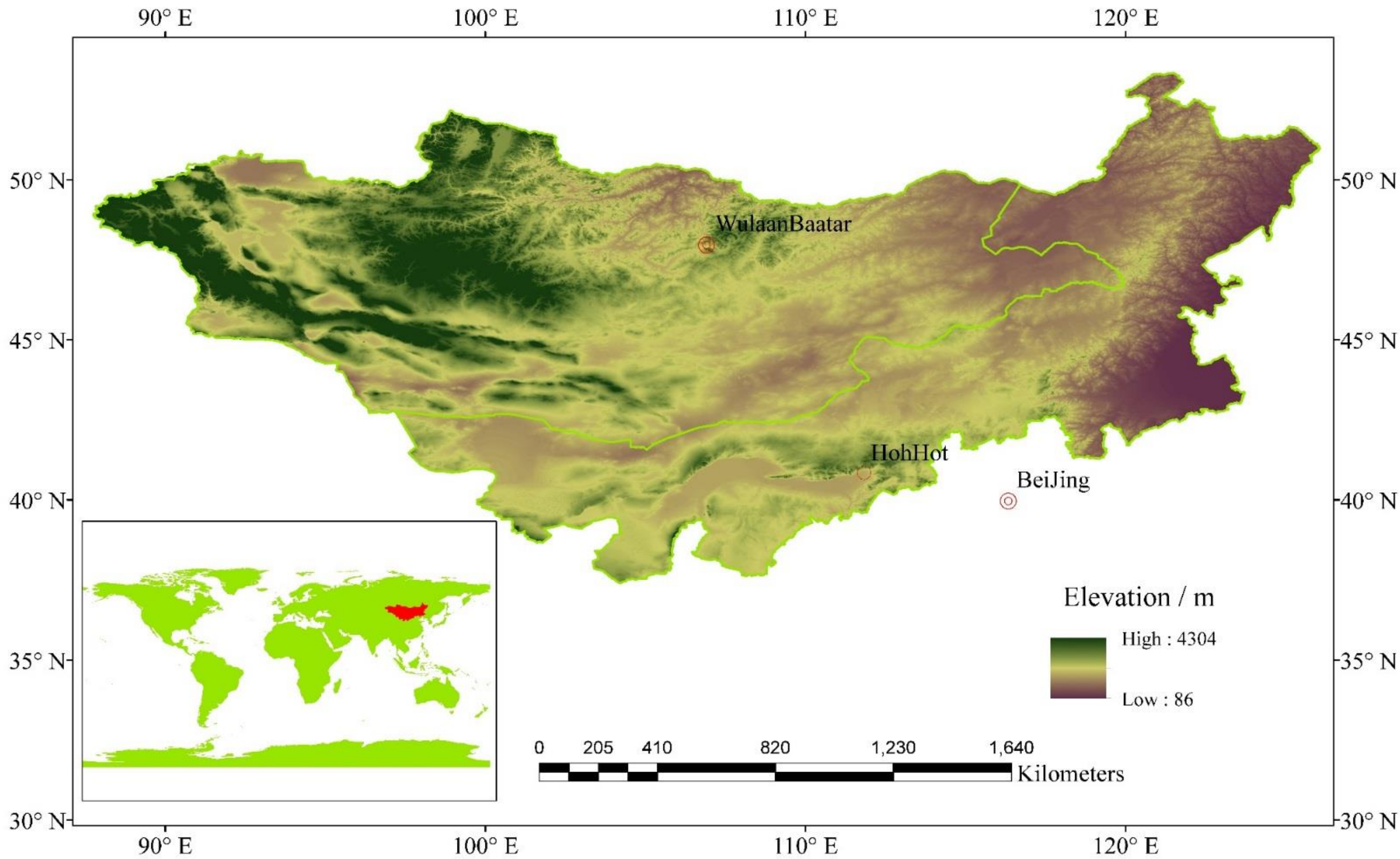

Figure 1**:** The main part of Mongolian steppe – topography map of Mongolia and Inner Mongolia.

2.2 Grazing systems of Inner Mongolia (China) and Mongolia

Mongolians mainly live in Mongolia and Inner Mongolia and are mainly the herders of “five livestock”, i.e. sheep, goats, cows, horses and camels. Because of the historical background, Mongolia and Inner Mongolia were divided into two different countries from the early 19th century. Since then, the two countries have employed two different grazing systems whereby Mongolia maintained original nomadic grazing strategies (rotational grazing) and China introduced a continuous grazing system. Especially when the China’s Pasture Household Contract Responsibility System policy was implemented in 1990, herders began to fence their pasture land and graze their animals only at fixed locations (Table 1).

The Pasture Household Contract Responsibility System implemented in Inner Mongolia is a centrally designated policy which allocates pasture land to villages based on population size, livestock amount, grassland quality, grazing habits, etc. Pasture land is contracted to villagers by village committees for a period of 50 years. Meanwhile, herders in Mongolia carry out rotational grazing depending on grassland conditions and seasonal change and usually rotate once per two to three seasons (Shan et al. 2009; Wang et al. 2013).

Four-seasons rotational grazing (FSRG) is a grazing system in Mongolia whereby the pastures are commonly owned while the livestock are privately owned. Therefore, the pastures boundary and area are not exactly divided. The pastoralists carry out four-seasons rotational grazing based on the seasons and climatic conditions, pasture conditions, water sources and the livestock feeding habit (Shan et al. 2009). FSRG is the main grazing system which the Mongolian are practicing and is also different from rotational grazing. Firstly, the pastures are not fenced. Secondly, unlike the grazing and non-grazing periods of rotational grazing (RG) which are mechanically fixed, FSRG determines the grazing and non-grazing periods mainly based on the geographical conditions, seasonal variations, precipitations as well as grassland and livestock conditions. Thirdly, a distance range of 10 to 30 km is available between the pastures for different seasons such as summer and winter.

Table 1: Changes of Mongolia and China grazing systems

Country / Time	Mongolia		Inner Mongolia	
	1958-1990	**1990-today**	**1978-1990**	**1990-today**
Livestock Ownership	Common	Private	Private	Private
Pasture Ownership	Common	Common	Common	Private
Grazing Method	Rotational Grazing	Rotational Grazing	Rotational Grazing	Continuous Grazing

Mongolia has a land area of 1.567 million km^2, of which about 50 % are better preserved grassland and about 50 % are desert grassland and Gobi Desert (https://baike.baidu.com/item/%E8%92%99%E5%8F%A4%E5%9B%BD/209648?fr=aladdin). In 2016, Mongolia has a population of 3.19 million and Gross National Product (GNP) of 13.4 billion US dollars. Agriculture and animal husbandry are the main economic sector which comprise of 26.2% of the total GNP, of which 80% come from animal husbandry. There are 139.979 million livestock and FSRG is applied in managing the livestock (Zhen et al. 2008).

Animal husbandry is the foundation of Mongolia's national economy; hence, grassland is essential for animal husbandry development. Mongolian graze their livestock at natural pastures throughout the year as there are abundant plant resources, with more than 2,250 species, of which most of them are nontoxic and suitable for feeding. After Mongolian Revolution achieved its victory in 1911, a policy which was formulated to develop animal husbandry and crop farming while protecting grassland ecological environment, has successfully brought about a rapid and sustainable development. Besides, Mongolia pays more attention in protecting soil and vegetation by advocating rational utilization and strictly preventing the phenomenon of over grazing and land exclamation (Skees and Enkhamgalan 2016).

Mongolian grassland is vast and sparsely populated and still retains its traditional nomadic grazing. They divide the grassland according to the type of grasslands and the characteristics of water sources or rotate the grazing grassland in winter, spring, summer and autumn. Such grazing system provides sufficient time for the grassland to rejuvenate, hence, maintaining its effective ecological function and ecosystem services which in return, made an outstanding contribution to the economic development of Mongolia. Even though the rapid and healthy development of animal husbandry in grassland has always been the foundation of Mongolia's economic development, long-term causes due to natural factors and irrational human activities have deteriorated the ecosystem despite Mongolia has rich grassland resources. The deteriorated ecosystem has induced challenges in maintaining the stability and sustainable development of grassland's animal husbandry (Sneath 1998).

Ninety percent of available natural grassland in China are undergoing degradation of different extent (Akiyama and Kawamura 2007). The area of Inner

Mongolia is 118.3 million square kilometers, which occupies 12.3% of total area of China. Meanwhile, Inner Mongolia's grassland has an area of 68.18 million square kilometers and is 57.6% of total grasslands area in China but 75% of the area have been moderately to seriously degraded, as shown by reduced vegetation coverage, desertification, salinization etc (Xijiritana et al. 2013). By the end of 2016, the entire Inner Mongolia had a population of 25.048 million and an agriculture and animal husbandry population of 14.36l million or 60.18%. Meanwhile, Inner Mongolia has about 4.21 million or 16.8% Mongolians. According to the statistics, only about 2.2 million or 50% of the Mongolians can speak their own Mongolian language (Aruna, 2017). In 2016, Inner Mongolia achieved Gross Domestic Product (GDP) of 281.66 billion US dollars, with the ratio of agriculture and animal husbandry sector, industry sector and tertiary sector being 8.8 : 48.7 : 42.5. The total crops planting area was 80,000 square kilometers and the number of livestock was up to 135 million in 2016. Ranks as the largest natural grassland in China, Inner Mongolia is an important location for livestock production.

From 1949 to late 1970s, Inner Mongolia's pasturing areas experienced three major land reclamations with mass immigrations. The first immigration happened from 1958 to 1960, when a total of 192,000 people or an average of 64,000 people per year immigrated. It was followed by immigration of 24,000 people or an average of 6,000 people per year from 1961 to 1964. The third wave of immigration occurred from 1965 to 1979, when 716,000 people or an average of 50,000 people per year immigrated. These three immigrations have reclaimed a total of 25,000 square kilometers of grasslands (Se, 1998). According to a study in Inner Mongolia, it is shown that the reclamation of one hectare of grassland can cause desertification of three hectare of grassland surrounding it (Daoerjipalamu, 1996). In other words, desertification occurs easily on bare land of grassland. Therefore, large-scale reclamation of grassland had directly led to the large-scale degradation of grassland, which exponentially decreased the size of grassland suitable for nomadic grazing and forced the pastoralists to switch to continuous grazing, engaged in farming and animal husbandry simultaneously or only farming. By 1949, Mongolians engaged in farming had already accounted for two thirds of Mongolian population in Inner Mongolia (Sun, 2006). The proportion of Han population in pastoral areas is increasing rapidly. According to the statistics of 33 Pastoral Areas, the population increased about 90 thousand people annually from 1990 to 1980. Meanwhile, the population of Mongolian from 1950 to 1980 dropped from 56% to 22% in Alxa League and dropped from 90% to 28% in Xilinguole League (Ao, 2004). In 1949-1985, the area of Inner Mongolia grassland decreased by 92 thousand square kilometers (Bao, 2006). Although there were still four-season grassland in the northern part of the pasture, along the boundary between China and Mongolia, the distance for nomadic grazing was only about 10 kilometers while the southern part of the pasture was no longer suitable for nomadic grazing (Shan et al. 2009). In response to the large-scale degradation and desertification of grasslands, Inner Mongolia implemented the Three-North Shelter Forest Program (‘Three- North’ representing northwest, north and northeast regions of China), which is a large-scale artificial forest ecological engineering project. The Chinese government decided in 1979 to list this project as an important project for national economic construction in order to improve the ecological environment. The project is expected to take 70 years divided into seven phases and currently it is of the fifth phase. The project of retuning farmland to forest and grassland, harnessing the source areas of Beijing and Tianjing sandstorms as well as establishing ecological protection and vegetation restoration projects such as nature reserves to conserve and improve the ecological environment and to ensure a stable and sustainable development of livestock husbandry (Hao and Li 2011).

2.3 The overview of study area

The study area is the typical steppe located at the boundary region of Inner Mongolia (China) and Mongolia. The steppe is divided into two areas, Nalan Soum of Mongolia and Naren Soum of Inner Mongolia. Both areas are purely utilized as grazing land, basically have the same vegetation types, weather, topography, soil, production method (grazing) and stocking rate. The soil is made up of chestnut soil and humus layer of 5-10 cm thick; average annual rainfall from 1971 to 2016 was 220.6 ± 65.2mm whereby 60% to 80% of rain fell during the growing season (July to September) and the evaporation rate was 1505 ± 45.4mm. (Figure 2 and Table 2).

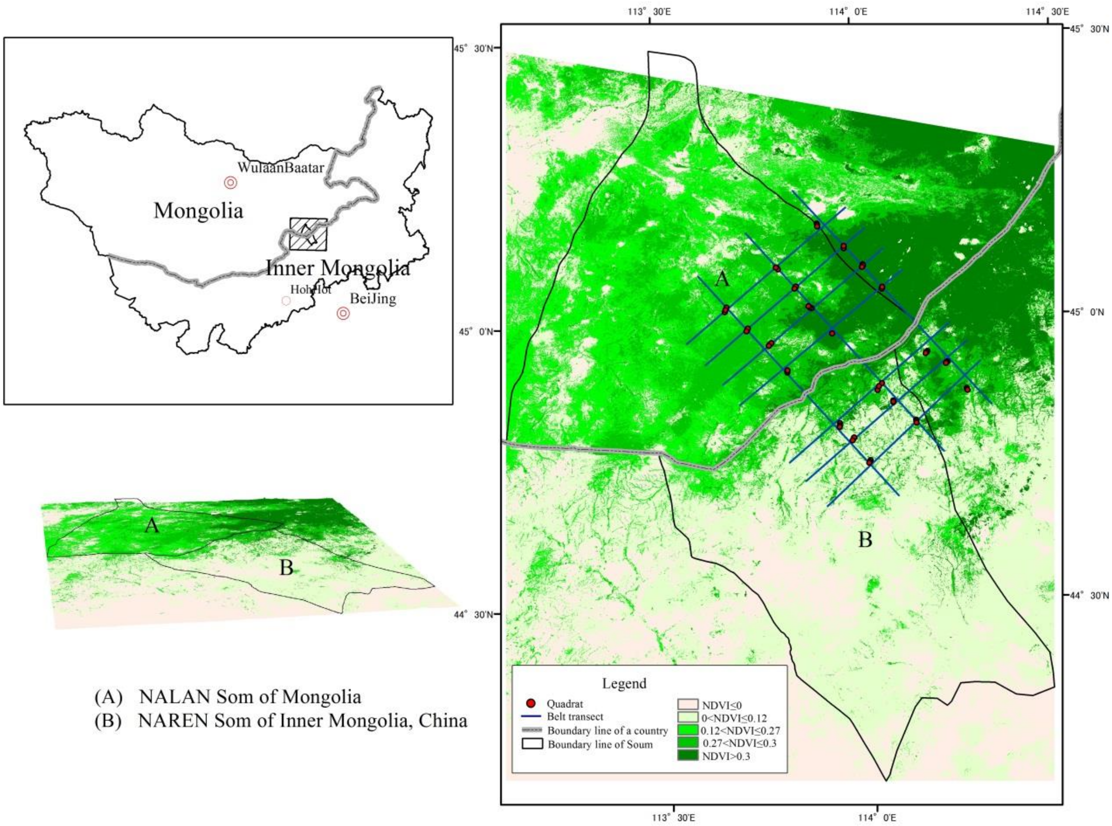

Figure 2.Study area and plot distribution

Table 2. Result of ecological factors in study area

Factors	Nalan Soum	Naren Soum
Annual mean temperature (°C)	1.41a	1.03a
Annual mean precipitation (mm)	216.80 (a)	224.49 (a)
Altitude (m)	1356.21a	1346.39b
Average annual evaporation (mm/y)	1505.14a	1498.52a
Average stocking rate (sheep unit/km^2)	42a	50a
Soil type	Chestnut soil	Chestnut soil
Soil humidity (VWC)	7.5%a	6.9%b

Note: The lowercase letters indicate the significant difference at 5% level;
Source: Meteorological Bureu of Xilingol League and National Agency for Meteorology and Environmental Monitoring of Mongolia.

Stocking rate = The total number of livestock (sheep unit) owned by the herder where the quadrat is located / The total area of the grassland owned by the herder;

Livestock data and grassland area were mainly obtained from the annual statistics data, and then verified via on-site survey and local community interviews, of which all types of livestock are being converted to sheep as the unit according to China's sheep unit conversion standard, as follow: 1 camel = 7 sheep, 1 horse = 6 sheep, 1 cow = 5 sheep and 1 goat = 1 sheep.

In study area, the structural species are feathergrass (*Stipa grandis*) and Chinese rye grass (*Leymus chinensis*) while the dominant species are needle leaf sedge (*Carex duriuscula*), needle grass (*Stipa krylovii*), prairie sagewort (*Artemisia frigida*), C*henopodium acuminatum*, *Cleistogenes squarrosa*, *Allium polyrhizum,* etc. Field survey data show that cross-border areas in China and Mongolia typical steppe have 44 plant species of 16 families. The comparison of different grazing systems found that the species composition in rotational grazing area (38 species) is the richest, followed by continuous grazing area (35 species) and forbidden grazing area (29 species) (Table 3).

