Relationship of Plant Species Diversity and Sampling Area Under Different Grazing Intensities in the Steppe of Northern China

Zhang, Wei hua; Chen, Chao; Huang, Ding; Arshad, Muhammad Naveed; Wang, Li xue

Published in:
Rangeland Ecology and Management

DOI:
10.1016/j.rama.2023.01.004

Publication date:
2023

Citation for published version (APA):
Zhang, W. H., Chen, C., Huang, D., Arshad, M. N., & Wang, L. X. (2023). Relationship of Plant Species Diversity and Sampling Area Under Different Grazing Intensities in the Steppe of Northern China. *Rangeland Ecology and Management*, *87*, 150-157. https://doi.org/10.1016/j.rama.2023.01.004

Relationship of Plant Species Diversity and Sampling Area under Different Grazing Intensities in the Steppe

Zhang Wei-hua[1,5], Chen Chao[2,3*], Huang Ding[3,4†], Muhammad Naveed Arshad[6], Wang Li-xue[3,7]

1. Institute of Land Engineering Technology, Shaanxi Provincial Land Engineering Construction Group, Xi'an 710075 P.R. China; 2. Institute of Grassland, Flowers and Ecology, Beijing Academy of Agriculture and Forestry Sciences, Beijing 100097 P.R. China; 3. Grassland Department of China Agricultural University, Beijing 100193 P.R. China; 4. National Field Station for Grassland Ecosystem, Guyuan 076550, China; 5. College of Resources and Environment, China Agricultural University, Beijing 100193 P.R. China; 6. Institute of Biological, Environmental and Rural Sciences (IBERS), Aberystwyth University, Wales, SY23 3EB UK; 7. Research Group of Forage Grass, Tianjin Academy of Agricultural Science, Tianjin 300384 P.R. China

ABSTRACT: The relationship between sampling area of plant community and number of species contained in it has an importance in vegetation ecology. Using nested quadrat survey, the relationship between plant species and sampling area were discussed under different grazing pressure in the steppe, and also the determination of minimum sampling area was calculated herein. Ten curve models were selected to fit the species-area relation of plant community in a typical steppe of North China. The residual standard deviation (RSE), correlation index (CRI), average value of absolute deviation (AAD) and average value of absolute relative deviation (AARD) were used as the evaluation indexes for model fitting. The results show that the curve equations $S=B+CA^Z$ and $S=C(1-e^{-BA})^Z$ have the best simulation effect. According to the simulation results, the minimum sampling areas are determined as 1.16 m^2 (T0), 1.23 m^2 (T7), 1.28 m^2 (T10), and 1.10 m^2 (T14), presenting the minimum sampling area is feasible when the second derivative is zero. Generally, sheep grazing reduced the species richness of steppe though some of the plans flourished whilst some others disappeared or dismissed, but increased spatial heterogeneity, especially on a smaller scale. However, there are also variance in different area scales and grazing intensities. When

---

[*]This work was supported by "Special Fund for Agro-scientific Research in the Public Interest (201203062)". First author, Wei-hua Zhang, E-mail: zhangwh.sdj@foxmail.com; corresponding author, Chao Chen, E-mail: xiaoyingwulu@163.com/chenchao@grass-env.com;
[†]Ding Huang contributed equally as corresponding author, E-mail: huangding@263.net.

the sampling area was small (< $2m^2$), heavy grazing T14 increased the number of plant species per unit area; yet light grazing T8 reduced the number of plant species per unit area of steppe. When the sampling area was large (> $16m^2$), grazing reduced the number of plant species per unit area in natural steppe. Anyhow, the effect of grazing intensity on plant species fluctuated greatly when the sampling area was medium (2 m^2 ~ 16 m^2). In general, the similarity of plant communities had an increasing trend with accumulated sampling area, though it varied at different grazing intensities.

Key Words: Grazing intensity; Sampling area; Species-area curve; Steppe

Introduction

The relationship between the number of species and sampling area has always been an important issue discussed in vegetation ecology. Species-area relationship, also known as species-area curves, is the basis of ecological investigation and research, and many ecology problems can be solved by using species-area relationship (Drakare et al. 2006; Zhou et al. 2016; DeMalach et al. 2019; Matthews et al. 2021). For example, the number of species in the community can be estimated by using species-area curve (Williams 1943; Caprariis et al. 1976; Bunge and Fitzpatrick 1993; Liu et al. 1999); and the species-area curve can also be used to determine the minimum sampling area of the community (Barkman 1989; Liu et al. 1999; Navarro-Rosales and Bell 2022) and evaluate the change of plant biodiversity (Malcolm et al. 2006; Vellend et al. 2013; Chisholm et al. 2018). Many researches on the relationship between plant species richness and sampling area have been carried out in various plant community types, including natural forests (Chen et al. 2019), artificial forests (Liu et al. 1999), shrub communities (Chen et al. 2007), subalpine meadow (An 2010; Zhang et al. 2013), artificial forage community (Tang et al. 2005) and fragmented landscapes (Chisholm et al. 2018), as well as on the relationship between plant species and sampling area under different grassland utilization modes

(Zhuo et al. 2013). However, there are relatively fewer studies focusing on the changes of plant communities along sampling area gradient under different grazing intensities in the steppe (Wang et al. 2010; Han 2018), though grazing is the main reason of rangeland degradation in the region (Khishigbayar et al. 2015; Munkhzul et al. 2021). The effect of grazing that affected the spatial heterogeneity of grasslands on a large scale was well discussed, but the effect of sampling scale was relatively less discussed, especially on a smaller scale in the steppe. Thus, a sheep grazing experiment was conducted to determine the effect of animal grazing pressure on the changes of plant communities in a frail system of steppe that was susceptible to grazing, especially on a relatively smaller scale. Meanwhile, the minimum sampling area was also referred in the study, in order to discuss the effect of grazing pressure on plant community composition. For the minimum sampling area, it is the area required to provide sufficient environmental space (environmental and biological characteristics) for a specific community type in the minimum section, or to ensure the true characteristics of the species composition and structure of the community type (Wang et al. 1996). Similar to the researches of species-area relationship, there was less studies focus on the changes of minimum sampling area under different grazing gradient in the steppe; though a series of studies considered minimum sampling area under different types of plant communities adjacent to the steppe (Tang et al. 2005; Chen et al. 2007; Zhuo et al. 2013). Thus, by model fitting, the minimum sampling area was calculated, in order to provide basic advice for grazing management and researches on grassland ecology in the steppe.

