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Soil salinity drives vegetation changes by grazing exclusion in semiarid regions

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Abstract

Understanding the responses of vegetation to grazing exclusion along a salinity gradient is useful for the management of grasslands. We studied the responses of vegetation to grazing removal (ungrazed areas) in three semiarid regions with different soil salinity levels: non-saline, moderately saline and hyper-saline. The results showed that Bray-Curtis dissimilarity between grazed and ungrazed areas were highest in the non-saline region. In the hyper-saline region, the grazing removal had no significant effect on any of the diversity indices, while in the non-saline regions, vegetation changes were occurred by grazing exclusion at the highest magnitude. Generally, the magnitude of vegetation changes by livestock grazing exclusion was decreased along the soil salinity gradient. This research could help to understand how disturbances and stresses interactively influence grasslands dynamics in semiarid regions and to understand the effects of grazing on grassland dynamics and sustainability in deserts in the context of salinization.

INTRODUCTION

Grazing plays an essential role in rangeland conservation, and well-planned grazing management promotes soil quality, biodiversity and related ecosystem functions and services (Liang et al., 2021; Milazzo et al., 2023). Carefully designed grazing system is the most vital management scheme for utilization of rangeland habitats fulfilling both economic and ecological objectives by maintaining and regulating plant yield, cover, species richness, species composition and diversity in the grazed areas (Duan et al., 2023). In semiarid regions, grazing could effectively control weeds and change community composition in agroforestry systems (Tohiran et al., 2017), alter community structure and species diversity in grasslands (Li et al., 2021) and mediate plant-soil interactions in shrublands (Navarro-Perea et al., 2023). However, the magnitude of changes on vegetation due to changes in grazing intensity might vary depending on the biotic and abiotic factors in these fragile ecosystems (Barthelemy et al., 2019; Rahmanian et al., 2019; Navarro-Perea et al., 2023).

Several biotic factors found to be driving the grazing-vegetation interaction. Grazing intensity has been considered as one of the most important factors together with livestock type (Tóth et al., 2018), vegetation type (Török et al., 2018a) and grazing system (Török et al., 2016). A literature review showed that many studies have conformed with the moderate-disturbance hypothesis (Fox, 1979) that moderate grazing increases species diversity, while heavy grazing does the opposite (Wang et al., 2018). The medium to low stocking rates had no effects on plant species richness and diversity, while medium to high stocking rates had a negative effect on plant species richness (Pizzio et al., 2016). It was found that heavy grazing improved grassland species diversity and in a study in Hungary, cattle grazing in high level of intensity increased grassland species richness (Toth et al., 2018). Beside the biotic factors, abiotic factors such as edaphic, topographic and climatic parameters have been shown as factors significantly affected the relationship between vegetation and grazing. Tahmasebi Koheyani et al. (2009) observed greater differences in plant community composition between grazed and ungrazed plots in nutrient-rich sites, compared to sites with a lower nutrient availability. In California, cessation of grazing decreased native species richness in grasslands, in relation to topography (Gornish et al., 2018). Rahmanian et al. (2019) reported that in Iran, effects of livestock grazing removal on vegetation characteristics varied depending on the climatic conditions such as precipitation and Martin et al. (2022) found significant effects of soil and grazing interaction on vegetation characteristics. However, none of these studies have addressed the effects of livestock grazing removal on vegetation in relationship with soil salinity stress in semiarid ecosystems.

Drylands occupy 40% of Earth's surface and harbor 40% of the human population (Reynolds et al. 2007) that their ecosystem services to human-being are numerous. Drylands supply fiber and food, contribute to the global economy with 30% of cultivated plants and livestock breeds adapted to dry conditions (Lee, Schaaf and UNESCO 2008), provide forage production and improve the preservation and resource status of soil, while maintaining biodiversity (Gratani et al. 2013). As a result, due to drylands importance in human life around the world, many studies have been published in relation with livestock grazing in these ecosystems. For instance, it has been shown than moderate grazing acted as a positive driver of ecosystem processes in arid and semiarid ecosystems, promoting important ecosystem functions, such as soil microbial activity, nitrogen and organic material stocks and, plant growth, production and diversity (e.g. Liu et al. 2012; Moret-Fernandez et al. 2021). In contrast, overgrazing had substantial negative effects on ecosystem functions and services, making the ecosystems more vulnerable to global change and desertification (Navarro-Perea et al., 2023). However, studies on the effects of grazing removal on vegetation in relationship with environmental stresses are scarce.