Table 3. Species composition in study area

Species	RG	FG	CG	Species	RG	FG	CG
Carex duriuscula	1	1	1	*Convolvulus ammannii*	1	0	1
Leymus chinensis	1	1	1	*Potentilla bifurca*	1	1	1
Stipa krylovii	1	1	1	*Lepidium apetalum*	1	0	1
Chenopodium acuminatum	1	1	1	*Ptilotricum canescens*	1	0	1
Cleistogenes squarrosa	1	1	1	*Saussurea mongolica*	1	1	1
Artemisia frigida	1	1	1	*Iris tenuifolia*	1	0	1
Allium polyrhizum	1	1	1	*Dontostemon micranthus*	1	0	1
Salsola collina	1	1	1	*Cymbaria dahurica*	1	1	1
Stipa grandis	1	1	1	*Artemisia sieversiana*	1	0	1
Allium tenuissimum	1	1	1	*Achnatherum splendens*	0	1	1
Caragana stenophylla	1	1	1	*Asparagus gobicus*	1	1	1
Neopallasia pectinata	1	1	1	*Allium mongolicum*	1	0	1
Artemisia annua	1	1	0	*Artemisia dracunculus*	1	0	1
Caragana microphylla	1	0	1	*Veronica didyma*	1	0	0
Oxytropis microphylla	1	1	1	*Poa annua*	1	1	0
Atriplex sibirica	1	0	0	*Koeleria litvinowii*	0	1	0
Kochia prostrata	1	0	1	*Haplophyllum dauricum*	1	0	1
Torilis scabra	1	1	1	*Limonium bicolor*	0	1	0
Heteropappus altaicus	1	1	1	*Bupleurum sibiricum*	0	1	0
Agropyron cristatum	1	1	1	*Galium verum*	1	0	0
Ephedra sinica	1	1	1	*Chenopodium aristatum*	0	0	1
Allium ramosum	1	1	1	*Allium condensatum*	0	1	0

Note: '1' represents the corresponding species, '0' represents no corresponding species

Chapter 3 Design of experiment and Research Methods

3.1 Design of experiment

As the topography characteristics of Mongolian grassland are flat with larger ecological niches and continuous landscape, two study locations at the boundary region of Inner Mongolia (China) and Mongolia known as Soum were chosen, one at each side along the boundary, which have similar biotic and abiotic conditions. By using the principles of quadrat and belt transect sampling methods, three lines perpendicular to the boundary at each side and seven lines parallel with boundary that went across the three perpendicular lines to form a rectangle shape were established with the help of Google Earth and GPS. The length of each perpendicular line which cut across both Mongolia and Inner Mongolia was 40 km long while the length of each parallel line was 20 km long, of which four lines were located in Mongolia and another three lines were located in Inner Mongolia. Among the four parallel lines located within Mongolia, one was set at the forbidden grazing area which was located 5 km away from the border. These three perpendicular lines and seven parallel lines were actually set up so that their intersection points became the marked points to set up three individual quadrats. Also, each quadrat had a distance of 150 m from one another. The field survey was carried out during the peak biomass period, which was from the end of July to Mid-August of 2016, and a total of 61 quadrats of 1m x 1m each were surveyed. In each quadrat, the number of species, total individual density, total aboveground biomass, total coverage and average height, soil type and its humidity were measured and recorded (Figure 3).

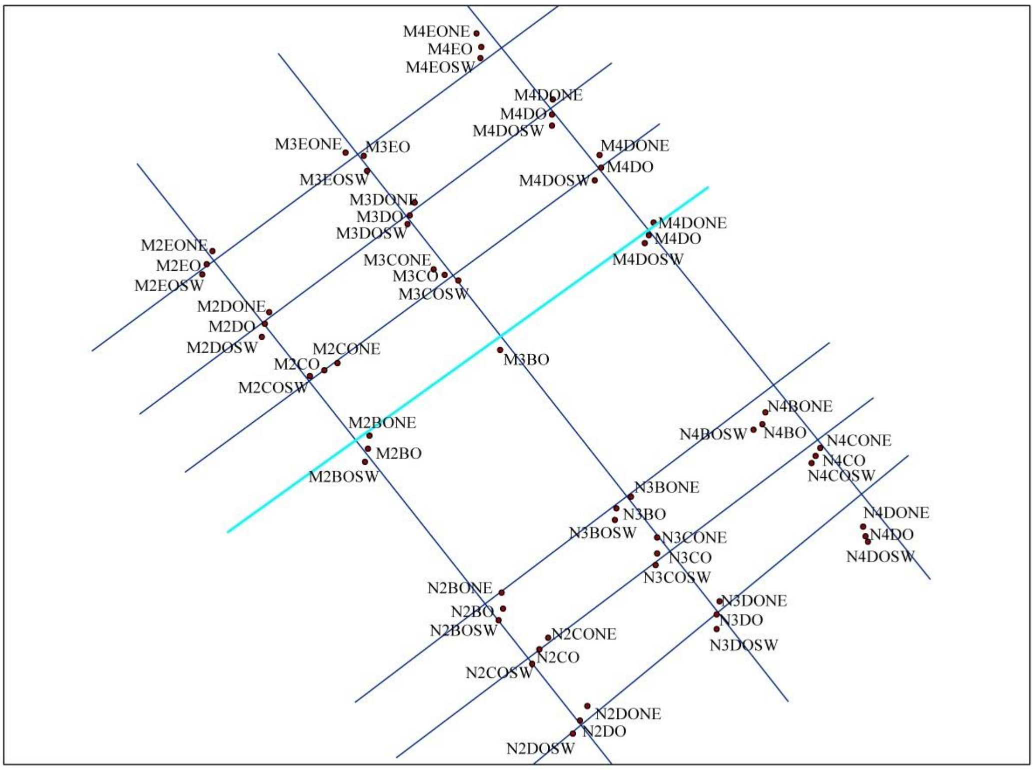

Figure 3. Design of experiments and spatial distribution of the quadrats.

3.2 Research Methods

3.2.1 General characteristics of plants

The plant community's characteristics were identified based on average height, total coverage, total individual density and total aboveground biomass (Wang et al. 2013) (Zhang et al.2017)

Average height is referred to the average which was taken from three plant height values per quadrat measured with measuring tape.

Total coverage is referred to the vertical projection of the outermost perimeter of the natural spread of foliage of all plant species found in each quadrat. It was calculated based on the average of three persons' visual measurement results.

Total individual density is referred to the total number of individuals for all species per quadrat, calculated via artificial statistics method.

Total aboveground biomass was calculated by using a destructive method whereby all plants in each quadrat were harvested and their fresh weight was measured with a 0.01g precision digital scale directly at the field site.

3.2.2 Species dominance calculation

Species dominance calculation:

$$\text{IV}\ (\%) = \frac{\text{Relative Coverage}+\text{Relative Density}+\text{Relative Frequency}+\text{Relative Height}}{4} \quad (1)$$

Where,

$$\text{Relative Density} = \frac{\text{The number of individuals of a species}}{\text{The number of individuals of all species}} * 100 \quad (2)$$

$$\text{Relative Height} = \frac{\text{The average height of a species}}{\text{The sum of the average height of all species}} * 100 \quad (3)$$

$$\text{Relative Coverage} = \frac{\text{The coverage of a species}}{\text{The sum of the coverage of all species}} * 100 \quad (4)$$

$$\text{Relative Freqeuncy} = \frac{\text{The frequency of a species}}{\text{The frequency of all species}} * 100 \quad (5)$$

3.2.3 Species diversity calculation

Species diversity is the center of biodiversity and the most important structural and functional unity of biodiversity. It refers to the species abundant of animals, plants, microorganism etc. on earth. Species diversity includes two aspects: 1) refers to the species richness in a certain area and can be called the regional species diversity; 2) in ecology, it refers to the degree of evenness in species distribution and can also be referred to as biodiversity or community diversity. Species diversity is an objective index in measuring the abundance of biological resources in a certain area(Hurlbert 1971).

When measuring the species diversity of the regional habitats, the absolute number of species in the community is usually compared so that the result is more concise. Even though calculating the number of all species to express the species richness of the quadrat reflects the number of species in the community, it omits the difference in abundances of dominant species and rare species as well as it is susceptible to the effects of different field sampling area. Therefore, the result can be more accurate only by also applying Simpson dominance index, Shannon-Wiener index and Pielou evenness index (Rosenzweig 1995).

Simpson dominance index is contrary to diversity and evenness index which reflect the changes in the number of species. Large index value means uneven species distribution and prominent dominant species. Shannon-Wiener diversity index is a parameter of species diversity and heterogeneity in the community, which reflects the community's species richness and evenness but omits the species composition. Pielou's evenness index reflects the degree of evenness in distribution of the number of individual species in each community (Dickman 1968).

Based on the number of plant species enumerated in the quadrat, the individual number and dominance index for all plant species, the diversity index of the community is calculated as below:

Species Richness : R = S (6)

Shannon-Wiener Index : $H' = -\sum_{n=1}^{\infty} \text{Pi Ln(Pi)}$ (7)

Simpson's Diversity Index: $D = 1 - \sum_{n=1}^{\infty} (\text{Pi})^2$ (8)

Pielou's Evenness Index : $D = 1 - \sum_{n=1}^{\infty} (\text{Pi})^2$ (9)

Where, R is the species richness, S is the number of species, Pi is the dominance proportion of species i of the total dominance in the community.

3.2.4 Classification of plant community functional groups

Plant functional group refers to a group of species or taxa that have similar responses under specific environmental factors. It is distinguished based on their biological, morphological, life history or other biological characteristics that are relevant to an ecosystem processes and to the behavior of the species (Griffin 1988). Functional group is a basic unit to study the changes of plants according to its environment(Pérezharguindeguy et al. 2013). It is also an important unit for studying biodiversity and its role in ecosystem functioning (Lavorel et al. 1997).

Therefore, this study selected typical steppe located at China-Mongolia border area as study area to analyze the dominance of the ecological functional group and life-form functional group. Ecological functional group includes xerophytes, intermediate xerophytes, mesophytes and intermediate mesophytes while life-form functional group includes perennial grass, perennial weeds, annual grass as well as shrubs and sub-shrubs.

3.2.5 Normalized Difference Vegetation Index (NDVI)

Grassland vegetation survey is generally divided into two types, ie. ground monitoring and remote sensing monitoring methods. Ground monitoring method mainly determines the vegetation information such as growth, yield estimation, species change by measuring the height, coverage, yield, species and other parameters of grassland vegetation. Though ground monitoring of grassland vegetation is time consuming and straining, the characteristics of vegetation can be meticulously and comprehensively reflected. On the other hand, remote sensing monitoring method is time-saving and labor-saving, hence, allowing large-scale monitoring. Therefore, remote sensing monitoring has become the main method for grassland vegetation monitoring (Kawamura et al. 2005; Tucker 1979). Changes in vegetation is a complex physiological processes which are affected by many factors. However, some factors closely related to the changes in vegetation can be used to characterize the overall condition of the vegetation. And the overall condition of grassland vegetation can be shown by processing the remote sensing data of different time periods. Furthermore, studies have shown that NDVI can be used to indicate vegetation growth. The larger the NDVI value, the more photosynthetically active radiation (PAR) absorbed by the vegetation, the better vegetation growth and the better vegetation community. The vegetation has its own spectrum features, ie. strong absorption of visible lights and strong reflection of near-infrared (NIR) light. As there is a significant correlation between the two PAR spectral region and NIR spectral region (Yintai et al. 2010), red band and NIR band can be used to calculate vegetation index to reflect the vegetation growth condition. Examples of common vegetation indexes are NDVI (Fan et al. 2009; Wylie et al. 2002); Pure Vegetation Index, PVI (Li et al. 2016); Ratio Vegetation Index, RVI (Feng et al. 2006); Difference Vegetation Index, DVI (Feng et al. 2006); Modified Soil-adjusted Vegetation Index, MSAVI (Qi et al. 1994) and Enhanced Vegetation Index, EVI (Liu and Huete 1995). Both NDVI and MSAVI are usually used in arid and semi-arid typical steppe (Bao et al. 2014b).

The calculation method of NDVI is shown below:

$$\text{NDVI} = \frac{(P_{NIR} - P_{\text{Red}})}{(P_{NIR} + P_{Red})} \quad (10)$$

Where, NIR is the reflectance of near-infrared wavelength and Red is the reflectance of red wavelength.

NDVI is a type of vegetation index which has highest correlation with the greenness indices of herbaceous plants (Carlson and Ripley 1997). When vegetation coverage is 25% - 80%, the NDVI value increases linearly with vegetation coverage; when the vegetation coverage is larger than 80%, the monitoring sensitivity decreases (Meng 2006). Meanwhile, NDVI is more sensitive to the changes in soil and is suitable for arid area vegetation survey and the monitoring of vegetation during their early and middle growth phases. In order to highlight the differences of vegetation in the three contrasting areas, NDVI was applied in this study after comprehensive consideration.

Five periods of cloudless satellite images from the study area (126/29), obtained from Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM), were utilized for the study (http://earthexplorer.usgs.gov/). The image resolution was 30 m and Band 3 (0.66μm) and Band 4 (0.84μm) were mainly used. From these images, the dynamic changes of vegetation were identified through a series of image processing, i.e. geometric correction, atmospheric correction, radiometric calibration, NDVI calculation, clipping and statistical calculation (Table 4).

Table 4. Basic Information of TM Data in Study Area

Time	Path/Row	Band Information	Satellite/Sensor	Resolution
1989/8/3	126/29	(B3(0.66)\B4(0.84)	Landsat5/TM	30m
1993/9/15	126/29	(B3(0.66)\B4(0.84)	Landsat5/TM	30m
2005/7/14	126/29	(B3(0.66)\B4(0.84)	Landsat5/TM	30m
2011/7/31	126/29	(B3(0.66)\B4(0.84)	Landsat5/TM	30m
2016/8/13	126/29	(B3(0.66)\B4(0.84)	Landsat8/ETM	30m

In order to obtain an accurate NDVI value for the above 61 quadrats, a total of nine pixels which include the pixel located at the center of every quadrat and the eight surrounding pixels were included in the calculation to obtain the average NDVI value.

3.2.6 Plant community stability calculation

The M. Gordon stability test, especially after MacArthur proposed diversity-stability hypothesis in 1950s, the issues of diversity and stability have always been a debating topic (Macarthur 1955). Therefore, Pimm analyzed and pointed out that the reason for two conflicting hypotheses of diversity-stability relationship are due to diverse definitions of diversity, complexity and stability of ecology (Pimm 1984). Many studies have been carried out on the community diversity-stability, with considerable support for phenomena and logical reasoning, which inspiring many (Frank and Mcnaughton 1991; Tilman and Haddi 1992). Grassland ecosystems have dissipative structural features (Zhou 1989). Based on the dissipative structural hypothesis, the ecosystem achieves an orderly harmony through the interaction between function ↔ structure ↔ fluctuation. The 'fluctuation' mentioned here can be known as an ecological phenomenon, which refers to the deviation of the system from stability under the influence of internal factors or external factors. Fluctuation is the lever that triggers the change of ecological order and the change will inevitably lead to the change of stability. Therefore, the fluctuation is closely related to the structure and stability of the system. Stability is referred to the resiliency of the ecosystem returning to its original state after disturbance and is usually measured mathematically or empirically.

M. Godron stability test is a method discovered by French ecologist from industrial production and introduced it into plant ecology. It is a method to calculate the stability from the number and frequency of all species in a plant community (Godron et al. 1971). This study used M. Godron stability test to calculate plant community stability in the study area and to explore the stability of vegetation community under different grazing systems with the purpose of providing new ideas to reveal the stability mechanism of grassland. The method of M. Godron stability test was as follow:

i. First of all, the frequency of different species in the study community was arranged in descending order and plant species corresponding to their frequency;
ii. Then, the plant's frequency was converted into relative frequency and the cumulative value in descending order was calculated.
iii. The ratio of the corresponding plant species to the total species was calculated.
iv. The intersection point, coordinate x/y, is the smooth curve obtained from simulated scatter data points and the equation $y = 1 - x$. Axis-x is the cumulative relative frequency and axis-y is the ratio of the corresponding plant species to the total number of species. The coordinate 0.2/0.8 is the community stability point: the closer the distance (dx) between the intersection point and the stability point, the more stable the community.

Manipulation of Godron's stability test

The natural conditions of the study area are basically the same, the space span of the study area is not too large and the difference of frequency of plant species is not too big. Therefore, based on the calculated frequency of stability, the stability of vegetation coverage was calculated to compare the sensitivity of frequency of stability and coverage of stability to highlight the community differences in different grazing areas.

We manipulated Godron’s stability test to determine the vegetation stability in different grazing areas by replacing the frequency of various plants with coverage in the test. The manipulated method of M. Godron stability test was as follow:

i. First of all, the coverage of different plant species in the study community was arranged in descending order and plant species corresponding to their coverage;
ii. Then, the plant’s coverage was converted into relative coverage and the cumulative value in descending order was calculated.
iii. The ratio of the corresponding plant species to the total species was calculated.
iv. The intersection point, coordinate x/y, is the smooth curve obtained from simulated scatter data points and the equation $y = 1 - x$. Axis-x is the cumulative relative frequency and axis-y is the ratio of the corresponding plant species to the total number of species. The coordinate 0.2/0.8 is the community stability point: the closer the distance (d_x) between the intersection point and the stability point, the more stable the community.

3.2.7 Statistical analysis

Statistical calculation of the plant community, weather and livestock data were calculated with Excel 2010 software while the NDVI calculation of remote sensing data was performed mainly with ENVI5.0 and ArcGIS10.0. R 3.2 was also used to calculate randomization test based on the NDVI values and vegetation community data of Mongolia, Inner Mongolia and the boundary region, as well as the ecological factors between Nalan and Naren.

Chapter 4 Results of the study

4.1 General characteristics of plant community

The general characteristics of plant community include the community average height, total coverage, total individual density and total aboveground biomass.

Under different grazing systems, community average height reduces from forbidden grazing, 21.2 cm > rotational grazing, 14.8 cm > continuous grazing, 8.4 cm, with a significant difference among the three systems ($p<0.05$) (Figure 4).