Materials and methods

Overview of study area

The study area is located at the National Field Station for Grassland Ecosystems (41°46’ N, 115°40’ E, elevation 1, 380～1, 460 m) in the ecotone of Northern China, Hebei province. Steppe is the main vegetation type in the experimental area, low humidity meadow, saline alkali grassland and sandy grassland are also scattered in this region. *Leymus chinensis*, *Stipa krylovii*, *Carex duriuscula*, and Artemisia spp.

(including *A. scoparia*, *A. lavandulaefolia*, *A. brachyloba*, *A. desertorum*, *A. tanacetifolia*) are the dominant plants in the grassland; in addition, there are halobiotic species, such as *Iris lactea* var. *chinesis*, *Saussurea runcinate*, *Suaeda salsa*, *Halerpestes ruthenica*, as well as some biennials and annuals, *Atriplex sibirica*, *Atriplex centralasiatica*, *Chenopodium ficifolium*, *Dysphania aristata*, *Lepidium apetalum*, *Suaeda glauca*, and so on. Vegetation coverage varies greatly, ranging from 30.0% of overgrazing grassland to 85.0% in low humidity meadow. Consistently, soil type distributed dominantly with kastanozems soil, along with sandy loam and meadow soils. The average annual precipitation in this area is 300～450 mm and the annual mean temperature is 1 °C, ranging from -18.6 °C in January to 17.6 °C in July.

Experiment design and survey method

Enclosed fence was set to isolate sheep in different experimental groups, while healthy sheep were purchased and selected for a uniform weight according to the requirement of the experiment, around 45 kg at the beginning. Due to grazing pressure, sheep quantity was designed as different grazing gradients, namely T0 (control), T7 (light grazing), T10 (moderate grazing), and T14 (heavy grazing) (Table 1). The plot area was 150 m×100 m, selective grazing for 30 days in spring, 60 days in summer and 30 days in autumn lasted for a total of 4 months. Accordingly, the grazing gradient is converted by combining the number of sheep or sheep unit, which standardized that 1.8 kg hay with the water content of 14% and crude protein content of 8-10% was daily fed to an adult ewe weighted 50kg with lambs (NY/T 3647-2020).

Nested quadrat survey was conducted on steppe grassland under different grazing gradients. The sampling area of nested quadrat varied from 1/64m^2, 1/32m^2, 1/16m^2, 1/8m^2, 1/4m^2, 1/2m^2, 1 m^2, 2 m^2, 4 m^2, 8 m^2, 16 m^2, 32 m^2, 64 m^2, to 128 m^2. Among them, the area of 128 m^2 is used as the detection of the curve. The survey sequence is shown in the figure below (Fig. 1).

Data analysis

Ten model curves were selected as the fitting models of species area curves, which are (1) Linear equation, $S=Z+CA$; (2) Quadratic equation, $S=Z+CA+BA^2$; (3)

Logarithmic formulation, $S=Cln(A)+Z$; (4) Second-order Logarithmic formulation, $S=Z+ClnA+B(lnA)^2$; (5) Power function, $S=CA^Z$; (6) Modified-power function, $S=B+CA^Z$; (7) Hyperbola equation, $S=CA/(1+BA)$; (8) Sigmoid function, $S=B/(1+e^{(A-C)/Z})$; (9) Chapman-Richards growth function, $S=C(1-e^{-BA)}Z$; (10) The exponential gives rise to maximum, $S=Z+B(1-e^{-CA})$.

Both the first-order linear model (1) and the second-order polynomial model (2) are simple growth models, in which (1) the number of species increased per unit area is fixed; Logarithmic models (3) and (4) are widely used growth models. Parameter Z is the number of species per unit area, and C and B are the number of species increased when the area is expanded by "e" or "e^2" times; Power function model (5) and its improved model (6) are the most widely used growth models, which can well describe the species-area relationship on multiple scales. Parameter C is the number of species per unit area, parameter Z is a measure of spatial heterogeneity, and parameter B is an adjustment parameter; Hyperbolic model (7) was introduced by de Caprariis (1976) to quantitatively study the suitable sampling area of a given lithologic unit or fossil community. In this model, when the sampling area is 0, the number of species is also 0, and when the sampling area approaches infinity, the number of species will approach C/Z; Both ordinary inverse curve model (8) and Chapman inverse curve model (9) are single increase curve models, which have the potential to be used as species-area estimation curve; The exponential model (10) is a fitting curve between the sampling area and the number of vascular plant species verified by Miller and Weigert (1989).

Where a is the area, s is the number of plant species in a, and C, Z and B are the parameters in the model, e.g., appropriate constants. The linear model of parameters is solved by linear least square method; the nonlinear model of parameters is solved by Gauss Newton's nonlinear least square method. The residual standard deviation (RSE), correlation index (CRI), average value of absolute deviation (AAD) and average value of absolute relative deviation (AARD) are used as four evaluation indexes for the goodness of model fitting. The larger the CRI and the smaller the RSE, AAD and AARD, the better the fitting effect of the model.

$$\mathrm{RSE} = \overline{\frac{\mathrm{Q}}{\mathrm{n-k-1}}};$$

$$\mathrm{CRI} = 1 - \frac{(\mathrm{n}-1)\mathrm{Q}}{(\mathrm{n}-\mathrm{k})TSS};$$

$$\mathrm{AAD} = \frac{1}{\mathrm{n}}\sum_{\mathrm{i}=1}^{\mathrm{n}}|Si - Sti|;$$

$$\mathrm{AARD} = \frac{1}{\mathrm{n}}\sum_{\mathrm{i}=1}^{\mathrm{n}}\left|\frac{Si - Sti}{Si}\right|。$$

$Q = \sum_{i=1}^{n}(S_i - S_{ti})^2$, $\mathrm{TSS} = \sum_{i=1}^{n}(S_i - S_a)^2$, $S_a = \frac{1}{n}\sum_{i=1}^{n} S_i$;

Where S_i and S_{ti} are the observed value and the number of species calculated by the equation respectively, S_a is the average value of Si, *n* is the sample content, and *K* is the number of parameters in the model. The smaller the average of residual standard deviation, absolute deviation and relative deviation, the better the fitting effect of the model; the larger the correlation index, the better the fitting effect of the model. Select the optimal curve equation and calculate the first and second derivatives of the curve, so as to calculate the curvature of each point of the curve. When the curvature is the largest, it is the increasing turning point of the area species curve.

