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Local and regional steppe vegetation palatability at grazing hotspot areas in Mongolia

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Background: Climate and livestock grazing are key agents in determining current Mongolian steppe vegetation communities. Together with plant coverage or biomass, palatability of steppe community is regarded as a useful indicator of grassland degradation, in particular, at grazing hotspots in arid and semi-arid grasslands. This study analyzed relationships between livestock grazing pressure and steppe vegetation palatability at three summer pastures with different aridity (dry, xeric, and mesic) and livestock numbers (1,100, 1,800, and 4,100 sheep units, respectively). At each site, it was surveyed coverage, biomass, and species composition of different palatability groups (i.e., palatable [P], impalatable [IP], and trampling-tolerant [TT]) along a 1-km transect from grazing hotspots (i.e., well) in every July from 2015 to 2018.

Results: In results, total vegetation coverage increased with wetness, 7 times greater at mesic site than dry one in averages (33.1% vs. 4.5%); biomass was 3 times higher (47.1 g m^{-2} vs. 15.7 g m^{-2}). Though P was the dominant palatability group, the importance of IP in total coverage increased with aridity from mesic (0.6%) to dry (40.2%) sites. Whereas, TT increased with livestock numbers across sites. Locally, IP was observed more frequently near the wells and its spatial range of occurrence becomes farther along the transects with aridity across sites from mesic (< 100 m) to dry (< 700 m from the well).

Conclusions: Our results showed that the importance of IP and its spatial distribution are different at both local and regional scales, indicating that the palatability parameters are sensitive to discern balance between selective-grazing demand and climate-driven foraging supply in Mongolian rangelands.

Keywords: aridity, Mongolia, palatability, selective grazing, summer pasture

Introduction

Occupying 3.5 billion ha worldwide, rangelands are managed using three systems: sedentary, transhumant, and nomadic (Shahriary et al. 2012). Mongolian rangelands are managed by transhumant (i.e., semi-nomadic) or nomadic patterns of land use (Fernandez- Gimenez and Allen-Diaz 1999; Johnson et al. 2006). The Mongolian rangelands have become vulnerable to multiple hazards, such as drought, degradation, and *dzud*, over the last several decades because of the increased frequency of extreme climate events and temporary failures to balance vegetation production and livestock consumption (Batima 2006; Dagvadorj et al. 2009; Dietz et al. 2005; Khishigbayar et al. 2015). This calls for more attention to understand the relationships between the foraging resource, climate variability, and livestock grazing in Mongolian rangelands.

Climate is an important determinant of vegetation composition (Wu et al. 2017; Zerbo et al. 2016). Among various climate factors, precipitation is particularly important to control the vegetative composition of plant communities in semi-arid and arid rangelands (Fujita et al. 2013; Graetz et al. 1988). Along the precipitation gradient from arid to semi-arid, the vegetation becomes dense and diverse and steppe-type varies gradually from desert steppe to typical steppe and to forest steppe in the Mongolian rangelands, where aridity primarily controls the composition of plant life forms (Fernandez-Gimenez and Allen-Diaz 1999; Narantsetseg et al. 2015).

Together with aridity, livestock plays an important role in altering plant species composition and coverage. One of critical impacts of livestock is to change the palatability of

the plant community (Narantsetseg et al. 2018). High levels of selective grazing and trampling pressure from livestock can cause a reduction in palatable plant species and an increase in impalatable plant species (i.e., grazing or trampling tolerant) at grazing hotspots. This is widely supported by field evidence from local grazing hotspot areas in Southern Africa (Egeru et al. 2015; Nangula and Oba 2004), Australia (Andrew 1988; Ludwig et al. 2001), North America (Nash et al. 1999), Europe (Reis and Sen 2017), and Central Asia (Fernandez-Gimenez and Allen-Diaz 1999; Fernandez-Gimenez and Allen-Diaz 2001; Narantsetseg et al. 2018; Shahriary et al. 2012). Field evidence advocates the use of a coverage fraction of grazing- or trampling-tolerant plants as a practical indicator of rangeland degradation (Yoshihara et al. 2010). Jamsranjav et al. (2018) used it to derive their conclusions that severe and irreversible degradation is rare, whereas extensive Mongolian rangelands are subject to slight or moderate land degradation.