Among drylands semiarid regions are considered as a subtype of dryland characterized by a mean annual precipitation between 200 and 700 mm (Kašanin-Grubin et al., 2002). The semiarid regions of Iran and the Middle East in general, have experienced a long history (>4,000 years) of livestock grazing (Rahmanian et al., 2019). Although there is a large body of studies on plant responses to grazing/grazing removal worldwide in semiarid rangelands, focusing mostly on species richness and diversity (e.g. Tessema et al., 2011; Navarro-Perea et al., 2023), most of the current knowledge of vegetation responses to grazing/grazing removal is based on local studies under specific environmental settings. In this study, we compared the effects of grazing removal on vegetation diversity and composition in historically grazed areas under contrasting stress provided by different levels of soil salinity, which provide novel information in the context of understanding grazing effects on vegetation. We assumed that the magnitude of vegetation changes (composition, functional group abundance, total richness and total diversity) induced by livestock grazing exclusion would be strongly influenced by soil salinity rate in semiarid regions. Generally, soil salinity together with increasing levels of salinization is one of the main challenges of contemporary land management. Climate change with more persistent droughts is expected to increase this trend forming an increasing challenge for the future (Negacz et al., 2022). According to the FAO, the global area of salt-affected soils covers 424 million hectares of topsoil (0–30 cm) (FAO, 2021) and studies showed that one billion hectares of land are negatively affected by salinity (e.g. Qadir et al., 2014). Therefore, there is a need to assess the relationship between grazing and vegetation in these lands particularly when accompany with different levels of salinity in soil. Given the sensitivity of arid lands to disturbances and couple with stresses in these fragile ecosystems (Zhuang et al., 2021; Ge and Liu, 2021), we hypothesized that changes in vegetation due to removal of livestock grazing would be increased along the soil salinity level; highest increases in vegetation cover, richness and diversity due to grazing removal would be occurred in regions with highest salinity content in soil.

MATERIAL AND METHODS

Study area

We selected three semiarid regions for sampling, characterized with different levels of soil salinity in northern Iran, Golestan and Mazandaran provinces. There are very homogenized climatic conditions, with a mean annual rainfall varying from 290 to 310 mm per year in all selected regions. Sheep is the dominant grazer in all three regions with a few goats (ca. 5 animal unit per ha, each sheep one and each goat 0.8 animal

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unit are accounted in standard measuring in Iran). Although different types of grazing animals may differ in their effects on vegetation (Tóth et al., 2018) and/or soil (Eldridge et al., 2017), for sheep and goat a quite similar grazing behavior and impact on herbaceous plant communities; as these animals are capable of picking individual plants or plant parts such as flowers, pods, and young shoots with their incisors (see also Jerrentrup et al., 2015). In a small part of the area of each region (40-150 ha), grazing animals had been fenced (ungrazed areas) for at least 20 years prior to the field work (2022) to study plant succession after removal of grazing (Figure 1). The Iranian Research Institute of Forests and Rangelands supported the fenced sites trials in order to provide experimental evidence for their habitat management strategies for the areas. Therefore, the fenced sites were constructed in places where vegetation was representative of the entire area to assess aboveground vegetation changes after grazing removal in each region. Three selected regions were i) Gonbad-e-Kavoos (hereafter called Gonbad) in Golestan province: the climate is semiarid with average annual temperature and rainfall, 18.5 °C and 290 mm, respectively. The salinity content is very high with electrical connectivity (EC) > 16 dS/m (extremely saline soil - hypersaline). ii) Peshert in Mazandaran province: the climate is semiarid with average annual temperature and rainfall, 12.0 °C and 300 mm, respectively. The salinity content is very low with EC < 2 dS/m (non-saline soil). iii) Chaparghoymeh (hereafter called Chapar) in Golestan province: the climate is semiarid with average annual temperature and rainfall, 17.1 °C and 291 mm, respectively. The salinity content is intermedium with EC between 4-8 dS/m (moderately saline soil) (Table 1). For soil salinity classification, agronomic classification of soil salinity based on EC was used (Hammam and Mohamed, 2020).

Vegetation and soil sampling

In each region in both grazed and fenced site (hereafter called ungrazed area), a sampling site was selected. The sampling site was an area that could be considered to be representative of the entire habitat in that location (Heady and Child, 1994); the size of the two sampling sites was similar in grazed and ungrazed areas (600×600 m) in all regions. Inside each sampling site, 15 (2×2 m) quadrats were randomly placed in both grazed and ungrazed areas. Then, vegetation composition was estimated during the growing season of 2022. The vegetation cover was recorded in the quadrats by visual estimation of each plant species in each quadrat (Heady and Child, 1994). It is known that the cover of vegetation is a health indicator of the rangelands (Karatassiou et al., 2022). In addition, 5 soil cores were randomly collected and combined for each quadrat for chemical analyses. The soil cores were collected from 0-10 cm depth using an auger of 7 cm diameter.