Curvature formula, $\mathrm{K} = \frac{|y''|}{(1+y'^2)^{3/2}}$

Where y' is the first derivative of the optimal equation, y'' is the second derivative of the optimal curve, and K is the curvature of the optimal curve.

The Jaccard index (C_J) was used to calculate the similarity of community,

$C_J = j/(a+b-j)$

Where *j* is the common species of plant communities *a* and *b*, and *a* and *b* are the species of corresponding plant communities, respectively. Meantime, the minimum area of plant community was measured by the proportion method of total species of plant community (84%, CEPE).

Excel 2010 and SAS 9.1.3 are used for data processing and analysis respectively, and Matlab 9.0 is used for data processing 2.0 calculate the first and second derivatives of the curve and draw it with Sigma plot 12.5.

Results

Changes of plant community under different grazing pressure

The results showed the number of plant species increased with accumulated sampling area in the mode of exponential growth, but obviously sheep grazing reduced the abundance of plant species in the steppe grassland (Fig. 2). Anyhow, there are variabilities due to the scale of sampling area and grazing intensity. When the sampling area was smaller than $2m^2$, the number of plant species per unit area increased with grazing intensity, with a maximum number under heavy grazing T14; on the contrary, it had a minimum value under light grazing T7; moderate grazing T10 contributed less effect on the number of plant species, presenting a similar trend to control T0. When the sampling area is larger than $16m^2$, it showed that sheep grazing reduced the number of plant species under all the grazing treatments in the steppe ($P<0.05$), and the differences between the three grazing treatments and control T0 continued to expand with the increase of the sampling area. Compared with control T0, the number of species reduced by 6.0～6.7 under all the grazing treatments when the sampling area reached 128 m^2. When the sampling area was in a medium level ($2m^2$~$16m^2$), the impact of grazing intensity on the number of plant species fluctuated greatly (Table 2). Anyhow, there was no significant difference between the three grazing intensities ($P>0.05$). In all, the results presented a fine relation between the number of plant species and sampling area, and it was obviously affected by grazing intensity.

The similarity of plant communities had an increasing trend with accumulated sampling area, but it varied at different grazing intensities. In general, the results showed light grazing T7 presented a higher similarity to banning-grazing (control, T0), whilst moderate grazing T10 and high grazing T14 shared a different similarity (Table 3). Anyhow, the spatial heterogeneity of grassland plant communities fluctuated greatly under a smaller spatial scale due to its range of variation (R), especially from 1/4 m^2 to 1/16m^2; but it turned to be relatively stable on a larger scale over 2 m^2.

On the aspect of plant species, some plants were dismissed, especially these plants in the family of Leguminosae and Liliaceae (Allium L.), such as *Astragalus adsurgens*, *Thermopsis lanceolata*, and *Allium mongolicum*; while some plants were depressed under higher grazing intensities, e.g. *Dysphania aristata*, *Atriplex centralasiatica*, *Atriplex sibirica*, *Halerpestes ruthenica*, and *Glaux maritima*; but some other plant species flourished under higher grazing pressure in the steppe grassland, for instance, *Potentilla multifida*, and its variety *P. multifida* var. *ornithopoda*, *Lepidium apetalum*, and *Cleistogenes squarrosa* (see Appendix).

Fitting and detection of species-area curve

Due to different grazing intensities under the treatments of T0, T7 and T14, the optimal curves pointed by the four indexes are the same, which are curves (6), (9) and (6) respectively; according to T10, the optimal curve pointed by the indexes RSE and CRI is curve (4), while the optimal curve pointed by the indexes AAD and AARD is curve (9). Since RSE and CRI are completely equivalent, the optimal curve processed for T10 is curve (9). By comprehensively analyzing the optimal options of four indicators of the 10 curves, the following table can be obtained (Table 4 & 5).

Based on the above table 3, the fitting curves under different treatments are set respectively, and the figures are presented as following (Fig. 3). Synthetically, the best one is model (6), followed by model (9), among the fitting models under different grazing intensities. For model (6), the core parameter that determines the change trend is Z: the larger the Z value is, the greater the slope of the model is. That is to say, the number of species increases rapidly with the increase of sampling area. But for model (9), the core parameter is B. The smaller the value of B, the faster the number of species increases.

Determination of sampling area and influence of grazing pressure

According to the curvature analysis, the turning points of the maximum curvature, e.g. the minimum areas, are 1.16 m^2 (T0), 1.23 m^2 (T7), 1.28 m^2 (T10) and 1.10 m^2 (T14), respectively (Table 6), presenting a similar result which indicated that quadrat of 1m^2 is reasonable and available in the steppe. Anyhow, minimum sampling area was restricted by heavy grazing, but promoted slightly by light and medium grazing. On the other hand, when the sampling area reached 32 m^2, the species number in each quadrat was more than 75% of the total species number for the three grazed treatments from T7 to T14 (76%, 76%, 76%), but a relatively lower percentage of 66% for control T0. While the sampling area reached 64 m^2, the species number in each quadrat was all more than 84% of the total species number under the four grazing intensities from T0 to T14 (85%, 93%, 90%, 91%).