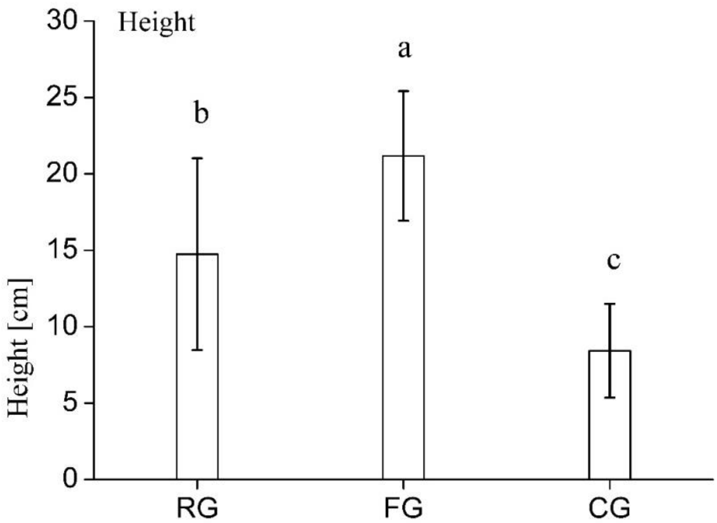

Figure 4. Community average height for different grazing systems.

Total coverage reduces from forbidden grazing (67.9%) > rotational grazing (64.3%) > continuous grazing (56.5%), with a significant difference between rotational grazing and continuous grazing ($p<0.05$) but not between rotational grazing and forbidden grazing as well as forbidden grazing and continuous grazing (Figure 5).

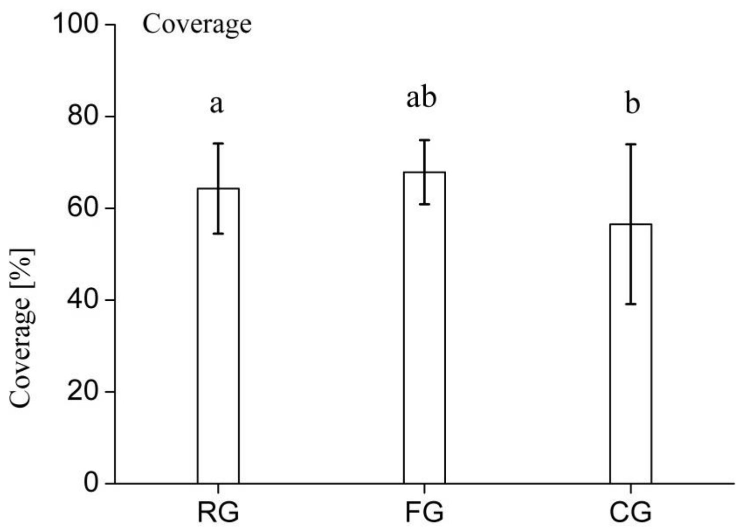

Figure 5. Community total coverage for different grazing systems.

Total aboveground biomass reduces from forbidden grazing, 455.9 g > rotational grazing, 268.4 g > continuous grazing, 122.2 g, with a significant difference among the three systems ($p<0.05$) (Figure 6).

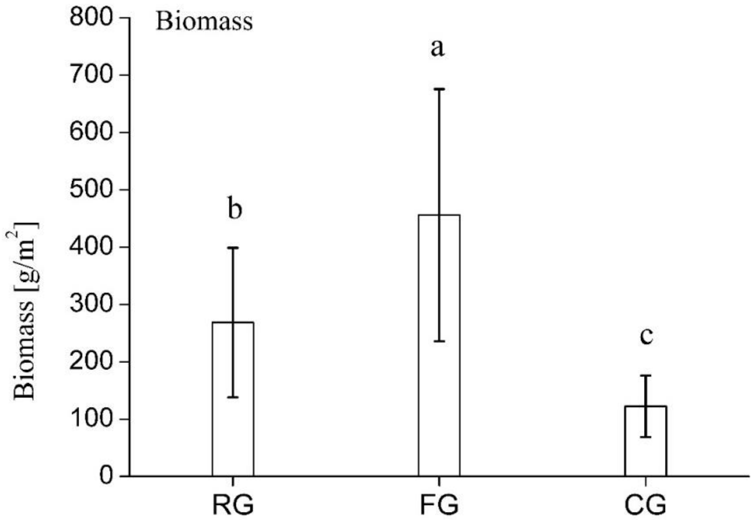

Figure 6. Community total aboveground biomass for different grazing system.

Total individual density decreases from rotational grazing, 439.4 individuals / m^2 > continuous grazing, 310.6 individuals / m^2 > forbidden grazing 228.4 individuals / m^2, among which, there is a significant difference between rotational grazing and both continuous grazing and forbidden grazing ($p<0.05$) but not between continuous grazing and forbidden grazing (Figure 7).

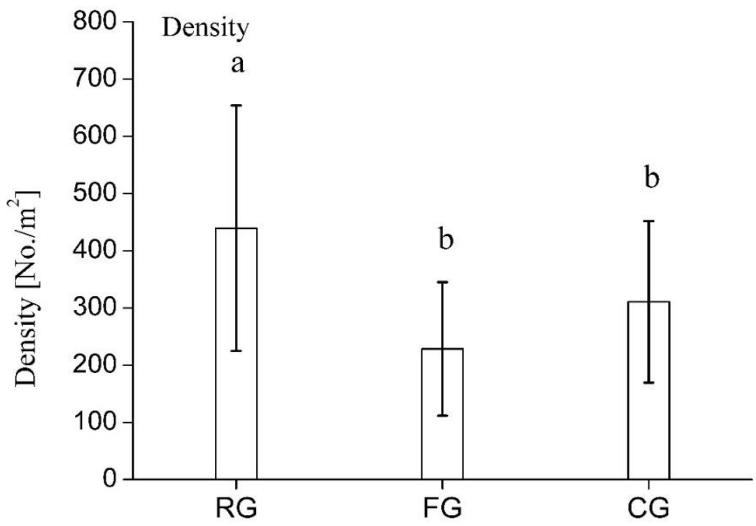

Figure 7. Community total individual density for different grazing system.

4.2 Analysis of species dominance

Species dominance can indicate the relative importance of each plant in the community and the optimum habitat of the plant. The changes in dominance can affect the community structure, ie. the higher the species dominance, the more obvious the species is at advantage position (Zhang, J.T. Sampling methods and community characterization. 2nd ed.; Sciences Publisher: Bei Jing, China).

Focusing on the plant species with species dominance larger than 3% in the entire study area, it is found that needleleaf sedge (*Carex duriuscula*), Chinese rye grass (*Leymus chinensis*), *Stipa krylovii Chenopodium acuminatum*, *Cleistogenes squarrosa*, prairie sagewort (*Artemisia* frigida), *Allium polyrhizum*, slender Russian-thistle (*Salsola* collina), needlegrass (*Stipa grandis*) and *Allium tenuissimum* have high average dominance in the grassland community of different grazing system, in which the cumulative dominance of these species accounted for 72.46 % (Table 5).

Table 5. Plant species with an average dominance larger than 3% in the study area.

Species	Dominance (%)	Order
Carex duriuscula	16.11±10.56	1
Leymus chinensis	10.99±9.94	2
Stipa krylovii	8.11±9.40	3
Chenopodium acuminatum	7.36±6.41	4
Cleistogenes squarrosa	6.62±5.63	5
Artemisia frigida	6.32±5.30	6
Allium polyrhizum	5.47±6.26	7
Salsola collina	4.66±4.03	8
Stipa grandis	3.66±8.34	9
Allium tenuissimum	3.16±2.90	10
Total	72.46	

The differences in responses of the ten species with dominance greater than 3% to the different grazing systems (Table 6), can be grouped into three types: rotational grazing type (two species), forbidden grazing type (two species) and continuous grazing type (six species).

Table 6. Dominance of major species for different grazing systems (%)

Species	RG	FG	CG	Promotion type
Carex duriuscula	22.27±10.24a	10.67±10.66b	11.37±7.45b	R
Leymus chinensis	11.15±13.23a	15.91±6.44a	9.56±5.91a	F
Stipa krylovii	3.46±5.08b	2.84±5.07b	14.13±10.23a	C
Chenopodium acuminatum	6.34±5.65a	6.58±7.77a	8.57±6.8a	C
Cleistogenes squarrosa	5.52±4.18b	3.57±2.5b	8.51±6.85a	C
Artemisia frigida	6.68±6.34a	5.61±5.37a	6.15±4.2a	R
Allium polyrhizum	5.34±7.99a	5.01±3.84a	5.71±4.81a	C
Salsola collina	4.15±3.71a	2.44±3.1a	5.75±4.32a	C
Stipa grandis	3.27±6.93b	12.8±13.68a	1.68±6.53b	F
Allium tenuissimum	1.99±2.33b	3.59±2.5ab	4.23±3.15a	C

Rotational grazing type: The dominance of C. duriuscula and A. frigida reduces from rotational grazing > continuous grazing > forbidden grazing.

C. duriuscula: The dominance in rotational grazing is 22.27%, forbidden grazing is 10.67% and continuous grazing is 11.37%. The dominance in rotational grazing is significantly greater than continuous grazing and continuous grazing ($p<0.05$) but no significant difference between forbidden grazing and continuous grazing.

A. frigida: The dominance in rotational grazing is 6.68%, forbidden grazing is 5.61% and continuous grazing is 6.15%. There is no significant difference among the three systems.

Forbidden grazing type: The dominance of *L. chinensis* and *S. grandis* reduces from forbidden grazing > rotational grazing > continuous grazing.

L. chinensis: The dominance in rotational grazing is 11.15%, forbidden grazing is 15.91% and continuous grazing is 9.56%. There is no significant difference among the three systems.

S. grandis: The dominance in rotational grazing is 3.27%, forbidden grazing is 12.8% and continuous grazing is 9.56%. The dominance in forbidden grazing is significantly greater than both rotational grazing and continuous grazing ($p<0.05$) but no significant difference between rotational grazing and continuous grazing.

Continuous grazing type: The dominance of *S. krylovii*, *C. acuminatum*, *C. squarrosa*, *A. polyrhizum*, *S. collina* and *A. tenuissimum* in continuous grazing is larger than rotational grazing and forbidden grazing. Among which, *S. krylovii*, *C. squarrosa*, *A. polyrhizum* and *S. collina* have dominance reduce from continuous grazing > rotational grazing > forbidden grazing (forbidden grazing area has no these species); while *C. acuminatum* and *A. tenuissimum* reduce from continuous grazing > forbidden grazing > rotational grazing.

S. krylovii: The dominance in rotational grazing is 3.46%, forbidden grazing is 2.84% and continuous grazing is 14.13%. The dominance in continuous grazing is significantly greater than both rotational grazing and forbidden grazing ($p<0.05$) but no significant difference between rotational grazing and forbidden grazing.

C. squarrosa: The dominance in rotational grazing is 5.52%, forbidden grazing is 3.57% and continuous grazing is 8.51%. The dominance in continuous grazing is significantly greater than both rotational grazing and forbidden grazing ($p<0.05$) but no significant difference between rotational grazing and forbidden grazing.

A. polyrhizum: The dominance in rotational grazing is 5.34%, forbidden grazing is 5.01% and continuous grazing is 5.71%. There is no significant difference among the three systems.

S. collina: The dominance in rotational grazing is 4.15%, forbidden grazing is 2.44% and continuous grazing is 5.75%. There is no significant difference among the three systems.

The dominance of *C. acuminatum* and *A. tenuissimum* reduce from continuous grazing > forbidden grazing > rotational grazing.

C. acuminatum: The dominance in rotational grazing is 6.34%, forbidden grazing is 6.58% and continuous grazing is 8.57%. There is no significant difference among the three systems.

A. tenuissimum: The dominance in rotational grazing is 1.99%, forbidden grazing is 3.59% and continuous grazing is 4.23%. The dominance in continuous grazing is significantly greater than rotational grazing ($p<0.05$) but no significant difference between continuous grazing and forbidden grazing as well as between forbidden grazing and rotational grazing.

4.3 Analysis of species diversity

Species richness, R, refers to the number of plant species in the community and is one of the most direct and effective method to depict the species diversity. Under different grazing systems, the R of rotational grazing, forbidden grazing and continuous grazing are 12.37, 11.43 and 12.52 respectively. The R value reduces from continuous grazing > rotational grazing > forbidden grazing, with no significant difference among the three systems (Figure 8).

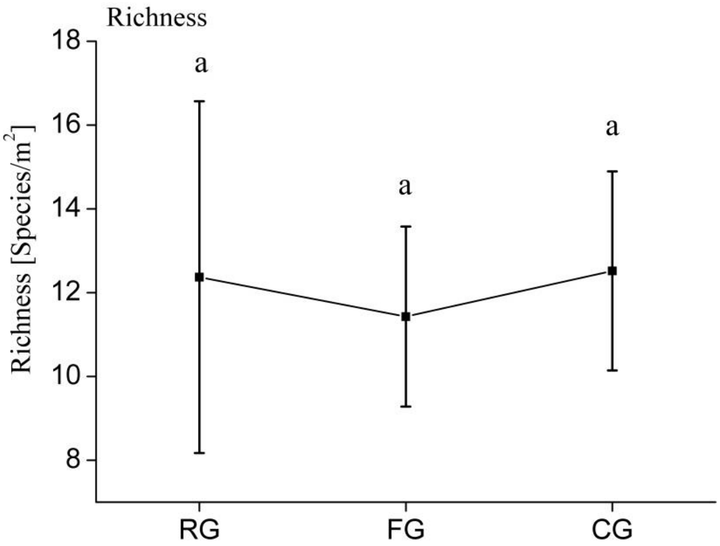

Figure 8. Species richness for three different grazing systems.

Shannon-Wiener index, also known as the information index, reflects the amount of information on the diversity of plant communities. Under different grazing systems, the Shannon-Wiener index for rotational grazing, forbidden grazing and continuous grazing are 2.19, 2.22 and 2.28 respectively. The index reduces from continuous grazing > forbidden grazing > rotational grazing, with no significant difference among the three systems (Figure 9).

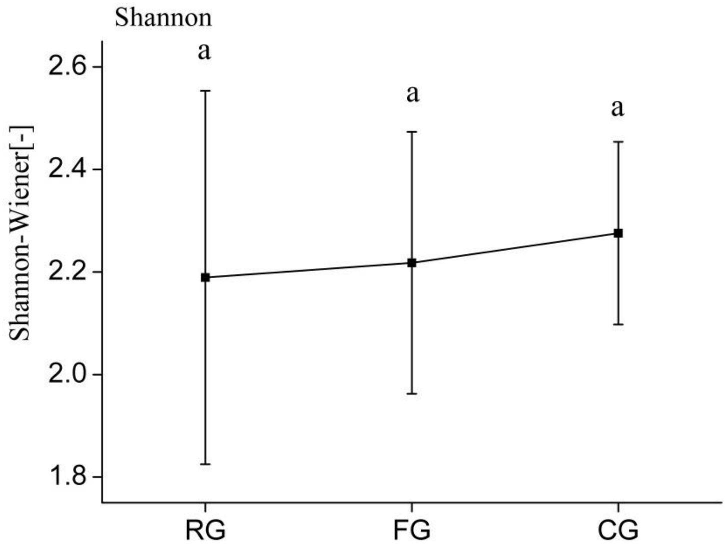

Figure 9. Shannon-Wiener index for three different grazing systems.

Simpson diversity index reflects the degree of differentiation of the species quantity. Under different grazing systems, the Simpson index for rotational grazing, forbidden grazing and continuous grazing are 0.85, 0.86 and 0.87 respectively. The index reduces from continuous grazing > forbidden grazing > rotational grazing. The index for continuous grazing and forbidden grazing are significantly greater than rotational grazing ($p<0.05$) but no significant difference between continuous grazing and forbidden grazing (Figure 10).

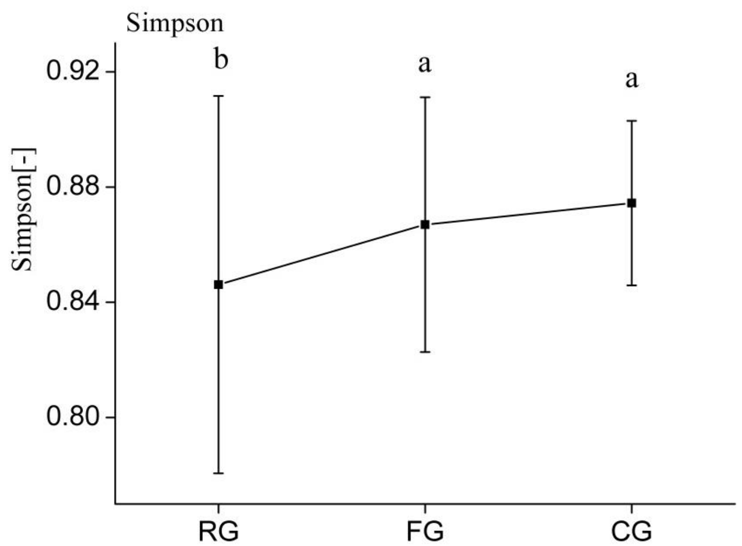

Figure 10. Simpson diversity index for three different grazing systems.

Pielou evenness index refers to the proportions of the number of individual species of various species in the community. Under different grazing systems, the index for rotational grazing, forbidden grazing and continuous grazing are 0.89, 0.92 and 0.91 respectively. The index reduces from forbidden grazing > continuous grazing > rotational grazing, with no significant difference among the three systems (Figure 11).