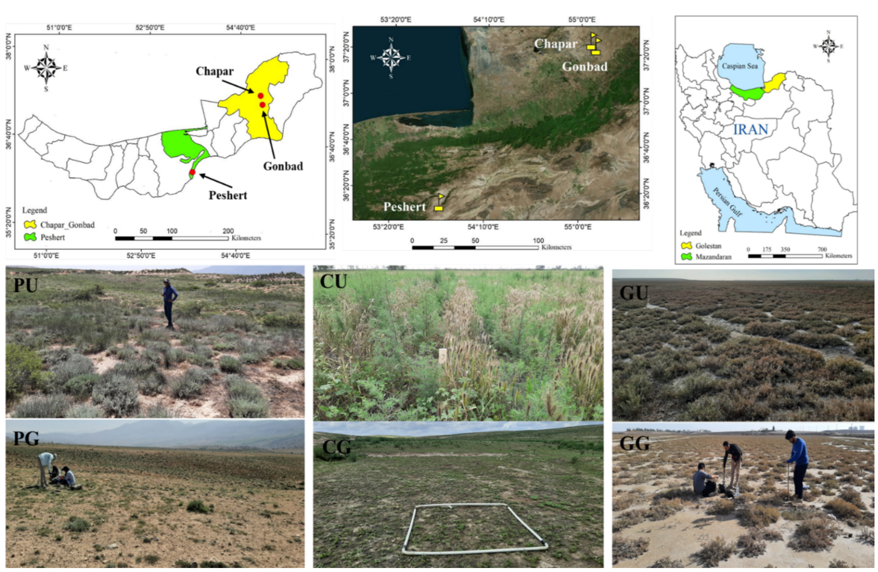

Figure 1. Geographic location of the study regions, Peshert, Chapar and Gonbad in two adjacent provinces

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(Mazandaran and Golestan) in Northern Iran; PU: Peshert-ungrazed, PG: Peshert-grazed, CU: Chapar-ungrazed, CG: Chapar-grazed, GU: Gonbad-ungrazed and GG: Gonbad-grazed.

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Soil laboratory processes

Soil pH and EC were assessed in soil–water suspension in the ratio of 1:2.5 (weight/volume). Soil pH was measured using a glass-electrode pH meter, while EC used a conductivity meter (Zandi et al., 2017). Organic carbon was determined by the loss of ignition method (Lal et al., 2001) and total soil N was assessed by wet oxidation using the Kjeldahl method (Zagal et al., 2009).

Statistical analyses

Dissimilarity of the species composition between grazed and ungrazed sites was calculated with the qualitative Sørensen (Sørensen, 1948) and quantitative Bray–Curtis dissimilarity indices. The Sørensen dissimilarity index is well known and widely applied, especially in the assessment of community dissimilarity (Hao et al., 2019) using $\frac{B+C}{2A+B+C}$ formula in which B and C are the number of species unique to each of the two grazed and ungrazed sites and A represents the number of species shared by grazed and ungrazed sites. We carried out the function "anosim" (analysis of similarities) of the "vegan" package of the R software, to measure the Bray–Curtis dissimilarities in plant composition between the grazed and ungrazed quadrates. We used permutation tests (999 permutations— Permutational Analysis of Multivariate Dispersions) to test the significance of the differences between grazed and ungrazed sites.

Total cover percentages and species richness and, the cover percentage of each morpho-functional group (annuals (grasses + forbs), perennials (grasses + forbs), forbs (annuals + perennials), grasses (annuals + perennials) and shrubs and Raunkiær's life-form scheme (Ellenberg and Mueller-Dombois, 1967) in each quadrat were calculated. The Raunkiær system is a system for categorizing plants using life-form categories (Raunkiær, 1934). In addition, diversity indices (Shannon, Simpson, Margalef and Menhinick) were calculated in each quadrat using PAST software. The vegetation diversity indices were measured according to Magurran (2004).

The data were checked for normality distribution using the Kolmogorov-Smirnov test. Two-way ANOVA (general linear model) was used to compare vegetation characteristics between different regions and between grazed and fenced areas. The regions (nominal) and the presence of grazing (binary) were included as fixed factors, while vegetation characteristics were introduced as dependent variables. Since the interactions between region and grazing were significant in most cases, we also used unpaired t tests to compare vegetation characteristics between grazed and fenced areas in each region, separately. All statistical analyses were done using SPSS 23.0 (SPSS Inc, USA; www.spss.com).

RESULTS

In Peshert, Chapar and Gonbad, the averages values of soil EC were 1.3, 4.2 and 17.7 ds/m, respectively and therefore, Peshert, Chapar and Gonbad regions can be considered as non-saline, moderately saline and extremely saline, respectively (Table1). In all regions, soil was poor in organic carbon and nitrogen contents particularly in grazed areas (Table 1).

Table 1. Mean values of climatic and edaphic characteristics in three sampled regions in Golestan province, Iran. G: Grazed area, U: Ungrazed area

Region	Climate	Coordinates	Mean annual precipitation (mm)	Soil pH	Soil pH	Soil EC (ds/m)	Soil EC (ds/m)	Soil organic carbon (%)	Soil organic carbon (%)	Nitrogen (%)
				U	G	U	G	U	G	U