Discussion and Conclusions

Effect of sampling scale, grazing intensity, vegetation type

Grazing affects the spatial heterogeneity of plant communities in a series of land types (Wang et al. 2002; Collins and Smith 2006; de Bello et al. 2007; McGranahan et al. 2012; Six et al. 2016; Wang et al. 2018; Song et al. 2020; Dastgheyb et al. 2021). Some of the researches showed grazing could increase the spatial heterogeneity of plant communities (Golluscio et al. 2005; Wang et al. 2018; Song et al. 2020); whilst other studies declared that grazing could decrease the spatial heterogeneity (Collins and Smith 2006). The conflict may be on the scale of sampling area. According to the study in alpine grassland of Qinghai-Tibetan Plateau (Song et al. 2020) and Northwest Heilongjiang Steppe of China (Wang et al. 2018), the sampling area were both at small scale (0.25 m^2 or 0.0625 m^2); and a small scale of 0.04 m^2 was conducted in the Patagonian steppe, though they focused on biomass heterogeneity of plant communities (Golluscio et al. 2005). As shown in the tallgrass prairie, it presented that grazing reduced the spatial heterogeneity at a larger scale under 10-, 50-, and 200-m^2 (Collins and Smith 2006). Our results showed that sheep grazing increased the spatial heterogeneity of plant communities on a smaller spatial scale in the steppe, mainly from 1/4 m^2 to 1/16 m^2 on aspect of species richness. Generally, spatial heterogeneity of plant community was affected by animal grazing, but the effect is scale-dependent, which was common in different vegetation types (Golluscio et al. 2005; de Bello et al. 2007; Olofsson et al. 2008; Chen et al. 2019). In addition, the spatial heterogeneity was also varied due to vegetation types, which was also confirmed by Zou et al. (2021) under different plant community types in desert steppe. Correspondingly, according to the optimal model curve, it shows when the plot area reaches 3.0 m^2, the upward trend of species number with the increase of sampling area slows down. Under different grazing pressure, the numbers of species under different sampling area are quite variable. On the whole, grazing reduced the number of species and meanwhile increased the minimum sampling area. On the other hand, plant structure was also reshaped by grazing, some plants flourished or depressed under different grazing intensities. Mainly, palatable plants turned to disappear quickly even under light grazing pressure; while these plants with palatability in the medium range can resist to some extent of grazing, but are depressed or dismissed under high level of grazing; anyhow, some rough and low-nutrition plants were intended to spread and expand (Teague and Dowhowe 2003). The result showed the plants belong to the family of Liliaceae (Allium L.) and Chenopodiaceae were prone to decrease or disappear in our study area, which was also confirmed by Han (2018) conducted in the desert grassland. This occurance was highlighted in other studies, such as in the similar type of steppe (Wang et al. 2002) and an alpine grassland (Song et al. 2020). Altogether, the disappearance of palatable plants provided new niche for the occurrence of rough plants or occasional species, which may increase the spatial heterogeneity of plant community. Anyhow, this experiment was conducted by using sheep as grazing animals. Whether the situation will change when cattle, goats (Fernández-Lugo et al. 2011), horses (Villalobos and Zalba 2010), bison (Collins and Smith 2006), rabbit (Olofsson et al. 2008) or even mix-grazing are employed; when the feeding habits of livestock changed, if this effect of grazing on plant community will change? All these questions need to be further studied. Anyhow, soil and topographic heterogeneity (Dastgheyb et al. 2021; He et al. 2022), even the sampling method (nested or random sampling, Chen et al. 2019), also had an effect on the species-area curve. Though these aspects were less discussed in the study, but it’s well needed for further study.

Fitting and detection of species-area curve

Due to the results of fitting of the species-area curve, Chapman-Richards growth function and Power function model and its improved model are the optimal curve to predict the trend of plants and sampling area in the steppe. According to related researches, Williams (1943) found that the species-area relationship conforms to the exponential model on the small scale, while the power function model is suitable for the medium scale. Meanwhile, Kilburn (1963) also found that the power function model is the best for relatively small scales while the logistic model is the best for large scales (Archibald 1949; He and Legend 1996). Our results of model fitting confirmed it was scale dependent, for Chapman-Richards growth function, it is suitable for a smaller scale in the steppe. On grazing intensity, our results showed species–area relationships became less steepe with the increasing of grazing intensity. According to the model fitting, our results declared the value of Z and B was smaller under the grazing treatments compared with control T0. That is to say, the number of species increases slowly with the increasing of sampling area under grazing pressure. Others factors, such as climatic conditions and plant life forms, may also affect the formats and parameters of species-area relationship (de Bello et al. 2007; He et al. 2022), though less discussed in the study.

Sampling area in the plant community

Due to survey and fitting of the species-area curve, it all showed that minimum sampling area is around 1.0 m^2 even under different grazing intensities in the steppe. This result was consistent with other studies conducted on a similar plant community for *Agropyron cristatum* of 1.4 m^2 on Loess Plateau (Tang et al. 2005), but a larger minimum sampling area of 5.6 m^2 for degraded mountain meadow in Nalati Pasture, Xinjiang (Zhuo et al. 2013). This indicated minimum sampling area was table in some certain plant community, but varied in different regions due to vegetation types. On plant composition, plant species increased with accumulated sampling area, maintained at a certain level over 84% of the total species number when sampling area reached 64 m^2, which was larger than that in subalpine meadow (32 m^2)

according to Zhang et al. (2013). Thus, our results can provide some basic advice for field survey and grazing management, especially for plant community ecology in this particular area in the steppe.

Acknowledgements

We are grateful and thank workers in National Field Station for Grassland Ecosystem, Guyuan for their convenient help with the survey, and Wang Liu-Ying (Inner Mongolia Agricultural University) for her help with excellent skills in the identification of plant species.

Author Contributions

ZWH analysed the data and wrote the manuscript; CC and WLX made the field survey and analysed the data of questionnaire survey; HD conducted the sheep grazing experiment; MNA polished and revised the manuscript.

Declaration of Competing Interest

The authors reported no declarations of interest.

Data Availability

All data included in this study are available upon request by contact with the corresponding author.

References

An, H.F. 2010. Study on species area relationship of plant community in subalpine meadow. Lanzhou, Lanzhou University (In Chinese with English Abstract)

Archibald, E.E.A. 1949. The specific character of plant communities. Ⅱ. a quantitative approach. Journal of Ecology 37, 260-274.

Barkman, J.J. 1989. A critical evaluation of minimum area concepts. Vegetatio 85, 89-104.

Bunge, J., Fitzpatrick, M. 1993. Estimating the number of species: a review. Journal of the American Statistical Association 88, 364-373.

Caprariis, P.D., Lindemann, R.H., Collins, C.M. 1976. A method for determining optimum sample size in species diversity studies. Mathematical geology 8, 575-581.

Chen, B.B., Jiang, J., Zhao, X.H. 2019. Species-area relationship and its scale-dependent effects in natural forests of North Eastern China. Forests 10(5):422.