Fractions of palatable and impalatable plant species in steppe vegetation communities result from the long-term impacts of livestock on vegetation, such as selective grazing and trampling (Thrash 2000), in which the numbers and types of livestock are related (Narantsetseg et al. 2018). The fraction of grazing-tolerant plants is known to be high in arid steppes and low in semi-arid steppes (Jamsranjav et al. 2018), but it also varies locally, with a higher fraction near grazing hotspots, such as a well or *ger* (a Mongolian mobile house), compared with remote pastures (Zerbo et al. 2016; Zerbo et al. 2018). Accordingly, several studies have reported high levels of grass coverage and biomass near livestock gathering places and a reduction of coverage and biomass with distance from hotspots in semi-arid regions (Farmer 2010; Jeltsch et al. 1997; Shahriary et al. 2012; Tuna et al. 2011). However, opposite or null spatial patterns have been observed, in particular, in arid regions (Nangula and Oba 2004; Narantsetseg et al. 2018).

The contrasting evidence implicates the effect of grazing on vegetation is different across steppe types because climate acts as an additional agent that modulates the livestock–vegetation interactions. Climate controls vegetation production and life forms (e.g., annual and perennial) and livestock numbers and types. For examples, above-ground standing biomass increases from arid to semi-arid steppes (Fernandez-Gimenez and Allen-Diaz 1999). Perennial herbaceous plant is the dominant life form in semi-arid steppes, but this changes to annual or biennial life form in arid steppe of Mongolia (Fujita et al. 2012; Narantsetseg et al. 2015). Climate also affects vegetation indirectly by regulating number and composition of local livestock. Forest steppe supports more livestock with a high proportion of big cattle or yak, but local herders in desert steppe raise lower livestock numbers, mainly goat and sheep.

Hence, both climate and livestock multiply characterize steppe production, life forms, and palatability of vegetation

communities in Mongolia, which shapes local and regional heterogeneity in present steppe vegetation. The multiple effect is, however, not fully understood yet in Mongolian rangelands. Though there exist many studies to survey steppe plant community (Fujita et al. 2013; Narantsetseg et al. 2018; Wu et al. 2017), it was rarely developed field evidences covering enough gradients of livestock pressure and climate together at both local and regional scales. The multiple effect has become particularly important to understand its potential linkage with an endemic livestock hazard (i.e., *dzud*) in Mongolian rangelands (Sternberg 2018), where temporary imbalances between the supply of palatable foraging resource and livestock demand can cause increased vulnerability to massive livestock mortality (Dietz et al. 2005; Middleton and Sternberg 2013).

To examine the multiple effects in Mongolian rangelands, this study investigated vegetation palatability and plant functional groups of steppe plant community near grazing hotspot areas across three regional sites with different aridity condition. Our study aims (1) to test how grazing density affects vegetation palatability and changes in vegetation functional groups near grazing hotspots, and then, (2) to analyze how regional climate alters the relations between grazing density and vegetation palatability.

Materials and Methods

Study site

The Mongolian steppe has distinct latitudinal patterns, ranging from the northern forest steppes to typical central and southern dry desert steppes (Fujita et al. 2012). Local herders move more than two times per year to feed their livestock, and they generally stay in summer and winter pastures longer than in spring and autumn pastures. Because summer pastures are actively grazed during vegetation growing seasons and are subject to higher selective-grazing pressure than other seasonal pastures, for this study, we focused on summer pastures. We selected surveying sites in the Tuin River Basin in Bayankhongor Aimag (Province) in central Mongolia. The Tuin River rises in the Khangai Mountains, a central Mongolian mountain range, and flows southward to the Gobi region, passing through a mesic forest steppe (FS) in the north, a xeric typical steppe (S) in the mid-ranges, and a dry desert steppe (DS) in the southern river basin. Three study sites were developed, one per steppe (Fig. 1).