Region	Climate	Coordinates	Mean annual precipitation (mm)	Soil pH	Soil pH	Soil EC (ds/m)	Soil EC (ds/m)	Soil organic carbon (%)	Soil organic carbon (%)	Nitrogen (%)
Peshert	Semiarid	53° 46‘ 39” 36° 14‘ 19”	300	8.49	8.31	1.2	1.4	2.39	1.16	0.17
Chapar	Semiarid	55° 05‘ 33” 37° 25‘ 57”	291	9.23	8.73	4.1	4.3	1.85	1.73	0.10
Gonbad	Semiarid	55° 08‘ 11” 37° 23‘ 39”	290	8.34	8.61	17.4	18.0	1.27	1.19	0.06

Vegetation composition and dissimilarities

In total, 52, 34 and 18 species were observed in Peshert, Chapar and Gonbad, respectively. In Peshert, 35 and 43 species were found in grazed and ungrazed quadrats, respectively and 26 species were common in both grazed and ungrazed quadrats. In grazed quadrats, *Artemisia sieberi* and in ungrazed quadrats both *A. sieberi* and*Festuca ovina* were the most abundant species. In Chapar, 32 and 21 species were found in grazed and ungrazed quadrats, respectively and 19 species were common in both grazed and ungrazed quadrats. In grazed quadrats, *Medicago minima* and *Plantago coronopus* and in ungrazed quadrats *Puccinella distance* and *Hordeum murinum*were the most abundant species. In Gonbad, 13 and 14 species were found in grazed and ungrazed quadrats, respectively and 9 species were common in both grazed and ungrazed quadrats. In grazed and ungrazed quadrats,*Halocnemum strobilaceum* was the most abundant species (Appendix 1).

The Sørensen dissimilarity index in Peshert, Chapar and Gonbad was 0.351, 0.283 and 0.286, respectively. As shown by the permutation tests with Bray–Curtis dissimilarities, vegetation composition differed significantly between grazed and ungrazed quadrats in Peshert and Chapar ($P<0.01$). However, the differences between grazed and ungrazed areas were non- significant in Gonbad (Figure 2).

Plant functional groups

Two-way ANOVA results demonstrated that most of the measured functional groups (annuals, perennials, forbs, grasses, shrubs, therophytes, hemicryptophytes and chamaephytes) significantly differed while total cover percentages were not differed between the regions. The main significant effect of grazing removal on total cover percentages, annuals, perennials, grasses, therophytes and cryptophytes was detected (Table 2 and 3). The effect of region × grazing removal interaction on total cover percentage, the cover percentages of annuals, perennials, grasses, therophytes and hemicryptophytes was significant (Table 2 and 3). In Peshert, total cover and the cover of most functional groups were significantly different between grazed and ungrazed areas while no significant differences of total cover and the cover of functional groups were observed between grazed and ungrazed areas in Gonbad region (Table 4). Total cover, the cover of annuals (therophytes) and grasses were significant between grazed and ungrazed areas in Chapar region (Table 4).

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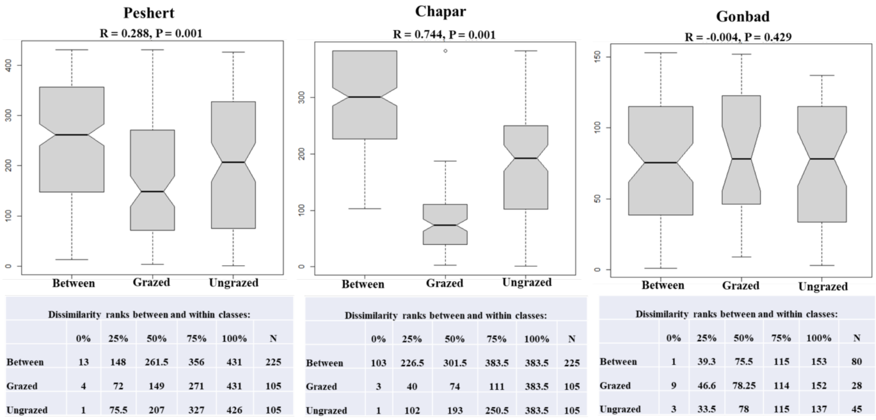

Figure 2. Using the permutation tests (999 permutations), the analysis of dissimilarities provides a way how to test the differences between grazed and ungrazed quadrats in each region. The figure shows there are significant differences in Bray–Curtis dissimilarities, expressing the internal heterogeneity in plant composition, between grazed and ungrazed quadrats in Peshert and Chapar regions (P<0.01).

Richness and diversity indices

We found that total species richness and diversity differed significantly between the regions (). The main significant effect of grazing removal on total richness and diversity indices was detected (Table 2 and 3). The effect of region × grazing removal interaction on total richness and diversity indices was significant (Table 2 and 3). Significant difference of total richness between grazed and ungrazed was observed only in Chapar region (Table 4). In Peshert, all diversity indices were significantly found higher in grazed than ungrazed areas (Fig. 3). In Chapar, the values of Shannon and Menhinick indices in grazed area were higher than ungrazed areas while there was no significant difference of Simpson and Margalef indices between grazed and ungrazed areas (Fig. 3). In Gonbad, the grazing removal had no significant effect on any diversity indices (Fig. 3).