Chen, H., Li, Y.Q., Zheng, S.W., Wang, L., He, F., Liu, J., Mu, C.L. 2007. Determination of species-area relationships and minimum sampling area for the shrub communities in arid valley in the upper reach of the Minjiang River. Acta Ecologica Sinica 27, 1818-1825. (In Chinese with English Abstract)

Chisholm, R.A., Lim, F., Yeoh, Y.S., Seah, W.W., Condit, R., Rosindell, J. 2018. Species–area relationships and biodiversity loss in fragmented landscapes. Ecology Letters 21, 804-813.

Collins, S.L., Smith, M.D. 2006. Scale-dependent interaction of fire and grazing on community heterogeneity in tallgrass prairie. Ecology 87, 2058-2067.

Drakare, S., Lennon, J.J., Hillebrand, H. 2006. The imprint of the geographical, evolutionary and ecological context on species-area relationships. Ecology Letters 9, 215-227.

Dastgheyb Shirazi, S.S., Ahmadi, A., Abdi, N., Toranj, H., Khaleghi, M.R. 2021. Long-term grazing exclosure: implications on water erosion and soil physicochemical properties (case study: Bozdaghin rangelands, North Khorasan, Iran). Environmental Monitoring and Assessment 193(1):51.

De Bello, F., Leps, J., Sebastia, M.T. 2007 Grazing effects on the species-area relationship: Variation along a climatic gradient in NE Spain. Journal of Vegetation Science 18(1):25-34.

DeMalach, N., Saiz, H., Zaady, E., Maestre, F.T. 2019. Plant species-area relationships are determined by evenness, cover and aggregation in drylands worldwide. Global Ecology and Biogeography 28(3):290-299.

de Villalobos, A.E., Zalba, S.M. 2010. Continuous feral horse grazing and grazing exclusion in mountain pampean grasslands in Argentina. Acta Oecologica 36, 514-519.

Fernández-Lugo, S., de Nascimento, L., Mellado, M., Arévalo J.R. 2011. Grazing effects on species richness depends on scale: a 5-year study in Tenerife pastures (Canary Islands). Plant Ecology 212, 423-432.

Golluscio, R.A., Pérez, J.A., Paruelo, J.M., Ghersa, C.M. 2005. Spatial heterogeneity at different grain sizes in grazed versus ungrazed sites of the Patagonian steppe. Ecoscience 12, 103-109.

Han, M.Q. 2018. Response of species diversity and productivity to different stocking rates in the *Stipa breviflora* desert steppe. Huhhot, Inner Mongolia Agricultural University. (In Chinese with English Abstract)

He, C.Q., Fang, L.Q., Xiong, X.Y., Fan, F., Li, Y.G., He, L.S., Shen, X.L., Li, S., Ji, C.J., Zhu, J.L. 2022. Environmental heterogeneity regulates species-area relationships through the spatial distribution of species. Forest Ecosystems 9, 100033.

He, F., Legender, P. 1996. On species area relations. American Naturalist 148, 719-737.

Khishigbayar, J., Fernandez-Gimenez, ME., Angerer, J.P., Reid, R.S., Chantsallkham, J., Baasandorj, Y., Zumberelmaa, D. 2015. Mongolian rangelands at a tipping point? Biomass and cover are stable but composition shifts and richness declines after 20 years of grazing and increasing temperatures. Journal of Arid Environments 115, 100-112.

Kilburn, P.D. 1963. Exponential values for the specie-s area relation. Science 141, 1276.

Liu, C.R., Ma, K.P., Yu, S.L., Wang, W. 1999. Plant community diversity in Dongling Mountain, Beijing, China — the fitting and assessment of species-area curves. Acta Phytoecologica Sinica 23, 490-500. (In Chinese with English Abstract)

Malcolm, J.R., Liu, C.R., Neilson, R.P., Hansen, L., Hannah, L. 2006. Global warming and extinctions of endemic species from biodiversity hotspots. Conservation Biology 20, 538-548.

Matthews, T.J., Triantis, K.A., Whitaker, R.J. (Eds.). 2021. The species-area relationship: Theory and application. Cambridge University Press.

McGranahan, D.A., Engle, D.M., Fuhlendorf, S.D., Winter, S.J., Miller, J.R., Debinski, D.M. 2012. Spatial heterogeneity across five rangelands managed with pyric‐herbivory. Journal of Applied Ecology 49, 903-910.

Miller, R.I., Wiegert, R.G. 1989. Documenting Cmpleteness, Species-area relations, and the species-abundance distribution of a regional flora. Ecology 70, 16-22.

Munkhzul, O., Oyundelger, K., Narantuya, N., Tuvshintogtokh, I., Oyuntsetseg, B., Wesche, K., Jaschke, Y. 2021. Grazing effects on Mongolian steppe vegetation-a systematic review of local literature. Frontiers in Ecology and Evolution 9, 1-13. Doi:10.3389/fevo.2021.703220

Navarro-Rosales, F., Bell, M.B.V. 2022. Woody vegetation within semi-abandoned olive groves: species-area relationships and minimum area values. Mediterranean Botany 43, e77457.

Olofsson, J., de Mazancourt, C., Crawley, M.J. 2008. Spatial heterogeneity and plant species richness at different spatial scales under rabbit grazing. Oecologia 156, 825-834.

Six, L.J., Bakker, J.D., Bilby, R.E. 2016. The combined effects of afforestation and grazing on Uruguayan grassland vegetation at multiple spatiotemporal scales. New Forests 47, 685-699.

Song, S.S., Zhu, J.L., Zheng, T.L., Tang, Z.Y., Zhang, F., Ji, C.J., Shen, Z.H., Zhu, J.X. 2020. Long-term grazing exclusion reduces species diversity but increases community heterogeneity in an alpine grassland. Frontiers in Ecology and Evolution 8, 1-12. DOI:10.3389/fevo.2020.00066

Tang, L., Hao, W.F., Sun, H.G., Liang, Z.S. 2005. Fitting and assessment of species-area curves of four native pasture communities on Loess Plateau. Agricultural Research in the Arid Areas 23, 83-88. (In Chinese with English Abstract)

Teague, W.R., Dowhower, S.L. 2003. Patch dynamics under rotational and continuous grazing management in large, heterogeneous paddocks. Journal of Arid Environments 53, 211-229.

Vellend, M., Baeten, L., Myers-Smith, I.H., Elmendorf, S.C., Beauséjour, R., Brown, C.D., De Frenne, P., Verheyen, K., Wipf, S. 2013. Global meta-analysis reveals no net change in local-scale plant biodiversity over time. Proceedings of the National Academy of Sciences of the United States of America 110, 19456-19459.