To obtain enough livestock pressure and climate gradients, we designed a stratified field survey covering both local and regional scales. Three local pastures with regionally different aridity conditions were selected from desert-, typical-, and forest-steppe regions (i.e., dry, xeric, and mesic, respectively) along the river basin in central Mongolia. The three summer pasture sites were chosen to meet the
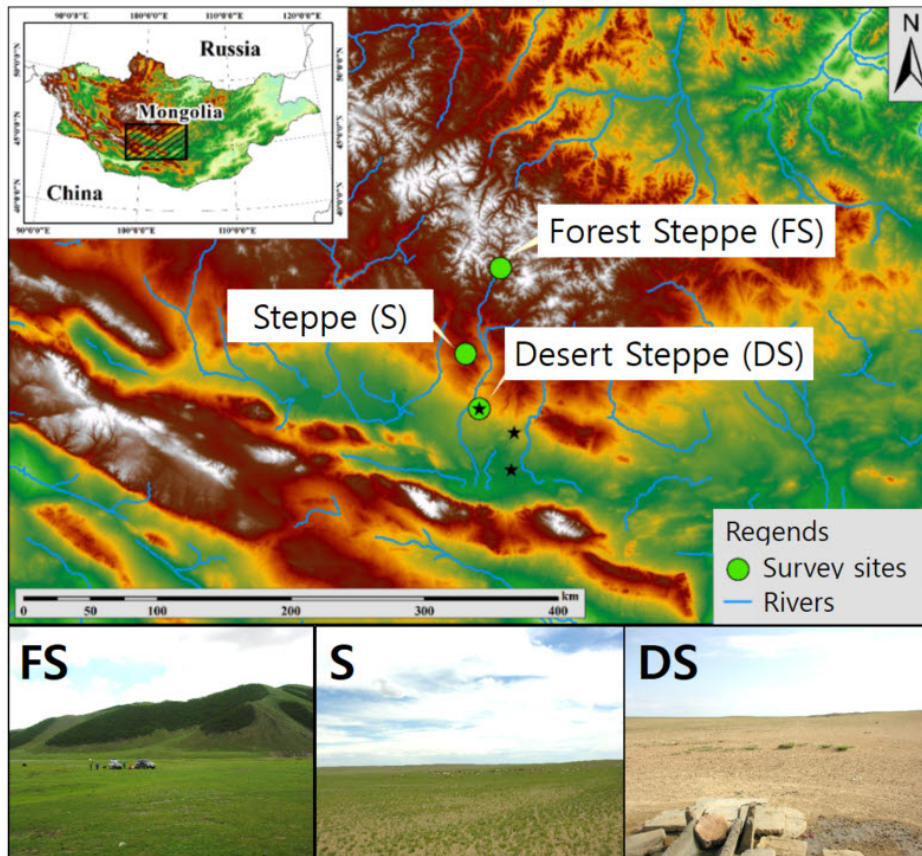
Fig. 1 A map of survey site locations (green circles) with photos of site landscape. Background map shows elevation ranging from 1,000 m (green color) to over 4,000 m (white). Blue lines are river networks. Asterisks are sites surveyed in Narantsetseg et al. (2018). FS: forest steppe; DS: desert steppe; S: typical steppe.

Table 1 Characteristics of the three summer pasture sites

Parameters	Desert steppe (DS)	Typical steppe (S)	Forest steppe (FS)
Site location	100° 46′ 29″ E; 45° 36′ 18″ N	100° 36′ 54″ E; 45° 58′ 4.4″ N	100° 54′ 34.6″ E; 46° 33′ 28.3″ N
Elevation (m)	1,600	1,978	2,202
Mean annual temperature (°C)[*]	5.2	1.9	0.5
Annual precipitation (mm)[*]	141.2	224.7	260.7
Total livestock number (sheep units)	1,147	1,836	4,090
Sheep (head)[†]	210	256	806
Cattle and yak (head)	3	30	344
Horse (head)	40	20	50
Goat (head)	710	1,400	967

[*]Values based on monthly weather data for the study period from weather stations located near each site. The monthly weather data were collected from the Institute of Meteorology and Hydrology, Mongolia. [†]Livestock data were collected through personal interviews with local herders in 2015.

site selection criteria of this study: different vegetation types, the cooperation of local herders with our long-term research, and distinct and discernable seasonal pastures. Across the sites, both annual precipitation and livestock population size increased northward from the DS to the FS site (Table 1). Livestock composition was considerably different among the sites. At the DS and S sites, the goat fraction was particularly high, whereas cattle and yak comprised a considerable portion of the FS site livestock fraction. In sheep units, the per-head grazing pressures of cattle, horses, and goats were 6, 7, and 0.9 times greater than that of sheep, respectively (Fernandez-Gimenez and Allen-Diaz 1999).