Table 2. Results of general linear models, testing the effects of region (salinity), grazing and region × grazing interaction on vegetation characteristics.

		df	Mean square	F	p-value		Mean square	F	p-va
Total cover	Region	2	190.25	0.84	0.43	Annuals	5323.81	50.78	0.00
	Grazing	1	8457.15	37.38	0.00		2702.24	25.77	0.00
	Region × Grazing	2	2112.86	9.33	0.00		1935.50	18.46	0.00
Perennials	Region	2	3510.58	17.22	0.00	Forbs	2963.81	18.32	0.00
	Grazing	1	1605.98	7.87	0.00		4.89	0.03	0.86
	Region × Grazing	2	779.75	3.82	0.03		0.79	0.05	0.99
Grasses	Region	2	1824.44	15.72	0.00	Shrubs	5910.12	31.17	0.00
	Grazing	1	5356.06	46.16	0.00		462.72	2.44	0.12
	Region × Grazing	2	2411.73	20.79	0.00		337.07	1.78	0.17
Therophytes	Region	2	6838.75	79.84	0.00	Cryptophytes	7.30	1.44	0.24
	Grazing	1	3982.50	46.49	0.00		1.04	4.15	0.04
	Region × Grazing	2	2886.88	33.70	0.00		12.27	2.42	0.09
Hemicryptophytes	Region	2	3958.27	23.17	0.00	Chamaephytes	940.87	9.16	0.00
	Grazing	1	223.52	1.31	0.25		241.27	2.35	0.13
	Region × Grazing	2	842.83	4.93	0.01		65.56	0.63	0.53
Simpson	Region	2	2.14	96.88	0.00	Shannon	13.32	88.47	0.00
	Grazing	1	0.25	11.46	0.00		0.96	6.37	0.01

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		df	Mean square	F	p-value		Mean square	F	p-va
	Region × Grazing	2	0.06	2.94	0.05		0.23	1.50	0.22
Menhinick	Region	2	13.56	53.13	0.00	Margalef	35.15	72.21	0.00
	Grazing	1	1.81	7.08	0.01		0.63	1.29	0.26
	Region × Grazing	2	1.08	4.22	0.02		1.78	3.66	0.03

Table 3. Mean total cover percentages (± SE), mean functional groups percentages (± SE), mean richness (± SE) and diversity indices (± SE) in the study areas

		Main effect of grazing in all three regions	Main effect of grazing in all three regions	Main effect of grazing in all three regions	Main effect of grazing in all three regions	Main effect of region on both grazed and un-grazed quadrats	Main effect of region on both grazed and un-grazed quadrats	Main effect of region on both grazed and un-grazed quadrats	Main effect of region on both grazed and un-grazed quadrats	Main effect of region on both grazed and un-grazed quadrats
	Responses	Grazed	SE	Ungrazed	SE	Peshert	SE	Chapar	SE	Gonbad
	Total cover	27.21	2.20	52.02	3.01	38.36	3.61	42.73	4.29	37.88
	Total richness	6.33	0.64	6.69	0.58	9.83	0.48	6.13	0.42	2.76
Functional groups	Annuals (Therophytes)	6.28	1.22	19.77	3.61	6.40	1.00	27.73	4.07	0.33
	Perennials	20.89	2.30	32.25	3.15	31.93	3.29	15.00	2.14	37.55
	Forbs	13.44	2.04	13.27	2.74	10.50	1.34	23.46	3.39	1.27
	Grasses	2.86	0.66	22.45	3.27	13.40	2.28	19.43	4.30	1.22
	Shrubs	11.02	2.49	17.72	3.32	13.53	3.38	2.83	0.71	35.38
	Cryptophytes	1.00	0.52	0.22	0.09	0.60	0.13	0.23	0.10	1.22
	Hemicryptophytes	16.42	2.16	21.12	3.12	19.03	2.78	8.70	1.85	35.38
	Chamaephytes	3.39	1.10	7.37	2.22	11.56	2.64	2.47	1.43	0.16
	Simpson	0.59	0.04	0.43	0.04	0.70	0.03	0.56	0.03	0.09
	Shannon	1.30	0.11	0.98	0.11	1.72	0.09	1.14	0.07	0.17
	Menhinick	1.33	0.89	0.92	0.66	1.81	0.14	0.93	0.06	0.31
	Margalef	1.70	0.21	1.40	1.08	2.62	0.18	1.28	0.10	0.18

Table 4. Results of non-paired t -tests comparing percentage cover between grazed and ungrazed areas in each region.