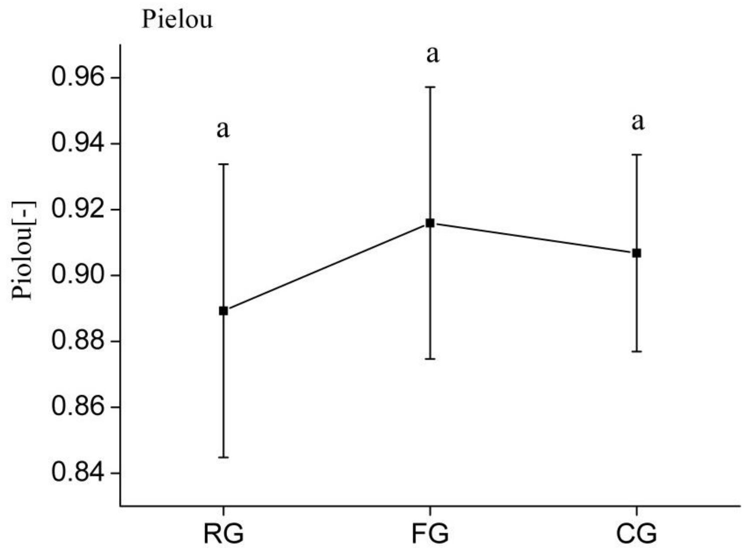

Figure 11. Pielou evenness index for three different grazing systems.

4.4 Analysis of plant functional groups' characteristics

Table 7 shows that under different grazing systems, the dominance of xerophytes for rotational grazing, forbidden grazing and continuous grazing are 55.6, 66.76 and 68.21 respectively. The dominance reduces from continuous grazing > forbidden grazing > rotational grazing. The dominance in continuous grazing and forbidden grazing are significantly greater than rotational grazing but no significant difference between continuous grazing and forbidden grazing;

The dominance of intermediate xerophytes for rotational grazing, forbidden grazing and continuous grazing are 27.39, 15.37 and 13.65 respectively. The dominance decreases from rotational grazing > forbidden grazing > continuous grazing. The dominance in rotational grazing is significantly greater than both forbidden grazing and continuous grazing but no significant difference between forbidden grazing and continuous grazing;

The dominance of intermediate mesophytes for rotational grazing, forbidden grazing and continuous grazing are 8.78, 10.17 and 11.62 respectively. The dominance decreases from continuous grazing > forbidden grazing > rotational grazing and there is no significant difference among the three systems;

The dominance of mesophytes for rotational grazing, forbidden grazing and continuous grazing are 8.23, 7.69 and 6.12 respectively. The dominance decreases from rotational grazing > forbidden grazing > continuous grazing and there is no significant difference among the three systems.

Table 7. The dominance of water-based functional group for different grazing systems.

		Mean ± SD			Mean ± SD
Xerophytes	RG	55.6±11.82b	Intermediate mesophytes	RG	8.78±6.31a
	FG	66.76±15.99a		FG	10.17±10.13a
	CG	68.21±13.46a		CG	11.62±8.96a
Intermediate xerophytes	RG	27.39±9.56a	Mesophytes	RG	8.23±6.72a
	FG	15.37±10.03b		FG	7.69±4.04a
	CG	13.65±7.3b		CG	6.12±7.94a

Note: SD refers to standard deviation.

Table 8 shows that the dominance of perennial grass for rotational grazing, forbidden grazing and continuous grazing are 24.62, 38.16 and 36.07 respectively. The dominance decreases from forbidden grazing > continuous grazing > rotational grazing. The dominance in forbidden grazing and continuous grazing are significantly greater than rotational grazing but no significant difference between continuous grazing and forbidden grazing;

The dominance of perennial weed for rotational grazing, forbidden grazing and continuous grazing are 43.28, 36.89 and 35.65 respectively. The dominance decreases from rotational grazing > forbidden grazing > continuous grazing. The dominance in rotational grazing is significantly greater than both forbidden grazing and continuous grazing but no significant difference between forbidden grazing and continuous grazing;

The dominance of annual grass for rotational grazing, forbidden grazing and continuous grazing are 24.61, 15.32 and 19.49 respectively. The dominance decreases from rotational grazing > forbidden grazing > continuous grazing and has no significant difference among the three systems;

The dominance of shrubs and sub-shrubs for rotational grazing, forbidden grazing and continuous grazing are 7.48, 9.63 and 8.4 respectively. The dominance decreases from forbidden grazing > continuous grazing > rotational grazing and has no significant difference among the three systems.

Table 8. The dominance of life-form functional group for different grazing systems.

		Mean±SD			Mean±SD
Perennial grass	RG	24.62±11.76b	Annual grass	RG	24.61±11.68a
	FG	38.16±17.27a		FG	15.32±17.88a
	CG	36.07±13.15a		CG	19.49±10.79a
Perennial weeds	RG	43.28±16.32a	Shrubs and sub-shrubs	RG	7.48±5.29a
	FG	36.89±8.96ab		FG	9.63±3.94a
	CG	35.65±11.71b		CG	8.4±5.69a

4.5 Normalized Difference Vegetation Index (NDVI)

Figure 12 shows that NDVI values in 1989 for rotational grazing, forbidden grazing and continuous grazing are 0.06, 0.11 and 0.04 respectively. The value decreases from forbidden grazing > rotational grazing > continuous grazing. The value in forbidden grazing is significantly greater than both rotational grazing and continuous grazing ($p<0.05$) but no significant difference between rotational grazing and continuous grazing.

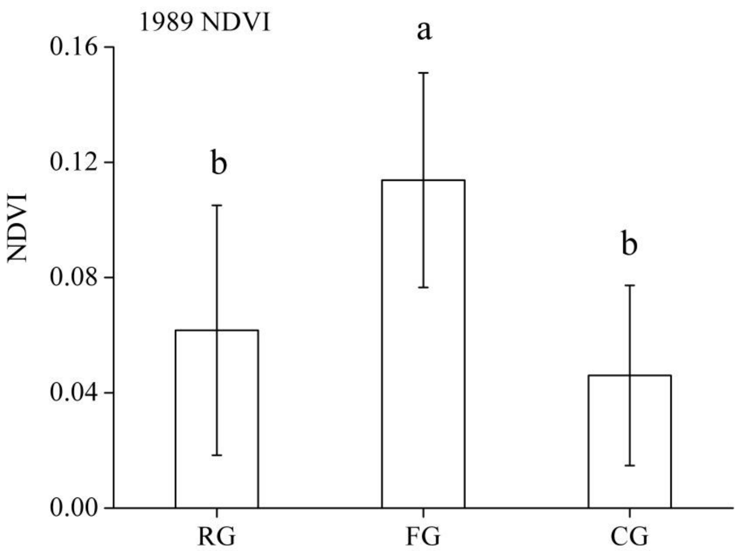

Figure 12. NDVI values in 1989 for three different grazing systems.

Figure 13 shows that NDVI values in 1993 for rotational grazing, forbidden grazing and continuous grazing are 0.11, 0.16 and 0.12 respectively. The value decreases from forbidden grazing > continuous grazing > rotational grazing. The value in otational grazing is significantly lower than forbidden grazing ($p<0.05$) but there is no significant difference between continuous grazing and both rotational grazing and forbidden grazing.

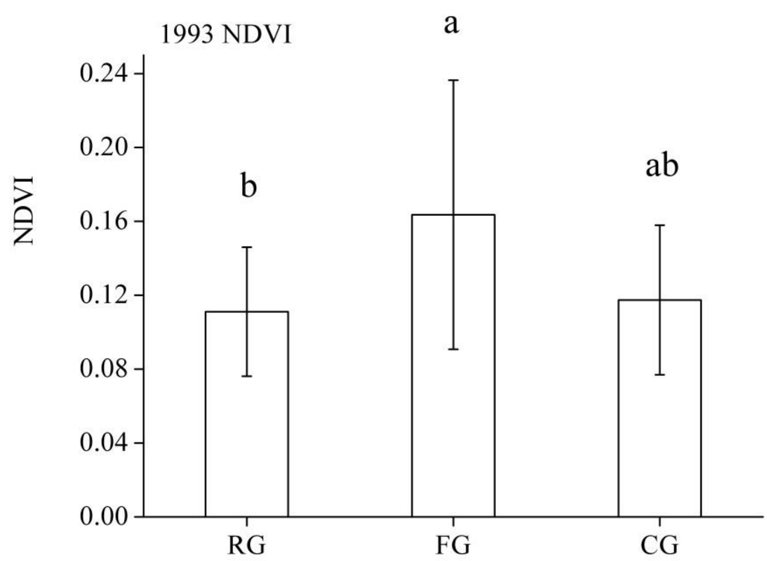

Figure 13. NDVI values in 1993 for three different grazing systems.

Figure 14 shows that NDVI values in 2005 for rotational grazing, forbidden grazing and continuous grazing are 0.04, 0.07 and 0.03 respectively. The value decreases from forbidden grazing > rotational grazing > continuous grazing. The value in forbidden grazing is significantly greater than continuous grazing ($p<0.05$) but there is no significant difference between rotational grazing and both forbidden grazing and continuous grazing.

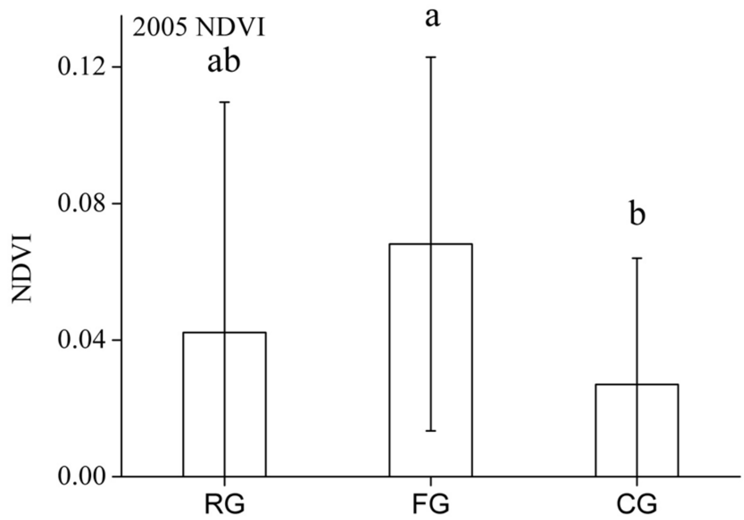

Figure 14. NDVI values in 2005 for three different grazing systems.

Figure 15 shows that NDVI values in 2011 for rotational grazing, forbidden grazing and continuous grazing are 0.3, 0.29 and 0.17 respectively. The value decreases from rotational grazing > forbidden grazing > continuous grazing. The value in rotational grazing and forbidden grazing is significantly greater than continuous grazing ($p<0.05$) but there is no significant difference between rotational grazing and forbidden grazing.

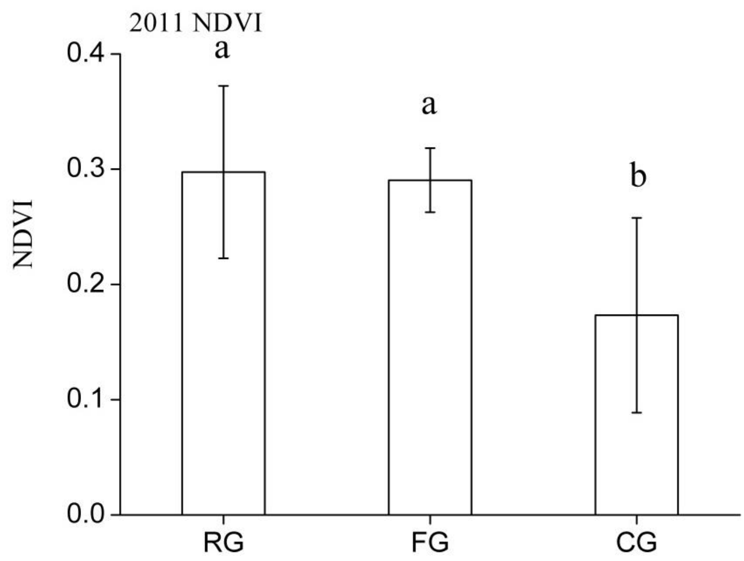

Figure 15. NDVI values in 2011 for three different grazing systems.

Figure 16 shows that NDVI values in 2016 for rotational grazing, forbidden grazing and continuous grazing are 0.07, 0.16 and 0.04 respectively. The value decreases from forbidden grazing > rotational grazing > continuous grazing and there are significant differences between the three systems (p<0.05)

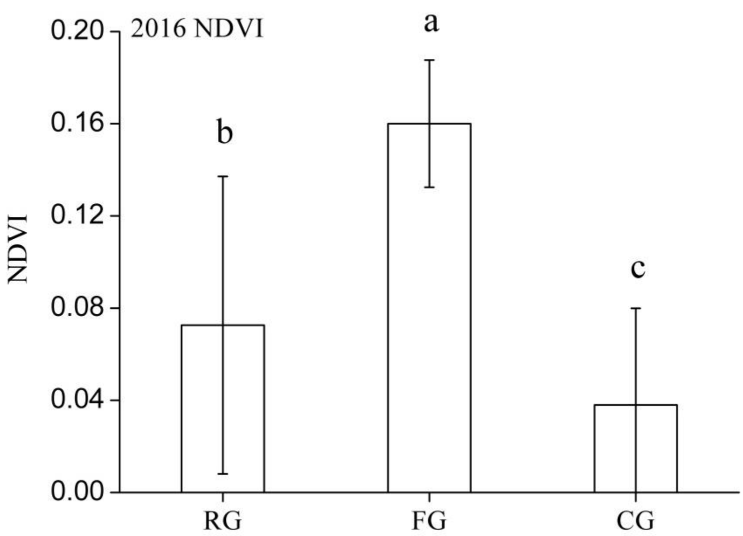

Figure 16. NDVI values in 2016 for three different grazing systems.

4.6 Plant community stability index

Figure 17 and Table 9 show the community stability result of three different grazing systems based on frequency: x/y and d_x of rotational grazing are 0.36/0.66 and 0.21 respectively; x/y and d_x of forbidden grazing are 0.37/0.63 and 0.24 respectively; x/y and d_x of continuous grazing are 0.34/0.66 and 0.20 respectively. The community stability index of continuous grazing is the highest, follows by rotational grazing and lastly, forbidden grazing, ie. continuous grazing > rotational grazing > forbidden grazing.

Table 9. Community stability based on frequency.

GS	TOC	CC	PV	C(x/y)	d_x	SO
RG	y=-1.2226x^2+2.138x+0.0544	0.9978	P<0.01	0.36/0.66	0.21	2
FG	y=-1.109x^2+2.0344x+0.0322	0.9957	P<0.01	0.37/0.63	0.24	3
CG	y=-1.3577x^2+2.2446x+0.0568	0.9854	P<0.01	0.34/0.66	0.20	1

Note: GS=Grazing system, TOC=Type of curves, CC=Correlation coefficient, PV=P value, C=Coorlinate, SO=Stability order.

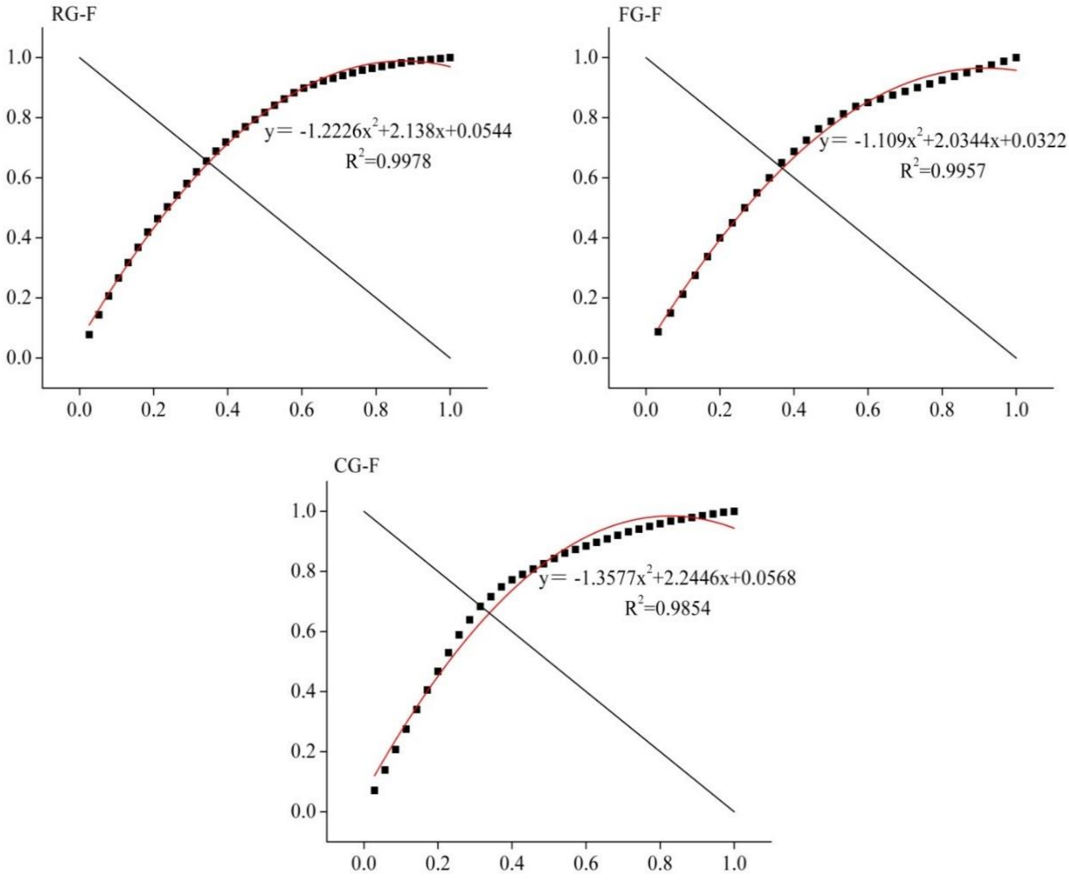

Figure 17. Stability graphs of different systems based on frequency.

Figure 18 and Table 10 show the community stability result of three different grazing systems based on coverage: x/y and d_x of rotational grazing are 0.26/0.74

and 0.09 respectively; x/y and d_x of forbidden grazing are 0.31/0.70 and 0.16 respectively; x/y and d_x of continuous grazing are 0.28/0.72 and 0.12 respectively. The community stability index of rotational grazing is the highest, follows by continuous grazing and lastly, forbidden grazing, ie. rotational grazing > continuous grazing > forbidden grazing.