Vegetation survey and analysis

At each local pasture, coverage, biomass, and palatability of steppe community were surveyed along a transect with varying grazing pressure from a grazing hotspot (i.e., a well). The distance from the hotspot was used as a proxy of livestock pressure that weakens farther from the hotspots.

A vegetation survey was conducted from mid-July to late July between 2015 and 2018. At each site, a place where livestock could drink water was chosen as the grazing hotspot, and a 1-km line transect was developed from the hotspot for the vegetation surveys. In the each transect, surveying points were placed at 50, 100, 200, …, 900, and 1,000 m from the hotspot. Each point had triple replicate

plots for surveying species composition and coverage and collecting above-ground biomass samples. The plot size was 1 m^2 and 0.5 m^2 for the vegetation survey and biomass sampling, respectively. The plot locations were recorded using GPS observations for repeated measures in every year.

At each plot, we first took a vertical photo to record visual evidence of the pasture condition, and the vegetation parameters (i.e., the name and coverage of the species) were then recorded based on the Braun–Blanquet scale method (Van der Maarel 1979). After the vegetation survey, the standing biomass was clipped to the level of the soil surface and kept in a paper envelope during the fieldwork. It was then oven-dried for 48 hours at 80°C in the laboratory to determine the dry above-ground biomass. The species nomenclature followed Grubov (2001).

The recorded species were grouped into various plant functional types based on life form and palatability, in which two life forms (i.e., annual and perennial) and three palatability functional groups (i.e., palatable, impalatable, and trampling tolerant) were applied. The palatability of the plant species was determined following the palatability classification scheme of Damiran (2005), where the impalatable (IP) group is consumed but undesirable or not consumable by or toxic to livestock, and the palatable (P) group is preferred-and-desirable for livestock foraging. The trampling-tolerant (TT) group included plant types with rosette or creeping or short culm morphological shapes. Although TT plants generally belong to the IP group, they are a good indicator of livestock trampling, so we separated them from the IP group in the data analysis. After grouping, the species coverage was summed for each group to calculate functional-group coverage. In addition, the relative importance value (RIV%) of each plant group was calculated with the functional-group coverage to investigate the percent fraction of each group to total coverage. The RIV was estimated and named as follows:

$$IP\% = \left(\frac{IP_{cover}}{IP_{cover}+TT_{cover}+P_{cover}} \right) \times 100, \quad (1)$$

$$TT\% = \left(\frac{TT_{cover}}{IP_{cover}+TT_{cover}+P_{cover}} \right) \times 100, \quad (2)$$

$$P\% = \left(\frac{P_{cover}}{IP_{cover}+TT_{cover}+P_{cover}} \right) \times 100, \quad (3)$$

where IP_{cover}, TT_{cover}, and P_{cover} are coverages of the IP, TT, and P plants, respectively.

For the triple replicates at each surveying point, the coverage RIV and biomass from 2015 to 2018 were averaged to produce multi-year point-level data (hereafter called point data). Then, the point data were averaged again for each

transect to produce transect-averaged data (hereafter called transect data). With the transect data, we conducted regional cross-site comparison to characterize the relations of the observed data with aridity and livestock number. However, the covariance between aridity and livestock number (Table 1) made it uncertain whether the changes in the transect data were primarily due to climate or grazing density. Hence, to control the climate condition, the observed point data was used to analyze local along-transect spatial variation and its relation with grazing density at each site. Here, distance from the hotspot was used as a proxy of grazing density.

Tukey's HSD test was used to test the statistical difference of each parameter across the sites and along the transects. Relationships between vegetation coverage and biomass were examined using Pearson's correlation coefficient. The statistical analyses were undertaken using SPSS, Version 23 (IBM Co., Armonk, NY, USA).

Results

Cross-site regional comparisons of plant functional types, coverage, and biomass

The total plant coverage for each site was significantly different among the sites ($p < 0.05$), increasing from the DS (4.5%) to the S (11.0%) to the FS (33.1%) (Table 2). The biomass also increased significantly from the DS to the FS, resulting three times higher biomass at the FS (47.1 g m^{-2}) than at the DS (15.7 g m^{-2}) (Table 1). Both the coverage and the biomass were highest at the FS, lowest at the DS, and in the medium range at the S. The regional patterns of coverage and biomass closely followed the northward increase of precipitation from the DS to the FS (Table 1).