Wang, B.S., Yu, S.X., Peng, S.L., Li, M.G. 1996. Experiment manual of plant sociology. Guangzhou, Guangdong Higher Education Press. (In Chinese)

Wang, M.J., Han, G.D., Zhao, M.L., Cui, G.W., Hong, R.M., Li, J.X., Yin, X.J. 2010. Application of transect sampling method in the research minimum area of grassland plant community. Journal of Northeast Agricultural University 41, 98-104. (In Chinese with English Abstract)

Wang, X., Yang, X.G., Wang, L., Chen, L., Song, N.P., Gu, J.L., Xue, Y. 2018. A six-year grazing exclusion changed plant species diversity of a *Stipa breviflora* desert steppe community, northern China. PeerJ 6, e4359. DOI:10.7717/peerj.4359

Wang, Y.S., Shiyomi, M., Tsuiki, M., Tsutsumi, M., Yu, X.R., Yi, R.H. 2002. Spatial heterogeneity of vegetation under different grazing intensities in the Northwest Heilongjiang Steppe of China. Agriculture, Ecosystems and Environment 90, 217-229.

Williams, C.B. 1943. Area and number of species. Nature 152, 264-267.

Zhang, R., Chen, J.Q., Hou, Y.C., Ma, L.N., Ding, L.M., Long, R.J., Shang, Z.H. 2013. Relationships between plant species number and sampling area for sub-alpine meadow plant communities. Chinese Journal of Ecology 32, 2268-2274. (In Chinese with English Abstract)

Zhou, N., Wu, J.S., Shen, Z.X., Zhang, X.Z., Yang, P.W. 2016. Species-area relationship within and across functional groups at alpine grasslands on the northern Tibetan Plateau, China.

Journal of Mountain Science 13, 265-275.

Zhuo, Q., Li, X.M., Yang, X., Feng, J.C. 2013. Fitting of species-area relationship and determination of minimum sampling area for two utilization ways of plant communities in Nalati pasture. Journal of Anhui Agricultural Sciences 41, 4242-4245. (In Chinese with English Abstract)

Zuo, X.A., Mao, W., Qu, H., Chen, M., Zhao, S.L., Liu, L.X., Wang, S.K., Yue, P., Ma, X.J., Zhao, X.Y., Medina-Roldan, E., Allington, G.R.H. 2021. Scale effects on spatial heterogeneity of herbaceous vegetation in desert steppe depend on plant community type. Ecological Indicators 127, 107769.

Table 1 Grazing gradients and seasonal setting

Grazing gradient	Sheep quantity		
	Spring	Summer	Autumn
Control, T0	0	0	0
Light grazing, T7	0	14	10
Moderate grazing, T10	10	10	10
Heavy grazing, T14	14	14	14

Table 2 Average number of plant species in a gradient quadrat area

Sampling area, m^2	**T0**	**T7**	**T10**	**T14**
1/64m^2	3.3	3.0	3.7	4.2
1/32m^2	4.2	3.7	4.3	5.5
1/16m^2	4.5	4.3	5.0	6.0
1/8m^2	5.7	4.7	6.0	7.5
1/4m^2	6.5	6.0	6.5	7.8
1/2m^2	8.0	7.5	7.5	8.5
1m^2	9.5	8.8	9.0	10.0
2m^2	11.0	11.2	11.0	12.0
4m^2	12.8	12.2	14.3	12.8
8m^2	15.2	13.8	15.7	14.3
16m^2	18.0	16.7	17.0	17.0
32m^2	21.0	19.3	19.5	19.8
64m^2	27.3	23.7	23.0	23.7
128m^2	32.0	25.3	25.7	26.0

Table 3 Similarity of plant communities under different grazing intensities along sampling area

C_J/m^2	T0-T7	T0-T10	T0-T14	T7-T10	T7-T14	T10-T14	R
1/64m^2	0.400	0.286	0.300	0.333	0.200	0.273	0.200
1/32m^2	0.250	0.182	0.417	0.375	0.250	0.385	0.235
1/16m^2	0.333	0.250	0.500	0.300	0.231	0.462	0.269
1/8m^2	0.400	0.385	0.538	0.231	0.286	0.467	0.307
1/4m^2	0.333	0.400	0.500	0.267	0.357	0.600	0.333
1/2m^2	0.412	0.474	0.500	0.300	0.389	0.526	0.226
1m^2	0.450	0.478	0.435	0.435	0.600	0.480	0.165
2m^2	0.500	0.480	0.500	0.462	0.682	0.519	0.220
4m^2	0.519	0.516	0.556	0.586	0.640	0.621	0.124
8m^2	0.500	0.625	0.484	0.613	0.692	0.600	0.208
16m^2	0.571	0.735	0.594	0.647	0.655	0.677	0.164
32m^2	0.561	0.811	0.639	0.658	0.667	0.657	0.250
64m^2	0.605	0.667	0.641	0.659	0.629	0.615	0.062
128m^2	0.659	0.711	0.674	0.714	0.861	0.775	0.202