Table 10. Community stability based on coverage.

GS	**TOC**	**CC**	**PV**	**C(x/y)**	d_x	**SO**
RG	$y=-1.1701x^2+1.7245x+0.3847$	0.9294	P＜0.01	0.26/0.74	0.09	1
FG	$y=-1.5384x^2+2.3522x+0.1201$	0.9854	P＜0.01	0.31/0.70	0.16	3
CG	$y=-1.2765x^2+1.9303x+0.2887$	0.9729	P＜0.01	0.28/0.72	0.12	2

Note: GS=Grazing system, TOC=Type of curves, CC=Correlation coefficient, PV=P value, C=Coorlinate, SO=Stability.

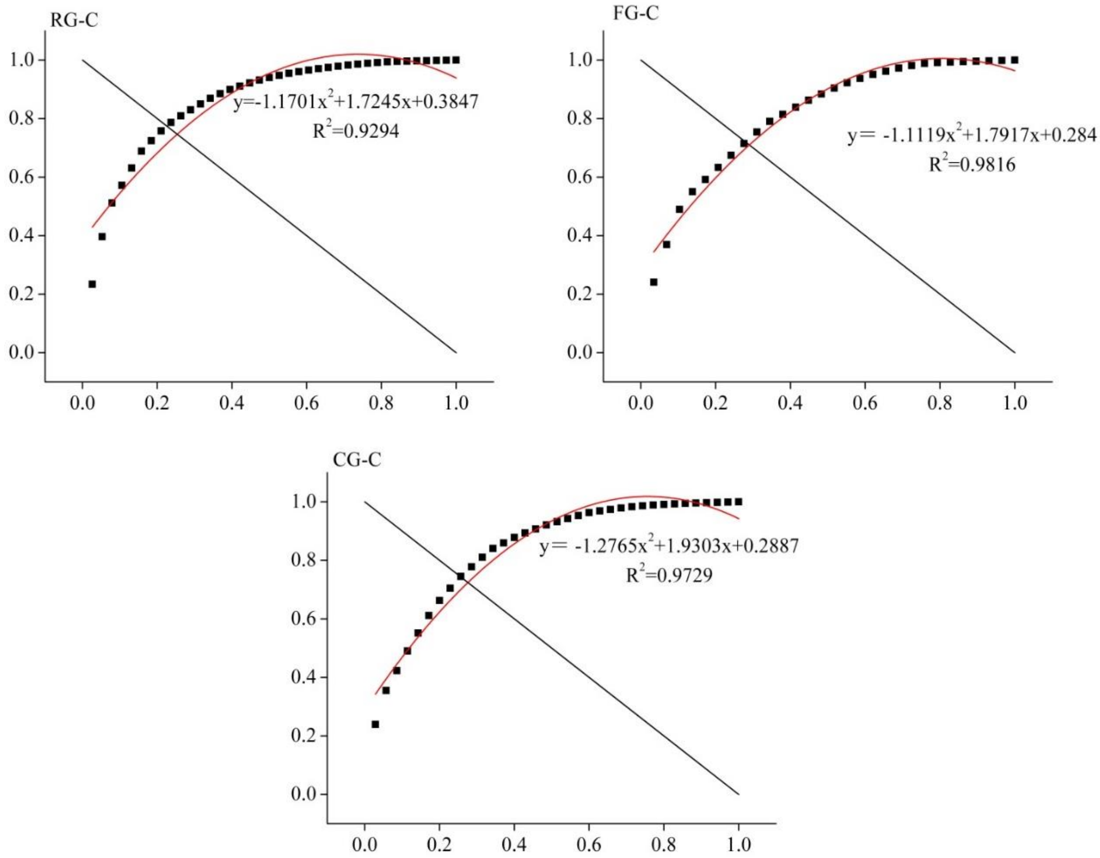

Figure 18. Stability graphs of different systems based on coverage.

Chapter 5 Discussion

5.1 Effects of different grazing systems on plant community characteristics

Herbivores can directly affect the changes in plant communities and richness because of their feeding behavior (Metera et al. 2010; Milchunas et al. 1988; Olff and Ritchie 1998a).

The results of average height, total coverage and total aboveground biomass of forbidden grazing are larger than both rotational grazing and continuous grazing, among which the average height and total aboveground biomass are significantly greater (Figure 4, 5 and 6), are the same as found in many other studies. This could be primarily due to livestock change and the impact from feeding, trampling and etc. that reduces the surface area for photosynthesis and changes the vegetation structure, hence, affecting plant community characteristics (Carrera et al. 2008; Huhta et al. 2003). Previous studies have shown that vegetation within forbidden grazing area which is not impacted by feeding and trampling, grow rampantly, hence, the average height, total aboveground biomass and species richness are significantly greater than those in the grazing areas (Deak et al. 2016; Firincioglu et al. 2007). However, some studies also pointed out that the dominant species in forbidden grazing area will directly or indirectly control the vitality of other species. Therefore, intense competition between species will suppress or eliminate other weaker species and would lower the species richness, reduce the number of shorter plants and eventually reduce the biomass (Brinkert et al. 2016; Collins et al. 1988; Grime 1977; Guo and Berry 1998; Loeser et al. 2007). This study shows that the total coverage of forbidden grazing has no significant difference with rotational grazing and continuous grazing; total individual density decreases from rotational grazing > continuous grazing > forbidden grazing; species richness decreases from continuous grazing > rotational grazing > forbidden grazing (Figure 5, 7 and 8). The above results explain that the average height, total coverage and total aboveground biomass of both rotational grazing and continuous grazing decrease, but the removal of surface and old plant tissues can induce new plant growth by providing larger growing space for weaker species and thus, increase the total individual density and species richness.

Even though the average height and total aboveground biomass of the forbidden grazing area are significantly greater than those in the grazing areas, the cumulative growth of plant height and biomass require compensatory plant growth experiments to determine the advantages in forbidden grazing and grazing areas. Grazing can have both mechanisms to suppress and enhance plant growth; and the compensatory plant growth is subjected to the net effect of suppressing and enhancing events, where, the net effect is closely related to the plant community type, grazing system, grazing intensity, environmental conditions, etc. (Oesterheld and McNaughton 1990).

The existence of significant difference in average height and total aboveground biomass between rotational grazing and continuous grazing (Figure 4 and 6) are likely the results of rotational grazing characterized by the effects of different sensitivity of grasses at different growing stages (Bai et al. 2004b), human intervention ensures the functions of ecosystem and the health of grassland to be maintained above its minimum threshold level by providing a sufficient resting period for regrowth before using the area again (Garcia et al. 2014). As a result, rotational grazing does not only increases grass production but also the stocking rate (Martin and Severson 1988). The grassland can recover if the degree of damage and richness do not exceed its ecological threshold, otherwise, grassland degradation will take place (Hao et al. 2013; Tilman et al. 1996).

5.2 Effects of different grazing systems on plant species dominance

The typical steppe of study area, where areas with different grazing systems are located, has a total of 44 species belonging to 16 families, of which families like Poaceae, Liliaceae and Asteraceae are the most abundant. Families Poaceae, Asteraceae, Liliaceae and Chenopodioideae are 18.18%, 15.91%, 13.64% and 11.36% respectively and together, they accounted for about 60%. They are followed by families Fabaceae and Brassicaceae with each accounted for 6.8% (Table 3).

Species dominance depicts the vegetation change under grazing condition and is more comprehensive and accurate than using single indexes such as plant or vegetation coverage and biomass (Wang et al. 1996). The dominance of *L. chinensis*, *S. krylovii*, *C. squarrosa*, *S. grandis* etc have high average dominance in grassland community under different grazing systems (Table 6). This is because long-term feeding and other behavioral disturbances induce changes in composition and structure of typical steppe's dominant species or dominant functional groups despite the differences in livestock feeding options, movement among different grazing systems. However, some perennial grasses such as *L. chinensis, S. krylovii, C. squarrosa, S. grandis* etc have strong adaptability. Though grazing area is heavily grazed upon, they have formed a typical steppe's unique perennial grass-dominated plant community (Fartmann et al. 2012; Kahmen and Poschlod 2004). This prove that these dominant species can maintain their strong competitive advantage and are dominant over the grassland plant community.

Besides, the dominance of *C. duriuscula, A. frigida, A. polyrhizum, A. tenuissimum* etc are relatively high in grazing areas with different grazing systems (Table 6). This indicates that the degradative succession of grassland in the study area is obvious and *C. duriuscula, A. frigida, A. polyrhizum, A. tenuissimum* and other species are more resistant to grazing (Schönbach et al. 2011). Especially the relatively high dominance for species like *C. acuminatum* and *S. collina* indicates that grassland degradation in study area is serious, resulting in an increase of annual grasses in grassland community.

Other than the succession due to grassland degradation, the intensity of selective effects of grazing is also the key factor that affect species dominance. The impacts of grazing on plant communities will ultimately be reflected in plant's composition and population structure. Grazing can affect the community structure from various aspects such as the number and growth of tiller buds (Olson and Richards 1988), spatial distribution of tiller (Briske and Butler 1989), basal area of the plant (Briske and Anderson 1990), compensatory properties between tiller density and individual size (Matthew et al. 1995) etc.

Qualitative indicator plant refers to a plant that appears (positive) or disappears (negative) when the grazing intensity exceeds a certain threshold and its occurrence can indicate the intensity of grazing (Waldhardt and Otte 2003).

Quantitative indicator plant refers to the degree of plant species dominance that are also regularly increased (positive) or decreased (negative) with the strength of grazing intensity. The degree of dominance can indicate the extent of grazing intensity. Positive indicator plant is the increaser while negative indicator plant is the decreaser (Dyksterhuis 1949).

Table 6 shows that *L. chinensis* and *S. grandis* in forbidden grazing area have higher dominance value, of which the dominance of *S. grandis* in forbidden grazing is significantly greater than rotational grazing and continuous grazing and this result conforms with the studies of An Yuan (2002) (Yuan and Han 2002), Yang Hao (2009) (Yang et al. 2009) and Li Yonghong (1993) (Li 1993). Studies have pointed out that *S. grandis* is a negative qualitative indicator plant for grazing while *L. chinensis* is a decreaser of quantitative indicator plant. With stronger grazing intensity, the dominance of *L. chinensis* and *S. grandis* tends to decline. The two plant communities in grazing grassland are seriously degenerated and become sparsely distributed remnant species due to long-term overgrazing, hence, the dominance of the two species is higher in forbidden grazing area. Matthew et al.

(1995) pointed out that the single tiller density of *S. grandis* shows a single peak growth pattern with the increase of grazing intensity within a certain range. It is useful adaptability for *S. grandis* to make up for the loss of leaf area due to grazing. Therefore, when the grazing intensity is reduced or removed, *S. grandis* can increase its biomass in a short period of time. Meanwhile, when the grazing intensity is out of the range of adaptability, the compensation characteristics disappear and the plant's aging rate and death rate accelerate (Matthew et al. 1995).

An Yuan (2002) studied the responses of *S. grandis* in different seasons to grazing and found that there is a large difference in the net primary growth during different growth seasons. During early summer, moderate grazing can stimulate the growth of *S. grandis* tillers, and it is good for removing litter, improving micro-ecological environment, increasing light and temperature of the plant base, promoting the growth of tillers and thus, increasing the net primary growth (Yuan and Han 2002). According to the equation, net accumulation of pasture = total growth – (dead weight + feed intake), Bircham and Hodgson (1983) pointed out that there are two reasons for the declining net primary growth of *S. grandis* in autumn under low grazing intensity (feed intake is relatively low): 1) decrease in total plant growth; 2) higher proportion of plant natural aging and death, whereby the effect of the latter is larger (Bircham &Hodgson,1983). Therefore, there is a suitable range of utilization rate for *S. grandis* population. By rationally utilizing *S. grandis* can reduce its rate of natural aging and death, increase its net primary growth and improve its utilization efficiency.

From the study of Li Yonghong (1994), increasing in grazing intensity gradually reducing the dominance of *L. chinensis*, which is thus a type of decreaser of quantitative indicator plants. Besides, the dominance of *L. chinensis* increases with the increase of grazing intensity before it decreases (Li 1994). Therefore, moderate grazing can promote the shooting and increase the dominance of *L. chinensis* to a certain extent though it causes plants to become smaller in size. He also pointed out that tussock of *S. grandis* has the similar results but would disappear in high grazing intensity area and would be replaced by *S. krylovii*. The results of this study show that the dominance of *S. grandis* and *L. chinensis* is larger in rotational grazing than in continuous grazing and the dominance of *S. grandis*, 1.68% in continuous grazing is much lower than *S. krylovii*, 14.13%. This phenomenon is also consistent with the above findings and theory.

Table 6 shows that the dominance of *C. duriuscula* and *A. frigida* in rotational grazing is the highest, follows by continuous grazing and lastly forbidden grazing, of which *C. duriuscula* in rotational grazing is significantly greater than continuous grazing and forbidden grazing ($p<0.05$). The dominance of *S. krylovii*, *C. acuminatum*, *C. squarrosa*, *A. polyrhizum*, *S. collina* and *A. tenuissimum* is the highest in continuous grazing area, among which the dominance of *S. krylovii, C. squarrosa*, *A. polyrhizum*, and *A. tenuissimum* in rotational grazing area is the second and the smallest in forbidden grazing area, and the dominance of other two species, *S. krylovii* and *C. squarrosa* in forbidden grazing area is the second and the smallest in rotational grazing area; the dominance of *S. krylovii* and *C. squarrosa* in continuous grazing is significantly greater than that of rotational grazing and forbidden grazing ($p<0.05$) while the dominance of *A. tenuissimum* in continuous grazing is greater than rotational grazing ($p<0.05$). These results are consistent with those indicated by Li Yonghong (1994), who pointed out that *C. duriuscula*, *A. frigida*, *S. krylovii*, *C. acuminatum*, *C. squarrosa*, *A. polyrhizum*, *S. collina* and *A. tenuissimum* are either positive qualitative indicator plants or increaser of quantitative indicator plants (Li 1994). For example, *A. frigida* found in study area, belongs to the lower layer's auxiliary species in non-degraded communities. During the degradation process, the declining of tall grasses has resulted in the increasing of the absolute amount and relative quantity of *A. frigida*'s aboveground biomass and density, eventually become the dominant species. *A. frigida* also contains monoterpene, sesquiterpene, santonin substances. Therefore, during its growing season, *A. frigida* is not preferred by those livestock. The species, *A. frigida*, has two types of reproductive methods, namely wind spread seeds and vegetative propagation of stolon and adventitious roots. Therefore, two types of roots can be formed. First, the deep root system develop by the growing of seed can grow up to 70 cm into the soil layer and second, the shallow adventitious root system which can only grow 0-30 cm into the soil layer. With the degradation of community, *A. frigida* can expands its population through two effective reproductive methods and take up resources and space with its developed root system. This allows the species to develop into a dominant population in the degraded community, hence, an increaser of quantitative indicator to indicate strong grazing intensity.

The main plant types in the typical steppe will gradually change into *A. frigida* grassland under continuous heavy grazing. Therefore, *A. frigida* plays a very important role in the study of grazing succession. However, it does not mean that *A. frigida* grassland is the last stage of degradation due to grazing. In extremely heavy grazing area, *A. frigida* will disappear too and left only with *A. polyrhizum*, *A. tenuissimum* or *C. acuminatum*, *S. collina* and other annual plants, and even bare land. *A. polyrhizum* are densely clustered by numerous closely aggregated bulbs and are vegetative propagated by tillers (Li 1994). The species root system is rather swallow and usually grow 0-20 cm into the soil uppermost layer only. Leaves are succulent with water storage tissues. If the plant water content is calculated with the formula, (fresh weight – dry weight)/ dry weight, young leaves of *L. chinensis* has water content up to 130 % only but *A. polyrhizum* has more than 300% of water. The soil uppermost layer where the root system is located is the layer where the soil water content has largest variation. Therefore, *A. polyrhizum* relies on its water storage feature and effectively resists the seasonal drought caused by uneven precipitation. This feature is not available in *C. squarrosa* though they share similar root system, vegetative propagation method and other colonization means. In addition, *A. polyrhizum* population can form a more compact block in the community and also help to maintain the relative stability of their population density (Wang et al. 2001).

The degeneration of grassland ecosystem due to the effects of grazing, has obvious adverse succession of the community. The dominance of *A. frigida* and *C. duriuscula* in rotational grazing is the highest while the dominance of *C. acuminatum*, *A. polyrhizum*, *A. tenuissimum*, *C. squarrosa* and other plants in continuous grazing is the highest. From above results, the dominance structure of three contrasting areas, the degradation degree of continuous grazing area is the largest; it is followed by rotational grazing area and lastly, forbidden grazing area. The *S. grandis* + *L. chinensis* grassland of forbidden grazing area has turned into a more grazing resistant *L. chinensis* + *C. duriuscula* + *A. frigida* + *C. squarrosa* grassland type or *C. duriuscula* + *C. squarrosa* + *A. polyrhizum* + *C. acuminatum* + *S. collina* grassland type.

It is noteworthy that all above-mentioned indicator plants, especially quantitative indicator plants, are relative to a certain type of grassland or a certain area, indicating that the indicator plants are regional (Li 1994).

5.3 Effects of different grazing systems on plant community diversity

Global change and human activities are affecting the biodiversity at an unprecedented rate throughout the world (Enrique et al. 2015; Grime 1998) and many the issues of grazing have been valued and studied in various fields (Li and Chen 1998; Wang 1996). Among them, the change pattern of species diversity is an important research direction and there have been a large number of studies on the relationship between species diversity and grazing on the community of grassland (Collins 1987; Grime 1973; Wang et al. 2001).