For the functional plant composition of all sites, P was the primary functional group explaining 74.2% of the plant coverage, followed by IP (19.5%) and TT (6.3%). Across the sites, the P% decreased significantly southward from 86.3% at the FS to 57.6% at the DS. This was similar for TT, which had a considerable reduction of TT% from 13.1% at the FS to 2.2% at the DS (Table 2). However, IP% varied oppositely to P% and TT% by increasing southward from 0.6% at the FS to 40.2% at the DS. In other words, IP coverage (40.2%) was comparable to P coverage (57.6%) at the DS ($p > 0.05$), where aridity was high, in spite of low livestock numbers (Table 1). This was clearly contrasted with the coverage fractions of low IP% and high P% at the FS (0.6% vs. 86.3%; $p < 0.05$), where aridity was low, but livestock numbers were high. As a whole, the sum of IP% and TT%, a proxy for livestock pressure, was highest at the DS (42.4%), lowest at the FS (13.7%), and medium at the S (21.3%), indicating that the proxy of livestock pressure follows the spatial pattern of aridity rather than livestock number (Table 2). On the other hands, for the life-form

Table 2 Site-level differences in plant functional type parameters in the study area

Parameter		Site		
		Desert steppe (DS)	Typical steppe (S)	Forest steppe (FS)
Vegetation coverage (%)		4.5 ± 0.7[c]	11.0 ± 1.8[b]	33.1 ± 4.7[a]
Biomass (g m^{-2})		15.7 ± 1.1[c]	34.2 ± 1.2[b]	47.1 ± 1.4[a]
(a) Palatability				
Coverage (%)	IP	1.8 ± 0.5[a]	1.9 ± 0.4[a]	0.2 ± 0.06[a]
	P	2.6 ± 0.3[c]	8.6 ± 1.3[b]	28.6 ± 3.9[a]
	TT	0.1 ± 0.04[b]	0.4 ± 0.07[b]	4.3 ± 0.8[a]
RIV (%)	IP%	40.2 ± 3.4[a]	17.6 ± 3.3[b]	0.6 ± 0.2[b]
	P%	57.6 ± 3.3[b]	78.7 ± 3.0[a]	86.3 ± 2.0[a]
	TT%	2.2 ± 0.7[b]	3.7 ± 0.5[b]	13.1 ± 1.9[a]
(b) Life form				
Coverage (%)	Annual	0.5 ± 0.2[a]	1.1 ± 0.3[a]	0.3 ± 0.08[a]
	Perennial	4.0 ± 0.5[b]	9.9 ± 1.5[ab]	32.8 ± 4.8[a]
RIV (%)	Annual	11.4 ± 2.5[a]	9.9 ± 2.0[a]	1.1 ± 1.6[a]
	Perennial	88.6 ± 2.5[a]	90.1 ± 2.0[a]	98.9 ± 1.6[a]

Values are presented as mean ± standard deviation.
IP: impalatable; P: palatable; TT: trampling tolerant; RIV: relative importance value.
Different letters indicate the significance of the Tukey's HSD test ($p < 0.05$).

groups, perennial plants accounted for roughly over 90% of total coverage, but the annual fraction increased with aridity from the FS (1.1%) to the DS (11.4%).

Along-transect variations of steppe plant community

Vegetation coverage and its RIV varied considerably with the distance from the hotspots along the transects (Fig. 2). The coverage was high near the hotspots at the S and FS but high in the middle of the transect at the DS (Fig. 2). At the DS, IP% was overall considerable and explained over 40% of the vegetation coverage by 600 m, with a peak of approximately 80% at 400 m. IP% was then reduced to approximately 20% beyond 700 m (Fig. 2A, B). At the S, IP occupied high fractions only near the hotspot; P became sharply dominant at over 80% from 200 m (Fig. 2C, D). In contrast to the DS and S, the FS had a negligibly small IP coverage but a meaningful TT% decreasing with the distance (Fig. 2E, F). These results indicate that livestock pressure (i.e., the distance from the hotspot) was apparently associated with the along-transect plant composition, indicating increased occupation of IP or TT plants near the hotspots. The pressure and composition were, however, nonlinearly related and sometimes indicated sharp composition transitions in the DS and S (one-way ANOVA $p < 0.05$).