Responses	Peshert	Peshert	Peshert	Chapar	Chapar	Chapar	Gonbad	Gonbad	Gonbad
	df	t-value	Sig	df	t-value	Sig	df	t-value	Sig
Total cover	28	5.13	0.00	28	7.61	0.00	28	0.99	0.94
Total richness	28	-0.87	0.39	28	2.32	0.03	28	1.06	0.30
Annuals (Therophytes)	28	3.09	0.00	28	5.55	0.00	28	-1.72	0.10
Perennials	28	4.11	0.00	28	1.49	0.15	28	0.01	0.99
Forbs	28	0.07	0.94	28	0.06	0.95	28	1.42	0.17
Grasses	28	4.58	0.00	28	7.47	0.00	28	-1.25	0.23
Shrubs	28	2.03	0.05	28	0.59	0.55	28	0.14	0.89

Responses	Peshert	Peshert	Peshert	Chapar	Chapar	Chapar	Gonbad	Gonbad	Gonbad
Cryptophytes	28	-2.80	0.00	28	0.96	0.34	28	-1.25	0.23
Hemicryptophytes	28	3.09	0.00	28	-1.60	0.12	28	0.14	0.88
Chamaephyte	28	1.21	0.24	28	1.79	0.08	28	-1.12	0.28

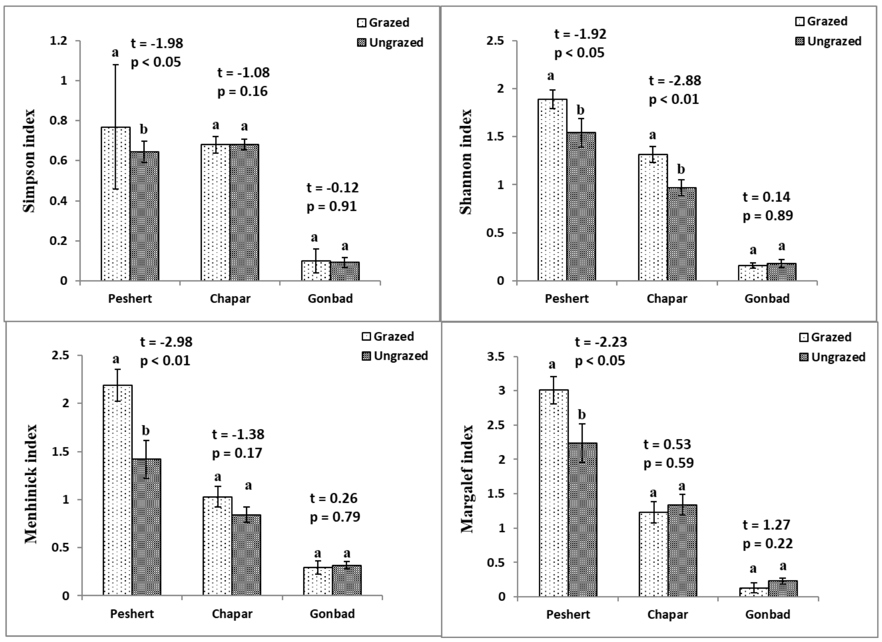

Figure 3. Effects of grazing removal on diversity indices in each region. Small letters show significant differences between grazed and ungrazed quadrates.

DISCUSSION

We confirmed our hypothesis partly, that the effect of grazing removal on vegetation was strongly region dependent but haven't confirmed that the magnitude of the grazing removal effects was higher in more stressful conditions caused by increased soil salinity. Our results indicated that the magnitude of vegetation changes by livestock grazing exclusion was decreased along the salinity of soil. Generally, two opposing directions of changes in semi-arid rangeland vegetation in response to livestock grazing exclusion have been reported (Gebremedhn et al., 2023). First, it is indicated that changes in vegetation by grazing exclusion are primarily driven by climatic conditions (e.g. Booker et al. 2013). Second, it is reported that the grazing intensity is the most important driver of vegetation changes in semiarid areas (e.g. Pricope et al. 2013). Indeed, these opposed results could have strong influences on the development of rangeland grazing management over the years in these areas. Now, it is difficult to predict which type of grazing system provides the highest benefits together with facilitation on positive vegetation changes, since we indicated that in similar climatic condition and grazing intensity, changes in vegetation by grazing exclusion is different depending on the stresses content such as soil salinity in the area.

Main effects of region on vegetation

We showed that all species, functional groups and diversity metrics were significantly affected by the sampled regions. The observed differences in these metrics are likely influenced by the different species pools of the regions (see also Török et al., 2018b). It is clearly based on the concept of habitat-specific species pools (Helm et al., 2015), that different type of grasslands have more or less different sets of species. In our case,

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non-saline grasslands had at least two to three times higher number of species compared to saline ones (52 species vs. 32 and 18 species), which can potentially establish in suitable habitat conditions. As a result, the differences between grassland composition could be strongly linked to the different species pools of grasslands subjected to grazing. However, both deterministic factors like the environmental heterogeneity and stochastic factors like dispersal limitations may shape the plant community species assembly in a semiarid region (He et al., 2023). Environmental differences particularly soil salinity in three regions might have a strong effect on changes in species composition and diversity indices in our studied regions. It was reported that in semiarid regions, environmental filtering plays a more critical role than plant competition and dispersal limitations in driving the assembly of plant communities (He et al., 2023). However, the variations in plant species composition in different regions may be partly related to stochastic processes such as seed dispersal, evolutionary and historical factors (Varzinczak et al., 2018) that need to be studied in the future projects.