There are no significant differences in species richness R, Shannon-Wiener index, Pielou evenness index among the three different grazing systems. This results explains that different grazing systems across the border between China and Mongolia have not had a significant impact on the species diversity of the community. From Simpson indexes of continuous grazing and forbidden grazing which are significantly greater than that of rotational grazing ($p<0.05$), it can be seen that the diversity is developing towards the direction of significant difference (Figure 8, 9, 10 and 11).

The results show that the species richness, R, reduces from continuous grazing > rotational grazing > forbidden grazing (Figure 8), because of the grasses are preferable and largely grazed by livestock, weeds and ephemeral plants have more living space and resources to grow (Mcintyre et al. 2003). Meanwhile, the dwarfing of plant due to grazing and the plasticity of plant morphology have led to a higher species richness index in continuous grazing area and rotational grazing area than forbidden grazing area. This is in line with the findings of many previous studies (Altesor et al. 2005; Oba et al. 2001). Some scholars also believe that forbidden grazing can increase the species diversity (Akiyama and Kawamura 2007; Spence 2007; Sternberg et al. 2000) and excessive disturbance would lead to the disappearance of some species, hence, reducing the species diversity. For example, strong grazing intensity will reduce or remove the palatable pasture while forbidden grazing will increase the palatable pasture, hence, increasing the species richness and diversity (Milchunas et al. 1988). Because livestock grazing dynamically regulate the species richness of the community by altering the rate of colonization and extinction of local plant species, when the extinction rate is lower than the colonization rate, it does not reduce the local species richness. On the contrary, when the extinction rate is higher than the colonization rate, it will not only reduce the local species richness but also may lead to the extinction of the entire community (Olff and Ritchie 1998b). According to the data of this study, the highest grazing intensity in continuous grazing area has not yet reached the stage whereby many species would extinct due to high grazing intensity. On the contrary, its species richness is slightly higher than both forbidden grazing and rotational grazing areas. Although there was no significant difference in the stocking rate between rotational grazing and continuous grazing, the grazing intensity of rotational grazing is lower than continuous grazing as well as the species and communities' average height, total coverage and aboveground biomass are much higher than those of continuous grazing. However, as *A. frigida* and *C. duriuscula* are at obvious advantage, which to some extent, they suppress the usual competitive growth among the inferior species such as *A. frigida, C. duriuscula* and *C. squarrosa*, resulting in the species richness of rotational grazing lower than continuous grazing. In addition, the study area of 1,400 km^2 with similar ecological factors in the cross-border areas of China and Mongolia, which has no significant difference in grazing intensity, is also an important reason for no significant difference in species richness among the three different grazing systems.

From the result of Pielou evenness index which express the distribution of the number of individual species, the index reduces from forbidden grazing > continuous grazing > rotational grazing (Figure 11). The main reason may be that forbidden grazing area is not affected by grazing, hence, vegetation distribution is relatively even and the relationship between species is stable. In another word, the non-equilibrium among species caused by the disturbance of typical steppe vegetation due to high grazing intensity is much greater than that of the non-equilibrium among species under natural condition (Liu et al. 2017). The difference between continuous grazing and rotational grazing is mainly due to continuous grazing area has high grazing intensity, serious grassland degradation, low option of feed which force the livestock to feed on less palatable plants in great amount. Therefore, the species in continuous grazing area cannot become dominant species, which resulting in a relatively even distribution of the number of individual species in continuous grazing area.

The trend of change for Shannon-Wiener index and Simpson index is basically similar, whereby continuous grazing > forbidden grazing > rotational grazing (Figure 9). Among them, the difference of Shannon-Wiener index in the three contrasting areas is very small as the difference between the largest index of continuous grazing and the smallest index of rotational grazing is less than 0.1. This is closely related to the above selected experimental site.

In grassland ecosystem with better nutrient conditions, some research findings support the hypothesis of intermediate disturbance is mainly because: under the condition without grazing disturbance, tall plant species have absolute advantage in the community and reduce the amount of light transmitted into the lower layer of community, which restrains the increase of species diversity; moderate grazing disturbance reduces the competitive advantage of tall plant species, allowing the species of lower layer to increase significantly and thus, presenting the distribution pattern whereby both tall plant species and dwarf plant species coexist, hence, increases the species diversity; under high grazing intensity condition, the communities have only a small number of grazing resistant species, hence, significantly reduces the species diversity (Connell 1978; Gibson 2009; Milchunas and Vandever 2014). However, the typical steppe in Inner Mongolia is an ecosystem limited by both water and nitrogen, hence, the species are mainly competing for underground resources such as water and nutrients. Owing to the limitation of water and nutrients, the community coverage is relatively low and the light competition among species is weak. Grazing further reduces the community coverage and inhibits the growth of non-grazing resistant species. Therefore, the typical steppe in Inner Mongolia demonstrate a pattern whereby the species diversity decreases with the increase of grazing intensity (Bai et al. 2004a). Moderate grazing disturbance has obvious ecological thresholds for different grassland community types and different grazing intensity. In wetter grassland of Mongolian steppe, moderate disturbance happens during low or intermediate grazing intensity, which is similar to the findings of Yang (2001) and Sasaki (2008). However, the more arid typical steppe is more resistant to grazing and moderate disturbance happens only during intermediate or strong grazing intensity or the more arid typical steppe does not support the theory of moderate disturbance at all (Yang et al. 2001). From the results of this study, the

Shannon-Wiener index of continuous grazing is greater than that of forbidden grazing and rotational grazing, which further indicates that moderate disturbance of typical steppe may occurs when the grazing intensity is strong. Comparing to continuous grazing, rotational grazing has the effect of reducing grazing pressure. The communities of *S. grandis* and *L. chinensis* which have absolute advantage in forbidden grazing area, degenerate to *A. frigida*, *C. duriuscula* etc, the dominant species in rotational grazing area but the species diversity of rotational grazing is not as good as continuous grazing. However, some studies suggested that the grazing conditions will change the intensity of competition among grassland species, resulting in the exclusion of some inferior species and leading to a decrease in the community's species diversity (Sun et al. 2013).

Besides, the presence of large number of rare species is an important indicator to determine the level of biodiversity (Gaston and Kunin 1997; Mouillot et al. 2013). This is another reason why the species diversity for forbidden grazing and rotational grazing in this study are low. The small number of auxiliary species and rare species and their small distribution range besides most rare species have good palatability and thus, easily become the feed of livestock under rotational grazing, resulting in their decreasing number or even extinction. Examples are *Agropyron cristatum*, *Heteropappus altaicus*, *Allium tenuissimum* and *Allium ramosum* that are with larger leaves, higher water content and more palatable (Zheng et al. 2011). In contrast, previous studies which calculated the diversity index based on biomass data suggested that dominant species have higher biomass and thus, play a leading role in ecosystem functioning while rare species are secondary and have limited impacts on ecosystem (Kraft et al. 2011; Mouillot et al. 2013). In this study, species dominance was calculated by relative height, relative coverage, relative density and relative frequency and finally obtained the Shannon-Wiener index. The biomass data of each species were not used to calculate the diversity index. During the actual survey, continuous grazing's degree of degeneration was relatively high, degree of fragmentation of tussock grass and other plant species was large as well as the frequency and the number of individual species were higher than rotational grazing and forbidden grazing may affect the species dominance, leading to higher species diversity in continuous grazing area.

The Simpson index of forbidden grazing and continuous grazing are basically equal and they are significantly greater than that of rotational grazing ($p<0.05$) (Figure 10). This result seems to be inconsistent with the intermediate disturbance hypothesis. In fact, the feeding of livestock is a very complex ecological process. Though livestock affect species diversity, plants also react with appropriate countermeasure to limit the behavior of livestock (Wang et al. 2010). When an individual of a plant coexists with a palatable species to form a neighbor relationship, the animal is attracted by more palatable plant, thereby reducing the need to feed on that particular species (Danell et al. 1993). In typical steppe with relatively few species, *S. grandis* and *L. chinensis* are the two species at advantage. According to the dominance data in rotational grazing area, less palatable species such as *C. duriuscula* grow steadily and below it, are the plants with least palatability such as *A.*

frigida and *C. acuminatum*. Though the degrading phenomenon is more obvious in rotational grazing area, compared with continuous grazing, the dominance of *S. grandis* and *L. chinensis* is relatively high. In sheep foraging, more palatable species such as *L. chinensis* are preferentially selected, hence, gradually decrease the dominance of *S. grandis* and *L. chinensis* and gradually increase the dominance of *C. duriuscula* and *A. frigida*. Besides, when the differences in the dominance among species become large, Simpson dominance index is relatively low. Therefore, the Simpson dominance index of rotational grazing which is less than that of forbidden grazing could be due to these facts. The reason for the difference in Simpson dominance index between continuous grazing and rotational grazing are basically similar to the difference in Pielou evenness index between continuous grazing and rotational grazing, that is the grazing intensity of continuous grazing is greater than that of rotational grazing.

5.4 Effects of different grazing systems on plant functional groups

Functional groups serve as bridges to connect environment, individual plants and ecosystem structures, processes and functions (Jhc et al. 2003; Kleyer 2002) and thus, the use of functional groups for related research has become effective and convenient means.

Plant functional groups have similar responses to external disturbances and environmental impacts, with major ecological processes having similar effects on plant groups (Lavorel and Garnier 2002). Selective feeding of livestock increases the heterogeneity of habitats and thus changes the composition, structure and diversity of species communities in grassland. The changes of grassland communities then affect the structure and function of the entire ecosystem (Yang et al. 2001). Grassland productivity and community structure are largely affected by the diversity and composition of plant functional groups (Tilman et al. 2001). Precipitation, environmental changes and grazing help to increase the diversity of functional groups and the coexistence of species (Lorenzo et al. 2012).

The table 7 show that the dominance of xerophytes and intermediate mesophytes reduce from continuous grazing > forbidden grazing > rotational grazing, and the dominance of xerophytes in continuous grazing and forbidden grazing are significantly greater than rotational grazing but no significant difference between continuous grazing and forbidden grazing. The dominance of intermediate mesophytes has no significant difference among three grazing systems. The dominance of intermediate xerophytes and mesopytes reduce from rotational grazing > forbidden grazing > continuous grazing, and the dominance of intermediate xerophytes in rotational grazing is significantly greater than that of forbidden grazing and continuous grazing but no significant difference between continuous grazing and forbidden grazing. The dominance of mesophytes has no significant difference among three grazing systems. These indicate that the water-based functional groups have significant differences in areas with different grazing systems. The aridification phenomenon of continuous grazing and forbidden grazing is significantly greater than rotational grazing. The main reason could be because forbidden grazing completely excludes grazing disturbance while continuous grazing has disturbances which are too frequent and strong, which caused the two are not conducive to soil moisture retention in grassland. According to the survey data, the variables such as total aboveground biomass, total coverage and average height of rotational grazing are higher than those of continuous grazing (Figure 5 and 6). And vegetation biomass and coverage can prevent or reduce the direct exposure of soil to sun, which effectively reduce the water moisture in soil from evaporation (Yang et al. 2005). Some study also found that appropriate grazing shows greater soil respiration rate during dry season and facilitate the soil of grassland to absorb and utilize the rainwater (Hou and Hai-Hong 2011). Mongolian rotational grazing is carried out based on the pasture growth and precipitation conditions. Such moderate grazing inhibits the plants from growing too tall and promotes the growth of tillers so that the number of individuals with the same genetic units increased (Yuan and Han 2002). It also improves the utilization rate of precipitation, at the same time reduces the direct scouring effect of rainwater on plant root soil and prevent soil erosion (Li et al. 2003). If the grazing disturbances are too frequent and intense, the compensatory characteristics of many species will disappear, which accelerate the individual rate of aging and death, rapidly decrease the aboveground biomass and vegetation cover and eventually expose a large area of topsoil (Liang et al. 2009). After the surface vegetation is destructed, other than increasing the surface air flow which encourage evaporation, the strong intensity of direct sunlight as no plants are available to block or absorb some for photosynthesis, also increase the soil temperature and evaporation rate which quickly reducing the soil moisture content (Tong 2000). Besides, high trample frequency of livestock which shrink the soil pores, reduce soil respiration rate and infiltration rate, and no interception of vegetation layer have made the soil layer prone to soil erosion and decreased significantly the utilization of rainwater (Gan et al. 2012). These may lead to a seriously dry and arid soil surface layer and the entire ecological environment despite significantly increasing the dominance of species resistant to grazing and drought (Su et al. 2005).

Forbidden grazing area lacks of livestock trampling which help loosening and crushing the soil, leading to hardening of ground surface, reducing infiltration rate and causing the soil layer prone to soil erosion. Besides, lacking of animal manure in the soil causes nutrient deficiency that eventually lead to soil drought and infertility (Gao et al. 2004). Because forbidden grazing eliminates the disturbances from livestock, the protein content of pasture decline with maturity while fiber content increase with maturity. This will affect the compensatory growth of pasture, hinder the ability to directly absorb rainwater and affect the effective utilization of precipitation. Therefore, the dominance of species resistant to grazing and drought is higher in forbidden grazing area (Lintuya et al. 2008). Study also stated that forbidden grazing can increase typical steppe soil nutrient and water content so as to restrain the degradation of soil in grassland but study also pointed out that factors such as soil nutrients and moisture are affected by many grassland factors such as natural conditions, the length of forbidden grazing period, soil texture and mechanical composition etc (Su et al. 2005).

From the analysis of the dominance of living plants in areas with different grazing systems (Table 8), the dominance of perennial grass and shrubs and sub-shrubs reduce from forbidden grazing > continuous grazing > rotational grazing, of which the dominance of perennial grass in forbidden grazing and continuous grazing are significantly greater than that of rotational grazing but no significant difference between forbidden grazing and continuous grazing. The dominance of shrubs and sub-shrubs has no significant difference among the three grazing systems. The dominance of perennial weed and annual grass reduce from rotational grazing > forbidden grazing > continuous grazing, of which the dominance perennial weed in rotational grazing is significantly greater than both forbidden grazing and continuous grazing but no significant difference between forbidden grazing and continuous grazing. The dominance of annual grass has no significant difference among the three grazing systems. The main reason could be due to the grazing of livestock in rotational grazing area, which inhibit the dominant species plants such as *S. grandis* and *L. chinensis* from growing taller, hence, facilitating the dominance of perennial weed such as *A. frigida*, *C. duriuscula*, *A. polyrhizum*, *H. altaicus* and *O. mocrphylla*. On the other hand, rotational grazing reduces the grazing intensity and to a certain extent, conducive to protect vegetation coverage and increase soil water retention capacity, which resulting in a significant increase of some annual grasses such as *S. collina*, *C. acuminatum*, *A. annua*, *D. micranthus* etc.

Li Yonghong (1993) believes that the species diversity of *L. chinensis* grassland and *S. grandis* grassland on grazing intensity is determined by the community interspecific competition and the growth inhibition or promotion of grazing on different plants (Lumushanburenbayier et al. 2013). Therefore, strong community interspecific competition in forbidden grazing area inhibits the growth of most plant species, allowing *S. grandis*, *L. chinensis* and other perennial grasses to take an absolute dominance position. In areas of all three grazing systems, the dominance of perennial grass is the highest while the dominance of perennial weed is lower because many perennial weeds are being suppressed. However, shrubs such as *C. stenophylla*, *C. microphylla* etc and sub-shrubs such as *E. sinica* etc are large in size, have deep root system and strong resistant to drought, hence, are less affected. Besides, forbidden grazing which has prevented livestock feeding, has caused the dominance of shrubs and sub-shrubs species become the highest. Liu Zhongkuan (2004, 2006) believes that the longer the grassland is enclosed, the more obvious the vegetation turning into shrubs which reduce the edibility and even cause adverse succession and degradation (Liu et al. 2006b; Liu et al. 2004).

According to the studies of Zuo Xiaoan and others (2005, 2006), under the pressure of over-grazing, the grassland degenerated and the community structure tending to be simple. In all stages of degradation, the functional groups of drought-tolerant and grazing-tolerant perennial grass maintain a higher dominant position, hence, playing an important role in maintaining the ecological function of the community. At the same time, shrubs and sub-shrubs in grassland is another important manifestation of grassland degradation (Ma et al. 2012; Zhao et al. 2008; Zuo et al. 2007). These also support the results of this study that the dominance of perennial grasses and shrubs and sub-shrubs in continuous grazing area is second only to that of forbidden grazing. The aridification phenomenon in continuous grazing area and forbidden grazing area are more serious than that of rotational grazing area, hence, the dominance of annual grasses which prefer high humididty habitat, is much lower.

In addition, the survey found that the phenomenon whereby *S. grandis* is being replaced by *S. krylovii* in continuous grazing region is very obvious (Table 6). The continuous grazing system in Inner Mongolia has caused a large area of grassland being fenced into smaller area and a loss of accessibility. Therefore, the number of horses and camels which require a large area of grassland for feeding and long-distance walking as well as also prefer to feed on grasses of genus Stipa is much smaller than those in Mongolia (Table 11). Grassland with grasses of genus Stipa is usually more valuable in spring and early summer because mature caryopsis has hard and sharp branches, which often puncturing the sheep' mouth and skin, affecting their health or mix with wool and influence wool quality. Nonetheless, grassland with mature caryopsis of Stipa does not affect larger size livestock such as camels, horses and cattle from feeding. Rotational grazing can be more effectively and flexibly adjust the use of different pastures, including the grassland with grasses of genus Stipa, by different types of livestock in different season. Even though the quantity of camels, horses and other larger size livestock is rather few in Inner

Mongolia, they are still affecting the Stipa grasses and shrubs and sub-shrubs to a certain extent because of their feeding behavior, resulting in the higher dominance of *S. krylovii* and shrubs and sub-shrubs species after the degradation of *S. grandis* in continuous grazing area.