By contrast, vegetation coverage was significantly correlated ($p < 0.05$) with biomass at each site, though the relationship was slightly weaker at the FS (r = 0.66) compared with 0.71 and 0.83 at the DS and S, respectively (Fig. 3). The slope between biomass and coverage was higher at the DS (4.8 g m^{-2} %$^{-1}$) and the S (3.2 g m^{-2} %$^{-1}$) than at the FS (1.2 g m^{-2} %$^{-1}$). The along-transect significant relationships between biomass and coverage were also reproduced

across the sites (r = 0.83; $p < 0.01$), suggesting that the biomass-coverage relationship was conservative in the steppes in spite of climate and livestock pressure gradients. The weaker correlation and lower slope at the FS seem relevant to the shorter standing biomass at the FS (3.1 ± 0.1) than at the DS (5.6 ± 0.8) and the S (13.9 ± 0.5), and also, the increased fraction of TT plants with creeping morphology at the FS. This implicates high livestock pressure at the FS, possibly higher than that at the DS and the S, in terms of forage consumption, leaving shorter standing biomass. This implication seems reasonable considering high livestock numbers at the FS, roughly four times greater than the DS in sheep units (Table 1), but it conflicts with the earlier finding of lower livestock pressure at the FS, with lower IP% and TT% than at the other sites (Fig. 2). We address this matter in the discussion section.

Discussion

Diversity and the fraction of plant species cover are determined by multiple environmental factors, such as climate and human activities (Stohlgren et al. 2000). Precipitation is the primary abiotic factor that determines the regional geographical affinity of herbaceous plant communities in arid and semi-arid grasslands (Schmidt et al. 2005). However, anthropogenic land-use activities, such as livestock husbandry, alter the composition and function of plant communities more spatially and heterogeneously (Hoshino et al. 2009; Yoka et al. 2013), both of which collectively determine the characteristics of current plant communities (Zerbo et al. 2016). Despite extensive livestock husbandry in the Mongolian rangelands, it is little understood how regional climate and local livestock graz-
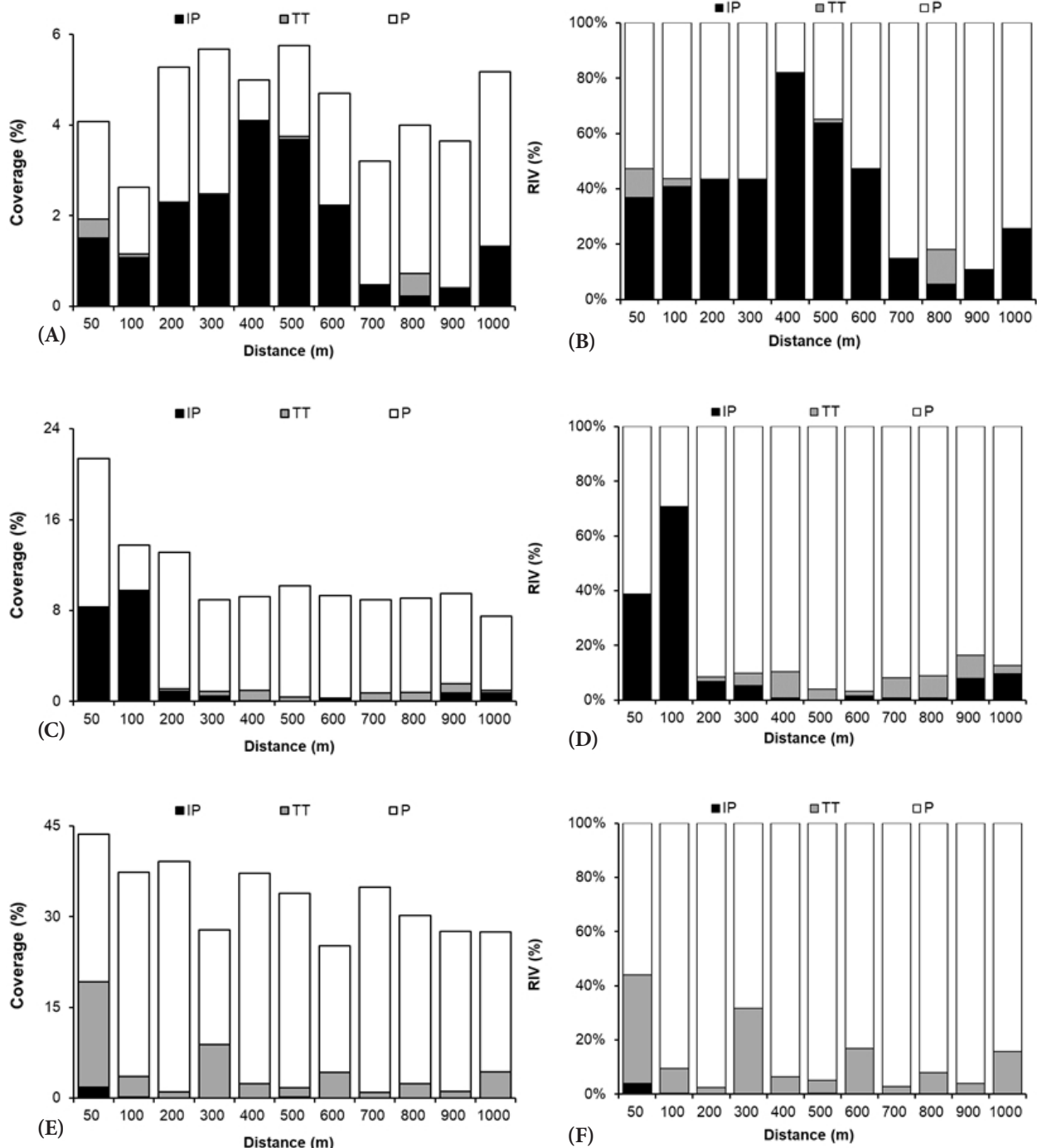
Fig. 2 Coverage and relative importance value (RIV%) of functional plant type composition along the (**A**, **B**) desert steppe, (**C**, **D**) typical steppe, and (**E**, **F**) and forest steppe transects. P: palatable; IP: impalatable; TT: trampling-tolerant.