Table 4 Sampling area curve fitting under different grazing intensities

Treatments	Models	B	C	Z	RSE	CRI	AAD	AARD
T0	(1)	_	0.2181	8.7981	20.3781	0.7666	3.6500	0.4563
	(2)	0.0026	0.5190	7.3310	9.1478	0.8961	2.2363	0.3100
	(3)	_	2.9224	11.7729	10.7041	0.8784	2.3600	0.2628
	(4)	0.3793	2.6595	8.8571	1.0335	0.9883	0.7329	0.0740
	(5)	_	9.1343	0.2560	0.3025	0.9965	0.3824	0.0346
	(6)	1.2218	7.8157	0.2824	0.2428	0.9972	0.2951	0.0287
	(7)	0.3171	8.4081	_	18.2476	0.7910	3.5583	0.4501
	(8)	28.9815	12.3645	11.3584	9.6911	0.8899	2.3922	0.3126
	(9)	6.6e-6	193.3701	0.2560	0.3331	0.9962	0.3828	0.0346
	(10)	23.7847	0.0412	6.4476	5.7759	0.9344	1.8010	0.2371
T7	(1)	_	0.1696	8.3397	20.4356	0.6610	3.6788	0.5081
	(2)	-0.0026	0.4713	6.8689	9.1431	0.8496	2.2358	0.3413
	(3)	_	2.4885	10.5780	4.1539	0.9317	1.5272	0.2097
	(4)	0.2394	2.3225	8.7374	0.3001	0.9951	0.3580	0.0351
	(5)	_	8.7236	0.2287	0.4075	0.9932	0.4323	0.0522
	(6)	2.2635	11.1465	0.1920	0.3097	0.9949	0.3372	0.0367
	(7)	0.6090	12.9686	_	10.6091	0.8240	2.6675	0.3816
	(8)	22.6866	6.1741	6.2878	6.9068	0.8864	2.0170	0.2833
	(9)	0.0081	28.5342	0.2479	0.2577	0.9958	0.3197	0.0302
	(10)	17.9630	0.0752	5.5402	22.4816	0.6302	3.6790	0.5081
T10	(1)	_	0.1631	9.0305	20.4808	0.6419	3.6817	0.4439
	(2)	-0.0024	0.4431	7.6654	11.0410	0.8086	2.3705	0.3028
	(3)	_	2.4325	11.1689	3.4885	0.9395	1.3135	0.1698
	(4)	0.2173	2.2891	9.4985	0.3148	0.9945	0.3698	0.0362
	(5)	_	9.4729	0.2110	0.4959	0.9913	0.4551	0.0470
	(6)	2.6616	12.3141	0.1737	0.4049	0.9930	0.4316	0.0458
	(7)	0.8055	17.0491	_	10.8132	0.8110	2.6485	0.3529
	(8)	21.3001	2.9744	3.2313	6.5341	0.8867	1.8276	0.1876
	(9)	0.0081	28.1925	0.2275	0.3834	0.9934	0.3547	0.0306
	(10)	16.6908	0.1198	5.7293	4.4231	0.9233	1.4692	0.1556
T14	(1)	_	0.1605	9.5780	15.6794	0.6959	3.1775	0.3424
	(2)	-0.0023	0.4247	8.2897	7.0170	0.8650	1.8798	0.2247
	(3)	_	2.2898	11.7183	4.1311	0.9205	1.5198	0.1523
	(4)	0.2328	2.1285	9.9289	0.4890	0.9906	0.4874	0.0521
	(5)	_	10.0910	0.1960	0.2699	0.9948	0.3761	0.0376
	(6)	1.1554	8.8411	0.2158	0.2646	0.9949	0.3403	0.0351
	(7)	1.3460	27.0429	_	16.6551	0.6770	3.2320	0.3585
	(8)	23.6834	6.1931	8.6354	5.4682	0.8948	1.6336	0.1902
	(9)	2.6e-5	79.8708	0.1960	0.2972	0.9943	0.3763	0.0377
	(10)	17.1064	0.0601	7.2881	3.7761	0.9274	1.3697	0.1613

Table 5 Different levels of curve

Treatments	Optimal curve	Suboptimal curve	Tertiary curve
T0	(6)	(5)	(9)
T7	(9)	(6)	(4)
T10	(9)	(4)	(6)
T14	(6)	(5)	(9)

Table 6 Determination of minimum area

Models	T0	T7	T10	T14
Curve 6	1.16	1.23	1.28	1.10
Curve 5	1.33	1.32	1.35	1.19
Curve 9	1.33	1.56	1.53	1.19

450 Appendix Species composition and its change under different treatments

	T0	T7	T10	T14
1	*Allium mongolicum*	——	——	——
2	*Artemisia brachyloba*	*Artemisia brachyloba*	*Artemisia brachyloba*	*Artemisia brachyloba*
3	*Artemisia eriopoda*	*Artemisia eriopoda*	*Artemisia eriopoda*	*Artemisia eriopoda*
4	*Artemisia lavandulifolia*	*Artemisia lavandulifolia*	*Artemisia lavandulifolia*	*Artemisia lavandulifolia*
5	*Artemisia scoparia*	*Artemisia scoparia*	*Artemisia scoparia*	*Artemisia scoparia*
6	*Artemisia tanacetifolia*	*Artemisia tanacetifolia*	——	*Artemisia tanacetifolia*
7	*Aster altaicus*	*Aster altaicus*	*Aster altaicus*	*Aster altaicus*
8	*Aster tataricus*	*Aster tataricus*	*Aster tataricus*	*Aster tataricus*
9	*Astragalus laxmannii*	——	——	——
10	*Astragalus tataricus*	*Astragalus tataricus*	*Astragalus tataricus*	*Astragalus tataricus*
11	*Atriplex centralasiatica*	——	*Atriplex centralasiatica*	——
12	*Atriplex sibirica*	*Atriplex sibirica*	*Atriplex sibirica*	*Atriplex sibirica*
13	*Carex duriuscula*	*Carex duriuscula*	*Carex duriuscula*	*Carex duriuscula*
14	*Chenopodium ficifolium*	*Chenopodium ficifolium*	*Chenopodium ficifolium*	*Chenopodium ficifolium*
15	*Cleistogenes squarrosa*	*Cleistogenes squarrosa*	*Cleistogenes squarrosa*	*Cleistogenes squarrosa*
16	*Halerpestes ruthenica*	——	*Halerpestes ruthenica*	——
17	*Hordeum brevisubulatum*	——	*Hordeum brevisubulatum*	——
18	*Inula japonica*	*Inula japonica*	*Inula japonica*	*Inula japonica*
19	*Iris lactea*	*Iris lactea*	*Iris lactea*	*Iris lactea*
20	*Ixeris chinensis*	*Ixeris chinensis*	*Ixeris chinensis*	*Ixeris chinensis*
21	*Lepidium apetalum*	*Lepidium apetalum*	*Lepidium apetalum*	*Lepidium apetalum*
22	*Leymus chinensis*	*Leymus chinensis*	*Leymus chinensis*	*Leymus chinensis*
23	*Lysimachia maritima*	——	*Lysimachia maritima*	*Lysimachia maritima*