Table 11. The number of livestock in Naren and Nalan Soum in 2016.

	Naren	Nalan
Camels	62（0.02%）	677（0.31%）
Horses	1988（0.61%）	18854（8.51%）
Cattles	17415（5.33%）	11348（5.12%）
Sheep	259289（79.39%）	108902（49.13%）
Goats	47857（14.65%）	81859（36.93%）
Total	326611	221640

5.5 Effects of different grazing systems on NDVI changes

NDVI is very sensitive towards the biophysical characteristics of vegetation (Sternberg et al. 2011), as all abiotic factors such as weather, topography and soil as well as grazing intensity are generally the same in the area (Table 2), the grazing systems could be the main cause which affect the grassland ecosystem (Wang et al. 2013; Zhang et al. 2007).

Nalan Soum in Mongolia introduced private ownership of livestock from 1990 however a rotational grazing system is still the main method of livestock management. On the other hand, Inner Mongolia has had a private ownership system since 1978 but the implementation of Pasture Houshold Contract Responsibility

System in 1990 has gradually replaced the use of rotational grazing system to continuous grazing system at Naren Soum (Table 1).

From 1989 to 2016, for a period of 28 years, the average stocking rate of herders at the sampling location in Nalan Soum in Mongolia was 42 sheep per km^2 while it was 50 sheep per km^2 at Naren Soum in Inner Mongolia, with no significant difference ($p>0.05$) (Table 2).

Results from the five periods of NDVI values show that the NDVI value for the continuous grazing region is becoming lower than the rotational grazing region (Figure 12, 14, 15 and 16). Near the end of the 18th century, the theory of rotational grazing was composed by James Anderson in Scotland. After that many other scholars carried out supporting studies at various locations, i.e. rotational grazing can increase grass production and improve grassland utilization (Derner et al. 1994; Jacobo et al. 2006; Michael et al. 1990). Some studies also explain that rotational grazing can facilitate grassland recovery, increase vegetation coverage and pasture quality (Savory and Stanley 1980). Especially, choosing a suitable grazing system for different topography conditions can improve grassland utilization and prevent degradation as well as be beneficial to livestock production (Hao et al. 2013). However, Derek W. Bailey proposed that in arid and semi-arid shrub lands, timely adjustments to animal numbers and practices that improve grazing distribution at regional and landscape scales are more likely to be effective in maintaining or improving rangeland health than fencing and rotational grazing (Bailey and Brown 2011). Martin and his colleagues explain that rotational grazing can facilitate grassland recovery when the grassland is unhealthy but such effects is minimum when the grassland is healthy (Martin and Severson 1988); Heitschmidt and his team(1987), who chose cows as target animals in his experiment in Texas, found out that the impacts of rotational grazing and continuous grazing on the environment are basically similar and the differences are mainly caused by the difference in grazing intensity (Heitschmidt et al. 1987). In addition, Heitschmidt (1982) also found that different grazing seasons and grazing systems affect vegetation differently (Heitschmidt et al. 1982).

The NDVI changes of forbidden grazing and the other two grazing systems (Figure 12, 13, 14 and 16) show that forbidden grazing managed to protect the total aboveground biomass, total coverage, etc. of the area because of the same reason as that of the plant community's characteristics between forbidden grazing and the other two grazing systems as described above. The results of NDVI values have no significant difference between forbidden grazing and rotational grazing in 2005 (Figure 14). Even in 2011, in which the NDVI value of rotational grazing is larger than forbidden grazing (Figure 15), have shown that the NDVI values for the grazing regions can be larger than the forbidden grazing region under certain conditions. For instance, as the rainfall of Nalan Soum (90 mm) in 2005 was lower than the average rainfall (216.80 mm), NDVI values of the study area were relatively lower, meanwhile, the NDVI values of rotational grazing and forbidden grazing shown no significant difference. Another example is the rainfall of Nalan Soum (217.56 mm) in 2011 was higher than the average rainfall, causing the NDVI values of the study area to be relatively higher, while NDVI values of rotational grazing were higher to the NDVI values of forbidden grazing, there was no significant difference between them. This result actually supports earlier scholars who suggest that moderate grazing can increase species richness and biomass. They also pointed out that the species richness and functional diversity are greatest during moderate grazing and thus, it can ensure sustainable use of grassland as it increases the plant community's complexity and stability (Mcintyre et al. 2003; Ruifrok et al. 2014). In addition, Collins and Loeser show that long periods of forbidden grazing reduces the species richness and production of plant communities (Collins et al. 1988; Loeser et al. 2007). Together with the findings that the total individual density and species richness of forbidden grazing are lower than that of rotational grazing and continuous grazing, the results have shown that more studies are needed to identify whether forbidden grazing is better for ecosystem health.

5.6 Effects of different grazing systems on plant community stability

The concept of stability comes from the cybernetics of system, often refers to the convergence of system deviation after being disturbed by external interferences, or the value of the system deviates from the equilibrium position. Introducing the concept of stability into ecosystem research has aroused widespread controversy in the field of modern ecology. New hypotheses and views are being introduced and are constantly being denied and amended. Although there are still many disagreements to the current understanding of ecosystem stability, people have initially reached consensus on the stability of the ecosystem after a long-term development. The stability of the ecosystem includes: 1) the ability of the ecosystem to maintain its status quo, that is, the ability to resist interferences; 2) the ability of the ecosystem to return to its original state after being disrupted, that is, the ability to recover after disturbance (Ma 2002).

Even though ecologists have proposed some methods to measure the stability in their studies (Goodman 1975), they have different degrees of shortcomings and are not comprehensive and effective in evaluating the stability of the actual ecosystem. Therefore, other researchers put forward their own stability evaluation indexes for different specific ecosystems (Xiaoli et al. 2003; Zhang et al. 2006). This study evaluated the stability of ecosystem from the perspective of community. The stability of plant community is a very complex issue as it includes the community composition, function and all interference factors (Wang et al. 2006). Though many scholars have done a great deal of work, many issues are still deserving for more in-depth studies. The number of species of a community and the number of individuals in a species, to a certain extent, reflect the characteristics of the community as well as the stage of development and the degree of stability of the community. In order to comprehensively reflect the actual situation of the community stability in typical steppe in cross-border areas of China and Mongolia, this study improved the M. Godron's stability test in measuring community stability and calculated both frequency of M. Godron's community stability test and coverage of the M. Godron's community stability test.

The calculated result for frequency of the M. Godron's community stability test (Table 9 and Figure 17) shows that the stability reduces from continuous grazing > rotational grazing > forbidden grazing. Among the three contrasting areas, the area with greater species richness is relatively stable while the area with lower species richness is unstable. Such results are consistent with the experiment of Liu Jingling (2006) on grassland plant communities in the middle and eastern parts of Inner Mongolia (Liu et al. 2006a).

The calculated result for coverage stability (Table 10 and Figure 18) shows that the stability reduces from rotational grazing > continuous grazing > forbidden grazing, mainly due to the forbidden grazing has coverage greater than rotational grazing and continuous grazing (Figure 5) but there is a big difference between the coverage of each species (Figure 19). For example, the coverage of *S. grandis*, *L. chinensis*, *K. prostrata* etc in forbidden area are 25.71%, 13.71% and 12.86% respectively, of which their coverage are at absolute advantage. The coverage of other species is less than 6.44%. The species richness of both rotational grazing and continuous grazing are greater than forbidden grazing and comparing to forbidden grazing area, the coverage among species is more even, eg. rotational grazing area's dominance of *C. duriuscula*, *L. chinensis* and *A. frigida* are 23.37%, 16.20% and 11.48% respectively. In continuous grazing area, other than *S. krylovii*, 15%, and *C. squarrosa*, 7.26%, are more prominent, the coverage of other species is more even.

The difference between continuous grazing and rotational grazing may be due to the coverage of continuous grazing is significantly lower than rotational grazing (Figure 5), and greater in variation (Figure 19). For instance, the average total coverage of rotational grazing is 64.30%, with standard deviation of 9.82 while the average total coverage of continuous grazing is 56.52%, with standard deviation of 17.42. This result is similar to the result of Bai Yongfei and his colleagues (Yong and Zhong 2000).

Pimm (1984) pointed out that there is no simple correlation between diversity and stability. Zhang Dianlin et al. (2006) also found out that the correlation between diversity and stability is not significant (Dianlin et al. 2006; Pimm 1984). There are two reasons to explain this situation:

(1) The changes in dominance of structural species. When the structural species are the plant species in later stage of succession and occupies a relatively large advantage, there is a good consistency between species diversity and stability; when the plant species in early stage of succession occupies a relatively large advantage and the plant species in later stage of succession occupies less advantage, the species diversity and community stability are not consistent.

(2) Grazing disturbance. Grazing disturbance lays the foundation for the instability of the community. However, there is no simple linear relationship between species diversity and community stability but there is obvious uncertainty. Grazing can increase and decrease species diversity as well as can lead to changes in the stability of the community.

Therefore, the study of stability should emphasize on the basic and impact factors of diversity and stability. Combining species richness, species characteristics, community structure and interference factors to study the stability, thereby promoting the studies on the stability mechanism of the natural grassland.

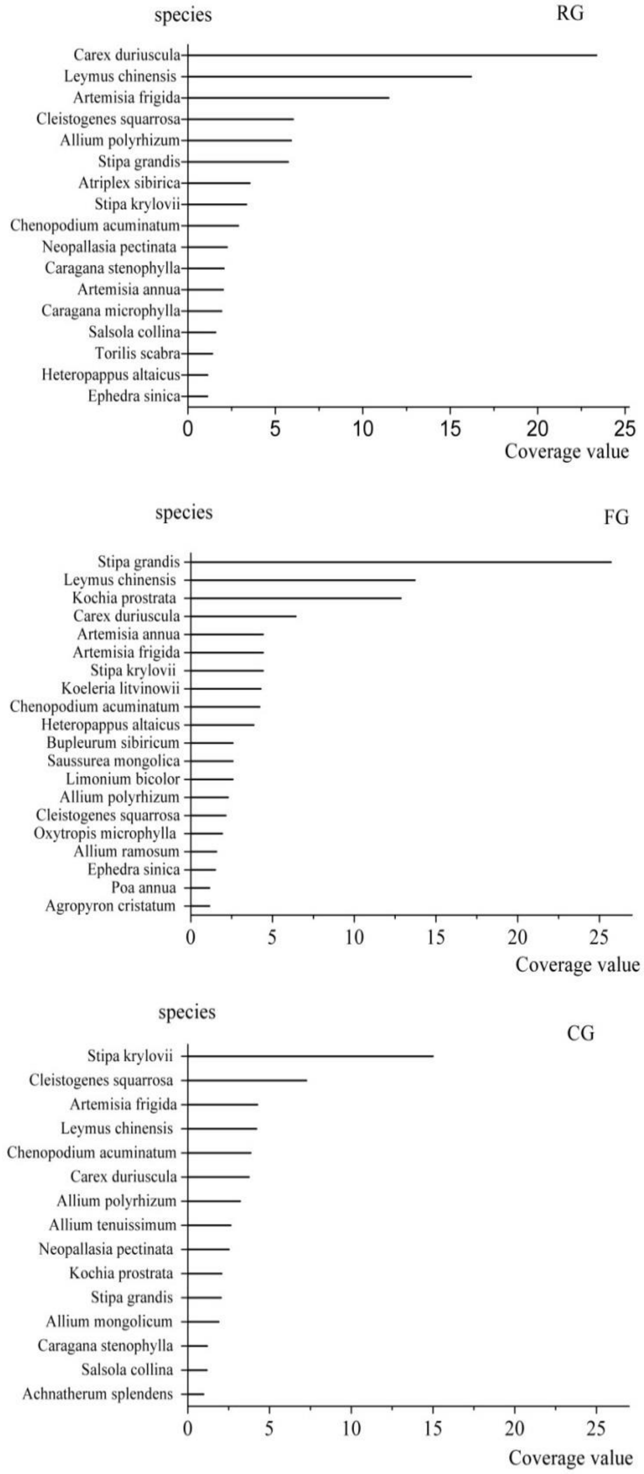

Figure 19. The coverage value of different grazing systems (Coverage value > 1%)

Chapter 6 Conclusions and remark

(1) The basic characteristics of plant community: the values of average height, total coverage and total aboveground biomass reduce from forbidden grazing > rotational grazing > continuous grazing. There are significant differences for average height and total aboveground biomass among the three grazing systems ($p<0.05$). The total coverage for forbidden grazing and rotational grazing are significantly greater than continuous grazing ($p<0.05$) but no significant difference between rotational grazing and forbidden grazing. It can clearly be seen that grazing system significantly change the basic characteristics of vegetation community in the study area. The main reason may be the behavior of livestock such as feeding and trampling that reduce the surface area of leaves which decrease the ability of photosynthesis as well as change the number and structure of pasture.

(2) The responses of 10 species with dominance greater than 3% in the entire study area to different grazing systems are analyzed and found that the effects of different grazing systems on different species are significantly different. Though the grassland degradation and adverse succession are very obvious in the study area, the typical steppe is still maintaining the perennial grass-dominated plant communities that are resistant to grazing and drought. *S. grandis* and *L. chinensis* are at absolute advantage in forbidden grazing area but their dominance reduces in rotational grazing area where *A. frigida* and *C. duriuscula* are at advantage. After *S. grandis* degenerated in continuous grazing area, *S. krylovii* is at advantage. Besides, the dominance of other species that are resistant to grazing and drought such as *C.*

acuminatum, *A. polyrhizum*, *A. tenuissimum* and *C. squarrosa* are obviously increasing in continuous grazing is the highest.

(3) There are no significant differences for species richness R, Shannon-Wiener index, Pielou evenness index among the three different grazing systems. This results explain that different grazing systems across the border between China and Mongolia have not had a significant impact on the species diversity of the community. From Simpson indexes of continuous grazing and forbidden grazing which are significantly greater than that of rotational grazing, it can be seen that the diversity is developing towards the direction of significant difference. Because of the grasses are preferable and largely grazed by livestock, weeds and ephemeral plants have more living space and resources to grow (Mcintyre S., 2003). Meanwhile, the dwarfing of plant due to grazing and the plasticity of plant morphology have led to a higher species richness index in continuous grazing area and rotational grazing area than forbidden grazing area. The Shannon-Wiener index of continuous grazing is greater than that of forbidden grazing and rotational grazing, which further indicates that moderate disturbance of typical steppe may occurs when the grazing intensity is strong. Comparing to continuous grazing, rotational grazing has the effect of reducing grazing pressure. The communities degrade from *S. grandis* and *L. chinensis* which have absolute advantage in forbidden grazing area, degenerate to *A. frigida*, *C. duriuscula* etc, the dominant species in rotational grazing area but the species diversity of rotational grazing is not as good as continuous grazing.

(4) In areas with different grazing system, the dominance of water-based functional groups and life-form functional groups are significantly different. The aridification phenomenon of continuous grazing and forbidden grazing is significantly greater than rotational grazing; the dominance of xerophytes in continuous grazing and forbidden grazing are significantly greater than rotational grazing; and the dominance of intermediate xerophytes in rotational grazing is significantly greater than that of forbidden grazing and continuous grazing. The dominance of perennial grass in forbidden grazing and continuous grazing are significantly greater than that of rotational grazing but no significant difference between forbidden grazing and continuous grazing. The dominance of perennial weed in rotational grazing is significantly greater than both forbidden grazing and continuous grazing but no significant difference between forbidden grazing and continuous grazing. Therefore, the aridification phenomenon of continuous grazing and forbidden grazing is significantly greater than rotational grazing, and then the dominance of perennial grass and shrubs and sub-shrubs species which are resistant to grazing and drought increase. The main reason may be due to a certain range of grazing intensity is more conducive for grassland to maintain its soil moisture and improve the vegetation community.

(5) Among the five periods NDVI data, the NDVI of rotational grazing in 1989, 2005, 2011 and 2016 are higher than those of continuous grazing, among which the NDVI of rotational grazing in 2011 and 2016 are significantly higher than those of continuous grazing. The results of forbidden grazing and grazing NDVI dynamics

show that forbidden grazing plays a protective role on aboveground biomass and coverage, for the same reasons as the above-mentioned basic characteristics.

(6) The calculated result for frequency of M. Godron's community stability test shows that the stability reduces from continuous grazing > rotational grazing > forbidden grazing, which manifests that the area with greater species richness is relatively stable while the area with lower species richness is unstable. The calculated result for coverage stability shows that the stability reduces from rotational grazing > continuous grazing > forbidden grazing. The total coverage may be closely related to species coverage but the stability of plant community is a very complex issue as it includes the community's composition, function and all interference factors.

Comprehensive analyses show that under the same natural conditions and grazing intensity, the results of status quo of quadrat survey and dynamic NDVI survey demonstrate that forbidden grazing area's average height, total aboveground biomass and NDVI values for most years are significantly greater than grazing areas; rotational grazing area's average height, total aboveground biomass and NDVI values for most years are higher than continuous grazing area but the cumulative growth height and cumulative biomass etc throughout the growing period in forbidden grazing area and grazing areas require plant compensatory growth experiments to distinguish the advantages of forbidden grazing area and grazing areas; community species diversity has not yet produced significant differences; because of improper grazing, the degradation and adverse succession of grassland communities are very obvious. The *S. grandis* + *L. chinensis* grassland of forbidden grazing area has turned into a more grazing resistant *L. chinensis* + *C. duriuscula* + *A. frigida* + *C. squarrosa* grassland type or *C. duriuscula* + *C. squarrosa* + *A. polyrhizum* + *C. acuminatum* + *S. collina* grassland type; the differences in functional groups are significant, the aridification phenomenon of continuous grazing and forbidden grazing is significantly greater than rotational grazing, and then the dominance of perennial grass and shrubs and sub-shrubs species which are resistant to grazing and drought increase.