ing determine current plant communities at local and regional scales. To answer this question, we investigated the plant species composition and biomass at local and regional scales with distinct gradients of livestock grazing intensity and precipitation in nomadic Mongolian rangelands.

Our field surveys indicate that the standing biomass and palatability type of plant communities varies at both the local and regional scales. It seems that their spatial patterns are controlled by aridity and grazing intensity in various ways. In one extreme, more precipitation facilitates more

biomass production (Clark Martin and Cable 1974; Fujita et al. 2012), allowing a higher stocking rate, in which production is high enough to support livestock consumption, which leaves high standing biomass but results in low IP fractions in the plant community (Table 2). In the opposite case, less precipitation produces less biomass production, which supports a lower stocking rate on the pasture, and production merely meets livestock consumption, resulting in low standing biomass but a high IP fraction extensively distributed (see Fig. 2) (Narantsetseg et al. 2018). We pro-
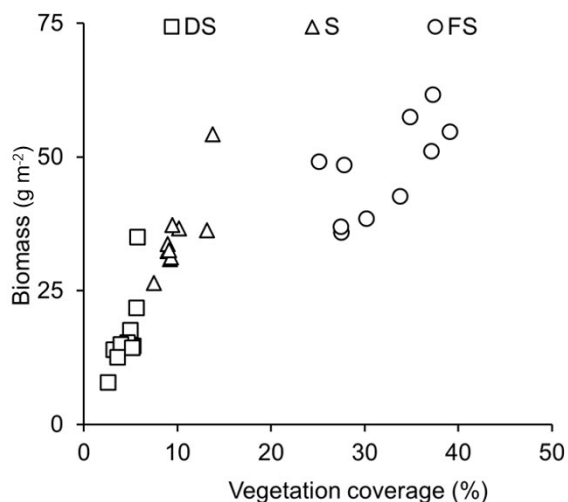
Fig. 3 Correlation between vegetation biomass (g m⁻²) and coverage (%) at the desert steppe (DS), typical steppe (S), and forest steppe (FS) sites.

pose that the FS and the DS correspond to the former and latter cases, respectively.