Main effects of grazing exclusion on vegetation

Grazing exclusion, as a restoration measure for recovering grassland ecosystem functions and services, has been extensively applied and considered to be rapid and effective (Filazzola et al., 2020; Li et al., 2022). Our study showed that in general, grazing exclusion had a significant positive effect on the plant cover, species and functional diversity of grasslands in northern Iran. This is consistent with previous studies in the semiarid rangelands (e.g. Li et al., 2012; Wang et al., 2014; Bakhshi et al., 2020; Karatassiou et al., 2022; Li et al., 2022). In general, livestock herbivores like sheep primarily focus on forage quality, having a high selectivity in grazing on plants (e.g. Bakker and Olff, 2003). Therefore, the effects of grazing on different functional groups supposed to be different. However, removal of grazing resulted in increasing of cover of most plant functional groups with the exception of cryptophytes and forbs. In accordance with studies from grasslands (e.g. Tahmasebi Koheyani et al., 2009), we detected a lower abundance of cryptophyte species under grazing removal conditions. Although, trampling may damage below-ground storage organs in grasslands (Dupre and Diekman, 2001) because of superficial soil disturbance, in particular when animal density is high, but removal of trampling may insert a higher competition power by some functional groups such as hemicryptophytes and chaemophytes in semarid rangelands, resulting in decline of cryptophytes after grazing removal. In addition, the responses of forbs were different from the responses of grasses and shrubs to grazing removal. Previous studies showed that forbs and grasses exhibited different responses to grazing in terms of their vegetation cover (e.g. Siebert and Dreber 2019; Fulbright et al., 2021). Non changes of forbs' ground cover in response to grazing removal in the current study, might be because they have better grazing tolerance than grasses (see also Gebremedhn et al., 2023). In addition, forb response to grazing in terms of their ground cover may vary depending on the forb species, e.g. *Plantago coronopus* decreased and *Malva neglecta* increased in response to the grazing removal.

Effects of grazing and region interaction on vegetation

The results showed that qualitative Sørensen dissimilarity between grazed and ungrazed areas varied in a relatively small range (0.283 to 0.351) from the lowest to the highest salinities. These results are accordance with Xiang et al. (2021) in which the total Sørensen dissimilarity value between exclosure and intensively grazed sites was 0.334. However, we observed that quantitative dissimilarity and the differences in total and functional groups cover percentages and plant richness between grazed and ungrazed sites, generally decreased with soil salinity. This can be comparable with the findings of Zhao et al. (2016) and Xiang et al. (2023), who found that some vegetation characteristics like plant biomass due to grazing exclusion decreased with studied abiotic stress, i.e. altitude. This could be due to several mechanisms. i) different vegetation types in different regions had different dominant species and plant abundance due to the fact that the productivity of grasslands is community-dependent (Zeng et al., 2015). On the other hand, the effects of grazing and grassland utilizations by livestock vary depending on the vegetation types. For example, a recent systematic review found that grazing had different effects on the vegetation in different habitats, viz. dry, desert, high mountain steppes and meadows (Munkhzul et al., 2021). In our study, three vegetation types and different dominant plant species were observed in three studied regions, that is, 1) semiarid steppe grasslands occurred at Peshert with dominant species of *Artemisia sieberi* . This shrubby aromatic plant is a

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distributed species in Central Asia and Iran (in the Irano-Turanian floristic region) in which low salinity rate (1.75 ds/m) caused significant abundance of *A. sieberi* in these regions (Mirdavoudi et al., 2022). Although *A. sieberi* has low attraction for grazing, but the data showed that the cover percentage of this species was drastically increased after grazing removal (132%). Another dominant species in Peshert is perennial grass *Festuca ovina* that was increased its percentage cover by grazing exclusion about eight-times. Ghorbani and Mashkoori (2017) indicated that the responses of this species to different grazing intensities were different in relationship with abiotic factors in its habitats and had highest abondance in the absence of grazing in south-east aspect. 2) semiarid grassland occurred at Chapar with herbaceous dominant species, *Puccinella distance* in ungrazed areas and *Medicago minima* in grazed areas. *P. distance* is a halophytic perennial plant species and provide forage for livestock grazing in saline rangelands (Sepehry et al., 2012). Since this species is a high palatable one (class I in the palatability classification scheme, Sepehry et al., 2012), it can be supposed that in case of grazing removal, the species sexually and vegetatively grows and increases vegetation cover in the ungrazed areas. In contrast, an annual palatable herb, *M. minima,* is dominant in grazed areas. The seeds of this species have a high potential for dispersing by epizoochory and therefore it is able to disperse anywhere in the grazed areas, resulting a high percentage cover in the grazed areas. Generally, the typical Fabaceae species of the rangelands such as *Medicago* spp. were often found in the sheep wool and have high capability of dispersal by sheep (Kaligarič et al., 2016). 3) semiarid shrubby grassland occurred at Gonbad with shrubby dominant species, *Halocnemum strobilaceum* , in both grazed and ungrazed areas. Shrubs that are more prevalent at higher salinity and have more resistant to grazing may lead to smaller differences in the content of vegetation coverages between grazed and ungrazed sites (Ludvíková et al., 2014). It seems that *H. strobilaceum* has a high potential to recover itself after grazing. Previous studies reported that in comparison with other studies halophytic species, the highest values of allowable use, up to 75%, can be suggested for this species since it has ability to maintain the health and vigor of itself during grazing (Soltanpoor et al., 2022). ii) soil salinity may impact the factors that influence the content of vegetation characteristics, and these factors may be more or less pronounced in grazed versus ungrazed sites. One potential explanation could be related to the impact of soil on plant growth and biomass production. High-salinity soil in saline ecosystems often experience higher EC and stress content compare with non-saline ecosystems, which can restrict plant growth and biomass production. This may result in smaller differences in some vegetation characteristics, particularly in cover percentages between grazed and ungrazed sites at higher salinity. iii) it can be dedicated that one potential explanation of highest grazed and ungrazed differentiation in non-saline area is that the speed of recovery and positive turnover of vegetation after grazing removal is higher in this area due to more favourable condition comparing with sites with hypersaline condition. Wang et al. (2023) reported that some abiotic stress (e.g. dryness) affected the speed of ecosystem recovery after grazing removal, e.g. grazing exclusion facilitates more rapid ecosystem carbon sequestration of degraded grasslands in humid than in arid regions in China.