These indicate that under the same natural conditions and grazing intensity, the effects of different grazing systems on typical steppe plant communities are significant and to a certain extent, the rotational grazing system is better than continuous grazing system. However, due to the differences in vegetation type, grazing intensity, grazing period, livestock type and proportion and other environmental conditions, the impact of grazing systems on plant community is rather complicated. Therefore, in-depth researches from various aspects and angles that combine spatial differences, community species structure, interspecies relationship etc and utilize multiple research methods such as correlation analysis and principal component analysis are needed in the near future.

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放牧システムがステップ(典型草原)の植物群落への影響－モンゴル国遊牧地域と内モンゴル自治区定住地域の例として

NAYINTAI (食生産利用科学)

【目的】

1）同じ自然条件下での異なる放牧システムの植物群落への影響を明らかにすること；

2）モンゴル高原典型草原の草地劣化の原因解明

【手法】

土地の退化と砂漠化は土地の生物生産力を急激に低下させ、地球規模の深刻な生態と環境問題を引き起こしている．近年、アジア内陸から頻繁に発生するようになった黄砂も草原の退化と砂漠化が主な原因であることが明らかになった．本論文は、こうした地域、および地球規模の環境問題を引き起こしているモンゴル高原を対象とし、遊牧型と定住型の二つの異なる放牧システムの草原植物群落（草原劣化）への影響を明らかにすることを研究の目的とした．そのために，モンゴル国と中国(内モンゴル自治区)国境に跨る典型草原ステップ地域を調査地として選定し、基本的に同じ自然条件（気温・降水量・土壌と地形的要素）下の２つの隣接するソム（モンゴル語：町レベルの行政区域のこと）内において、それぞれ１つの調査用のサイトを設置し、また対象区として国境沿いに１つのサイト、合計３つのサイトで，（1m×1m）コドラートを計 61 箇所設けて、植物群落のサイト間の差を計測してフィールド検証を行った．三つのサイトにおける植物種の同定と生態的機能（Ecosystem function, ecosystem vitality）の同定を行うために、種の多様性（種数）、草丈、被度、個体数、地上バイオマス、土壌水分、植物のスペクトルなどの計測を行い、さらに時系列のランドサット（３０m分解能）の人工衛星データから正規化植生指数（NDVI）を算出し、植生被覆状態の長期変動を求め，グランドツルーツデータと衛星データの解析によって，放牧システムがステップ(典型草原)の植物群落への影響を明らかにした．

全文は６章で構成された．

【結果】

研究結果として、

１）コドラート調査の結果　植物群落のサイト平均草丈・トータル植被率(被度)・および地上バイオマスはそれぞれ：対象区（国境沿いの禁牧区：７プロット）　＞　遊牧区（モンゴル国サイト：２７プロット）　＞　定住型放牧区（内モンゴルサイト：２７プロット）順に減少していることが明らかに

なった．この三つのサイトでは植物群落のサイト平均草丈と地上バイオマスに統計学的な有意差（P < 0.05）が認められた．ただし、トータル植比率においてそれぞれ対象区と遊牧区の方が定住区より大きい結果となり、両者の間に有意差（P < 0.05）が認められたが、遊牧区と定住区の間では有意差が認められなかった．

２）植物群落の指標種　草原劣化は嗜好性の出現頻度や劣化指標種の出現頻度で定量的評価することが可能である．優先度が３％より大きい１０種の植物群落を選び比較したところ、それぞれの異なる放牧システム（禁牧区・遊牧区・定住区）において顕著な応答があった．全域において草原の退化（植物群落の劣化）が明確だが、典型草原ステップとしての耐乾性の多年生のイネ科の植物が優先している群落が維持されていることに変化はなく、対象区ではイネ科の優良牧草の大針茅（stipa grandis）と Leymus chinensis. (Trin.) Tzvel.(シバムギモドキ・イネ科:優良牧草)が優先しているのに対して、遊牧区では Artemisia frigida Willd.(冷蒿)と Carex duriuscula C.A.Mey (ノヤマスゲ・カヤツリグサ科:草原退化の指標植生)が優先し、定住区ではイネ科の優良牧草の大針茅（stipa grandis）から同じイネ科の優良牧草の Stipa krylovii. Roshev.が優先する草原に交替されていた．また、定住区ではほかにアカザ科の Chenopodium acuminatum Willd.、Allium polyrhizum、Allium tenuissimum、および Cleistogenes squarrosa (Trin.) Keng.などの嗜好性のない耐乾性の植物が増加傾向にあった．もともと定住区の草原では大針茅（Stipa grandis）と Stipa krylovii. Roshev.が多く分布し、遊牧区では Artemisia frigida Willd.(冷蒿)と Carex duriuscula C.A.Mey (ノヤマスゲ・カヤツリグサ科)が多く分布していた．

３）種の多様性指数　種の豊富さ（Species richness）指数（Ｒ），Shannon-Wiener 指数（Ｈ）、および均等度指数（Pielou's evenness index）（Ｊ’）の 3 つの指数を用いて、３つのサイトにおける植物群落の種の多様性を評価したところ、いずれも有意差が認められなかった．これにより、モンゴル国の遊牧区と内モンゴルの定住区では異なる放牧型による種の多様性の影響は顕著ではないことを示し、この地域ではまだ放牧圧の植物生態系への影響は限定的であることを示唆した．ただし、Simpson の多様度指数を用いて計算したところ、遊牧区より対象区と定住区の方が大きいことを示し、両者の値に有意さ認められた．つまり、遊牧区では植物の種の分布が偏って分布し、定住区と禁牧区では比較的均等分布していることを示した．一般的に、放牧圧が低い地区では非均等に分布し、放牧圧が高い地区では均等分布傾向がある．しかし、本研究では禁牧区も遊牧区より Simpson の多様度指数（1-λ）が高い傾向を示したため、放牧圧以外のほかの要因があると考えられる．例えば、モンゴルガゼルによる禁牧区（無人地帯）での採食の影響などが考えられる．

４）植物生態系の機能　植物生態系の機能を評価するために、研究地の植物生態系を植性機能による異なる群落（plant species with different functional groups）に分類した．主に水分型・生活型（water-based functional groups and life-form functional groups）に分類し、水分型では半湿生型・半乾生型・乾生型・極乾生型などに分類し；生活型では一年生・多年生・草本・半草本・潅木などに分類した．その結果、水分型では：定住区と対象区の植物群落は乾生型が支配的であり、遊牧区の群落は半乾生型（または半湿潤型）が支配的である；生活型では：定住区と対象区は多年生のイネ科の草本植物群落で構成され、遊牧区は多年生の潅木（イネ科以外）で主に構成されている．定住区と対象区の間では生態系の機能として生活型の有意差（$P<0.05$）が認められなかった．

５）時系列人工衛星データの解析結果　５時期の夏季のランドサット衛星（30ｍ解像度）データから計算されたサイト平均正規化植生指数（NDVI）を比較したところ、1990 年代初期の内モンゴル側の定住型放牧が始まってから 10 数年経った 2005 年ごろ、遊牧区と定住区では顕著な差があることが認められ、特に湿潤な年である 2011 年では、その差は有意であり、顕著であった．つまり、湿潤な年でも定住区では植生の回復が見られないと言うことは、土壌のシードバック（種）まで影響が及んでいる可能性があると示唆された．1989 年に比べて、2005 年、2011 年と 2016 年の平均 NDVI の値が遊牧区の方が定住区より高い結果となった．その中でも特に、2011 年と 2016 年の値の差に有意差（$P<0.05$）が認められ、遊牧区の方が定住区より全体的に高い値を示した．

６）生態系安定性指数（M. Godron’s Community Stability test）植物群落の M. Godron’s 安定性テストでは：　定住区　>　遊牧区　>　対象区　となった．ただし、植比率の M. Godron’s 安定性テストでは：遊牧区　>　定住区>　対象区となった．

考察として、植物群落の基本構成、優先種の特性、種の多様性、植物群落の機能、植物群落の安定性、および衛星植生指数(NDVI)などを指標として、異なる放牧システムの植物群落への影響について考察した．本研究の対象地域は国境の緩衝地帯であるために、比較的に人口密度や家畜密度が小さい．家畜放牧という人間活動の自然植物群落への影響は限定的あることを論じた上，降水量が少ない・土壌が疲弊して，植比率が乏しい脆弱生態系である乾燥・半乾燥のゴビ・砂漠地域では伝統的な遊牧型放牧が定住型放牧より草原に与えるインパクトが小さいことが明らかなった．

結論として、同じ自然条件と放牧の度合い(grazing pressure)の下で、それぞれの放牧方式が典型草原ステップの植物群落に大きな影響を及ぼしているものの、モンゴル国側の伝統的な遊牧方式による影響は現在の内モンゴルの定

住型の連続放牧方式より土地に対するプレシャーが小さく、植物群落に優しくて，その影響は種の多様性までは及んでいないものの，草丈、被度、地上バイオマス、群落密度、および NDVI 値間で顕著な差があることが認められた．主な結果を Journal of Land と ROH Journal(Research of One Health)上で公開し、この地域における政策の決定や科学研究のための基礎データを提供することができた.

Appendices

Study area

Grassland in Mongolia

Grassland at the border

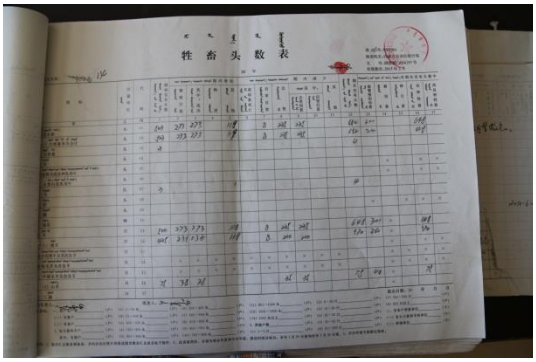
Grassland in Inner Mongolia

Dinner in grassland

Collecting grass for biomass

Interviewing the pastoralists

Measuring biomass at the field



Recording data


Collecting soil data


Unfenced grassland


Fenced grassland


Horses in Mongolia


Settlement in Inner Mongolia


Water pumping from spring


Pastoralist family in Inner Mongolia

Randomization test process:

$Height

$Height$FGvsRG

Asymptotic General Independence Test

data: Height by GrazingSystem (FG, RG)

Z = 2.3633, p-value = 0.01811

alternative hypothesis: two.sided

$Height$CGvsRG

Asymptotic General Independence Test

data: Height by GrazingSystem (CG, RG)

Z = -3.9776, p-value = 6.962e-05

alternative hypothesis: two.sided

$Height$CGvsFG

Asymptotic General Independence Test

data: Height by GrazingSystem (CG, FG)

Z = -4.8709, p-value = 1.111e-06

alternative hypothesis: two.sided

$Biomass

$Biomass$FGvsRG

Asymptotic General Independence Test

data: Biomass by GrazingSystem (FG, RG)

Z = 2.6364, p-value = 0.00838

alternative hypothesis: two.sided

$Biomass$CGvsRG

Asymptotic General Independence Test

data: Biomass by GrazingSystem (CG, RG)

Z = -4.3577, p-value = 1.314e-05

alternative hypothesis: two.sided

$Biomass$CGvsFG

Asymptotic General Independence Test

data: Biomass by GrazingSystem (CG, FG)

Z = -4.5567, p-value = 5.195e-06

alternative hypothesis: two.sided

$Density

$Density$FGvsRG

Asymptotic General Independence Test

data: Density by GrazingSystem (FG, RG)

Z = -2.3135, p-value = 0.0207

alternative hypothesis: two.sided

$Density$CGvsRG

Asymptotic General Independence Test

data: Density by GrazingSystem (CG, RG)

Z = -2.474, p-value = 0.01336

alternative hypothesis: two.sided

$Density$CGvsFG

Asymptotic General Independence Test

data: Density by GrazingSystem (CG, FG)

Z = 1.3933, p-value = 0.1635

alternative hypothesis: two.sided

$Coverage

$Coverage$FGvsRG

Asymptotic General Independence Test

data: Coverage by GrazingSystem (FG, RG)

Z = 0.90041, p-value = 0.3679

alternative hypothesis: two.sided

$Coverage$CGvsRG

Asymptotic General Independence Test

data: Coverage by GrazingSystem (CG, RG)

Z = -1.9658, p-value = 0.04933

alternative hypothesis: two.sided

$Coverage$CGvsFG

Asymptotic General Independence Test

data: Coverage by GrazingSystem (CG, FG)

Z = -1.6291, p-value = 0.1033

alternative hypothesis: two.sided

$Richness

$Richness$FGvsRG

Asymptotic General Independence Test

data: Richness by GrazingSystem (FG, RG)

Z = -0.57569, p-value = 0.5648

alternative hypothesis: two.sided

$Richness$CGvsRG

Asymptotic General Independence Test

data: Richness by GrazingSystem (CG, RG)

Z = 0.16107, p-value = 0.872

alternative hypothesis: two.sided

$Richness$CGvsFG

Asymptotic General Independence Test

data: Richness by GrazingSystem (CG, FG)

Z = 1.0971, p-value = 0.2726

alternative hypothesis: two.sided

$NDVI1989

$NDVI1989$FGvsRG

Asymptotic General Independence Test

data: NDVI1989 by GrazingSystem (FG, RG)

Z = 2.3749, p-value = 0.01755

alternative hypothesis: two.sided

$NDVI1989$CGvsRG

Asymptotic General Independence Test

data: NDVI1989 by GrazingSystem (CG, RG)

Z = -1.5324, p-value = 0.1254

alternative hypothesis: two.sided

$NDVI1989$CGvsFG

Asymptotic General Independence Test

data: NDVI1989 by GrazingSystem (CG, FG)

Z = -3.6268, p-value = 0.0002869

alternative hypothesis: two.sided

$NDVI1993

$NDVI1993$FGvsRG

Asymptotic General Independence Test

data: NDVI1993 by GrazingSystem (FG, RG)

Z = 2.0188, p-value = 0.04351

alternative hypothesis: two.sided

$NDVI1993$CGvsRG

Asymptotic General Independence Test

data: NDVI1993 by GrazingSystem (CG, RG)

Z = 0.60701, p-value = 0.5438

alternative hypothesis: two.sided

$NDVI1993$CGvsFG

Asymptotic General Independence Test

data: NDVI1993 by GrazingSystem (CG, FG)

Z = -1.7393, p-value = 0.08198

alternative hypothesis: two.sided

$NDVI2005

$NDVI2005$FGvsRG

Asymptotic General Independence Test

data: NDVI2005 by GrazingSystem (FG, RG)

Z = 0.83487, p-value = 0.4038

alternative hypothesis: two.sided

$NDVI2005$CGvsRG

Asymptotic General Independence Test

data: NDVI2005 by GrazingSystem (CG, RG)

Z = -1.2148, p-value = 0.2245

alternative hypothesis: two.sided

$NDVI2005$CGvsFG

Asymptotic General Independence Test

data: NDVI2005 by GrazingSystem (CG, FG)

Z = -2.2331, p-value = 0.02554

alternative hypothesis: two.sided

$NDVI2011

$NDVI2011$FGvsRG

Asymptotic General Independence Test

data: NDVI2011 by GrazingSystem (FG, RG)

Z = -0.13156, p-value = 0.8953

alternative hypothesis: two.sided

$NDVI2011$CGvsRG

Asymptotic General Independence Test

data: NDVI2011 by GrazingSystem (CG, RG)

Z = -4.4006, p-value = 1.08e-05

alternative hypothesis: two.sided

$NDVI2011$CGvsFG

Asymptotic General Independence Test

data: NDVI2011 by GrazingSystem (CG, FG)

Z = -2.9458, p-value = 0.003221

alternative hypothesis: two.sided

$NDVI2016

$NDVI2016$FGvsRG

Asymptotic General Independence Test

data: NDVI2016 by GrazingSystem (FG, RG)

Z = 3.2085, p-value = 0.001334

alternative hypothesis: two.sided

$NDVI2016$CGvsRG

Asymptotic General Independence Test

data: NDVI2016 by GrazingSystem (CG, RG)

Z = -2.1492, p-value = 0.03162

alternative hypothesis: two.sided

$NDVI2016$CGvsFG

Asymptotic General Independence Test

data: NDVI2016 by GrazingSystem (CG, FG)

Z = -4.5274, p-value = 5.97e-06

```
alternative hypothesis: two.sided
> independence_test(formula = Precipitation ~ Location, data = df_1)
        Asymptotic General Independence Test
data:  Precipitation by Location (Nalan, Naren)
Z = -0.4947, p-value = 0.6208
alternative hypothesis: two.sided
> independence_test(formula = Temperature ~ Location, data = df_2)
        Asymptotic General Independence Test
data:  Temperature by Location (Nalan, Naren)
Z = 1.7741, p-value = 0.07605
alternative hypothesis: two.sided
> independence_test(formula = Altitude ~ Location, data = df_3)
        Asymptotic General Independence Test
data:  Altitude by Location (Nalan, Naren)
Z = 0.58784, p-value = 0.5566
alternative hypothesis: two.sided
> independence_test(formula = SoilHumidity ~ Location, data = df_4)
        Asymptotic General Independence Test
data:  SoilHumidity by Location (Nalan, Naren)
Z = 0.80067, p-value = 0.4233
alternative hypothesis: two.sided
> independence_test(formula = Evaporation ~ Location, data = df_5)
        Asymptotic General Independence Test
data:  Evaporation by Location (Nalan, Naren)
Z = 0.25577, p-value = 0.7981
alternative hypothesis: two.sided
> independence_test(formula = Stocking ~ Location, data = df_6)
        Asymptotic General Independence Test
data:  Stocking by Location (Nalan, Naren)
Z = -1.6779, p-value = 0.09337
alternative hypothesis: two.sided
```