In this study, livestock numbers and distance from the grazing hotspots were used as proxies for grazing intensity at the regional and local scales, respectively. Grazing intensity increases selective-grazing and trampling pressure on palatable plants, which can disturb the natural relationships of inter-specific competition in pasturelands, enhancing the survival chances of IP and TT plants (Okayasu et al. 2012). Okayasu et al. (2012) suggested that IP coverage is naturally very sparse in steppes, usually less than 10% of total coverage in natural or negligibly degraded areas (Amiri et al. 2008). According to a rough threshold (i.e., 10%) of the natural IP fraction, the pastures in our study exhibited a gradient from light for FS (0.6 ± 0.2%) to severe degradation stages for the S (17.6 ± 3.3%) and DS (40.2 ± 3.4%) with respect to IP RIV (Table 2). When TT was included in IP, the sum of the IP and TT fractions roughly ranged from 15% to 45% from FS to DS, which belonged to the severe degradation stages even from FS.

This study shows that the degradation stages also varies locally from the grazing hotspots in Mongolian pastureland at the local scale. Narantsetseg et al. (2018) reported similar spatial patterns at multiple desert-steppe hotspot areas near our study sites (see locations marked with asterisk in Fig. 1). This study reconfirmed and extended such patterns across regional steppe vegetation communities in Mongolian rangeland. Both studies proposed that the grazing-induced change in plant communities (i.e., high IP fraction) can spread farther from the hotspots with more selective-grazing forcing. This inference suggests stronger selective-grazing pressure at the DS than at the other sites since the IP fraction was considerably high; up to 600 m away from the hotspot at the DS (Fig. 2B). Whereas, the range of high IP fraction was limited within 200 m at the S

(Fig. 2D) and the IP fraction was negligible at the FS (Fig. 2F). It further implicates applicability of the spatial measure of the high-IP range for a proxy of selective-grazing pressure. The low standing biomass and high and extensive IP fraction at the DS imply that the balance between foraging supply and livestock demand is potentially threatening the sustainability of pasturelands and livelihoods more than livestock density only.

By contrast with the negligible IP fraction, the TT fraction was remarkably high and extensively distributed at the FS (Fig. 2F). Moreover, it was found that the FS has short vegetation and a biomass-coverage relation different from other sites (Fig. 3). The results all together implicate that vegetation community at the FS has been receiving high trampling and grazing pressures but less selectively by large livestock herds. This inference seems reasonable since large livestock accounts for 60% of total livestock number in sheep units at the FS (Table 1) and yaks are bulk grazers that cut forages short to the bottom less selectively. Our results suggest the TT fraction as a useful indicator of grazing effect on steppe vegetation community with many bulk grazers.

Conclusions

This study analyzed steppe vegetation characteristics at grazing hotspots areas in Mongolian pastures. Results showed considerable local and regional spatial variations in vegetation palatability and life forms at grazing hotspots areas with grazing intensity and aridity. Though the P plants accounted for the major functional group of palatability among the P, IP, and TT at the three steppe sites, the occupation rates of each function group varied spatially. The IP fraction increased regionally with aridity across the pastures but decreased locally with the grazing intensity within the pastures. The high fraction and wide distribution of IP plants at the DS implies that even the low stocking rate is high enough to reduce the palatability of the plant community. By contrast, the low IP but high TT fractions and wide distribution of TT plants at the FS indicate that trampling and bulk grazing of large livestock herds enhanced the survival of short, creeping TT plants. We suggest that the TT fraction is a better indicator of steppe degradation in pastures with many bulk grazers than the IP fraction. In conclusions, the livestock grazing at the three hotspot areas already changed steppe vegetation characteristics to reduce vegetation palatability by increasing either the IP or the TT fractions. The change was most remarkable at the DS but still detectable at the FS. Hence, we suppose that the change of vegetation palatability at grazing hotspot areas is a widespread phenomenon across climate regimes in Mongolian steppes. With more extensive field evidences from other studies, our data col-

lected in this study would contribute to test the prediction in future study.

Abbreviations
P: Palatable plant
IP: Impalatable plant
TT: Trampling-tolerant plant
P%: Coverage percent of palatable plant
IP%: Coverage percent of impalatable plant
TT%: Coverage percent of trampling-tolerant plant
FS: Forest steppe
S: typical steppe
DS: Desert steppe
RIV: Relative importance value

Author's contributions
NA and SK designed this study and wrote the manuscript. JK and NC participated in field works. BS participated in writing the manuscript.

Availability of data and materials
The datasets generated during and/or analyzed during the current study are available from the corresponding author on request.

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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