24	*Medicago ruthenica*	*Medicago ruthenica*	*Medicago ruthenica*	*Medicago ruthenica*
25	——	——	*Oxytropis ciliata*	——
26	——	*Phragmites australis*	*Phragmites australis*	*Phragmites australis*
27	*Plantago depressa*	*Plantago depressa*	*Plantago depressa*	*Plantago depressa*
28	——	——	*Polygonum aviculare*	——
29	*Polygonum sibiricum*	*Polygonum sibiricum*	*Polygonum sibiricum*	*Polygonum sibiricum*
30	*Potentilla anserina*	*Argentina anserina*	*Argentina anserina*	*Argentina anserina*
31	——	*Potentilla chinensis* var. *lineariloba*	——	——
32	——	*Potentilla bifurca*	*Potentilla bifurca*	*Potentilla bifurca*
33	——	*Potentilla flagellaris*	——	*Potentilla flagellaris*
34	*Potentilla multifida*	*Potentilla multifida*	*Potentilla multifida*	*Potentilla multifida*
35	*Potentilla multifida* var. *ornithopoda*	*Potentilla multifida* var. *ornithopoda*	*Potentilla multifida* var. *ornithopoda*	*Potentilla multifida* var. *ornithopoda*
36	*Puccinellia tenuiflora*	*Puccinellia tenuiflora*	*Puccinellia tenuiflora*	*Puccinellia tenuiflora*
37	——	*Saposhnikovia divaricata*	——	——
38	*Saussurea amara*	*Saussurea amara*	*Saussurea amara*	*Saussurea amara*
39	*Saussurea runcinata*	——	——	——
40	*Sibbaldianthe adpressa*	*Sibbaldianthe adpressa*	*Sibbaldianthe adpressa*	*Sibbaldianthe adpressa*
41	——	——	*Silene jenisseensis*	——
42	*Stipa sareptana* var. *krylovii*	*Stipa sareptana* var. *krylovii*	*Stipa sareptana* var. *krylovii*	*Stipa sareptana* var. *krylovii*
43	*Suaeda glauca*	——	*Suaeda glauca*	*Suaeda glauca*
44	*Suaeda salsa*	——	——	——
45	*Taraxacum mongolicum*	*Taraxacum mongolicum*	*Taraxacum mongolicum*	*Taraxacum mongolicum*
46	*Teloxys aristata*	*Teloxys aristata*	*Teloxys aristata*	——
47	*Thermopsis lanceolata*	——	——	——

451

Fig. 1 Schematic diagram of nested quadrat survey (*a* and *b* are extension directions)

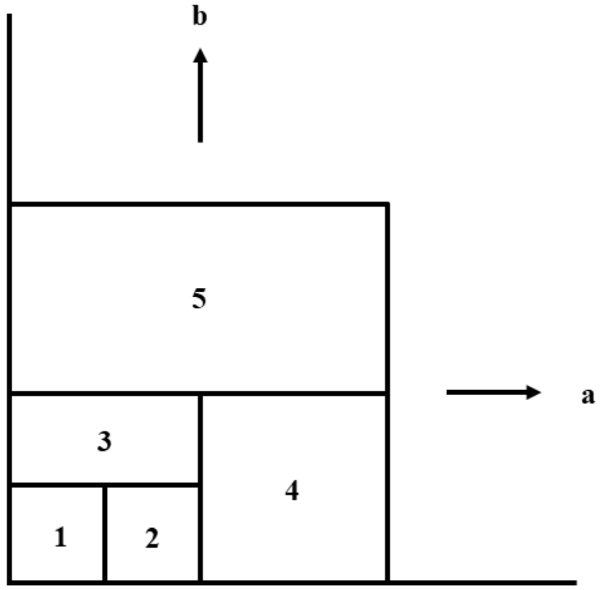

Fig. 2 Species-area curves under different grazing intensities

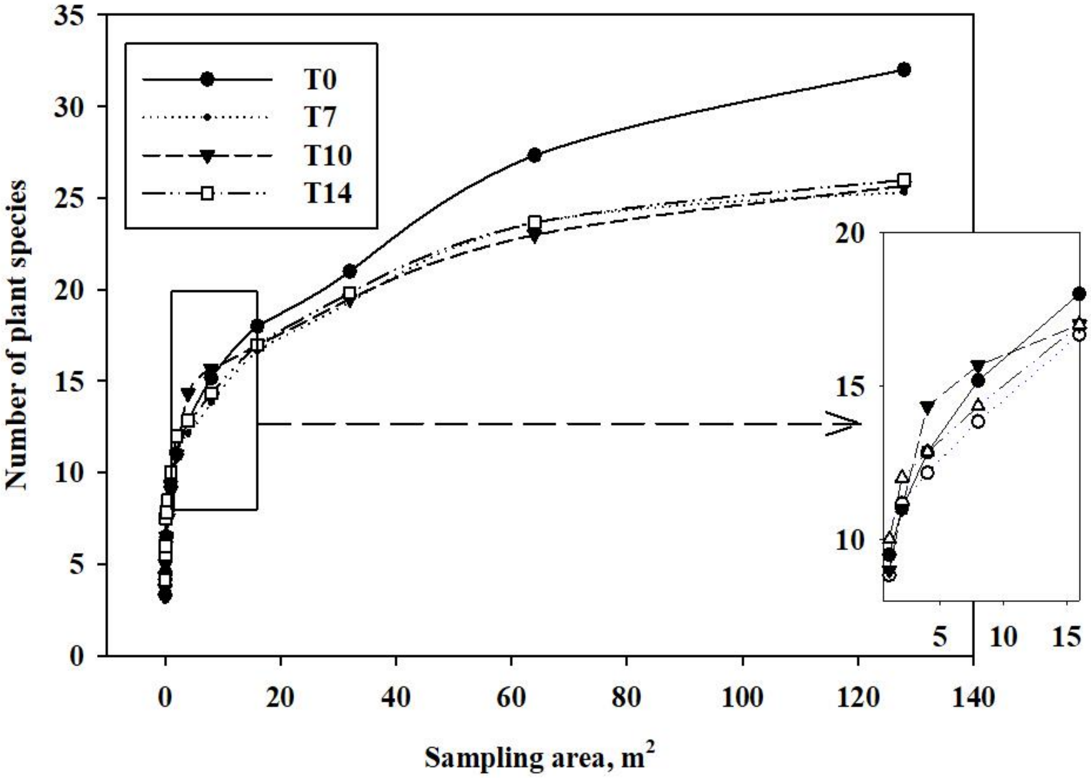

Fig. 3 Species-area fit curve under different grazing intensities