The observed patterns of functional groups in relation to soil salinity are similar to Tahmasebi Koheyani et al. (2009). They showed a higher differentiation of annuals and perennials between grazed and ungrazed areas in higher soil acidity (pH) compared with lower pH. It can be stated that only few stress-tolerant species are able to persist on nutrient-limited soils (Grime, 2001) such as Gonbad, even in the absence of grazing. In fact, high soil salinity conditions constrain and limit species diversity in saline areas. With decreasing salinity, however, the number and abundance of species including competitive and palatable species increased in the area. This indicates that the higher changes in species composition in non-saline soil compare with higher saline soil can be attributed to the explicit gradient of species richness and abundance from non-saline to hypersaline soils. A more pronounced effect of grazing on plant community composition and a related increasing dissimilarity between grazed and ungrazed sites in higher productive areas were observed in the previous studies (e.g. Osem et al., 2004). A high nutrient availability in non-saline soil is associated with competition for light rather than for resources, and generally allows the establishment of large, competitive and leafy species (Tilman, 1988). These conditions favour species with morphological and phenological characteristics that allow the plant species to compete efficiently for light (Grime, 2001), but at the cost of a lower resistance to grazing (Díaz et al. 2001). As a results, the vegetation changes by grazing removal can be occurred stronger and faster in non-stress condition due to lower resistance to grazing compare with stressful conditions.

Exclusion did not change the diversity in hypersaline soil while it decreased diversity indices in non-saline soil and changed moderately in moderately saline soil. Although, removal of grazing increased species richness in Peshert and Chapar, surprisingly the values of all types of diversity indices decreased in Peshert and in some indices in Chapar due to grazing exclusion. The potential explanation is that diversity is a combination of the number and abundance of species. Although removal of grazing increased species richness but probably decreased the evenness of species, resulting a decrease in species diversity. In grazed areas, the total abundance divides between different species in a higher evenness than in ungrazed when richness is lower in grazed areas than ungrazed areas.

CONCLUSIONS

Our findings provide evidence that soil salinity is a significant abiotic driver of herbivore effects on vegetation, across salinity gradient. Grazing exclusion had the highest effect under lowest salinity and waned with increasing salinity, increases in salinity are predicted to decrease the vegetation productivity of drylands, but decreasing their vulnerability to livestock effects. Our results provide insights into the management of grazing in different semiarid grasslands. First, exclusion of intensive grazing is associated with positive effects on vegetation, particularly under non-salinity condition where soils are predicted to have mainly higher productivity. Strategies that reduce livestock densities or prevent the access of livestock to the areas can be the most effective way to mitigate negative effects of grazing and halt vegetation degradation. Our results indicated that land managers should consider soil parameters particularly salinity when developing strategies of grazing by livestock in semiarid grasslands. This research could help to understand how grazing disturbance and stress in form of soil salinity influence grasslands dynamics in concert in semiarid regions and monitor the livestock management and decision making in these areas. Moreover, our results could help to understand the effects of grazing on grassland dynamics and sustainability in semiarid regions in the context of salinization.

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Appendix 1. Mean cover percentages of plant species in grazed and ungrazed quadrats in three regions (Peshert, Chapar and Gonbad), Golestan and Mazandaran provinces, Iran. Bold digits show most abundant species in each region.

	Peshert	Peshert	Chapar	Chapar	Gonbad	Gonbad
Plant taxa	Ungrazed	Grazed	Ungrazed	Grazed	Ungrazed	Grazed
Aegilops tauschii Coss.	0.27	0.00	0.00	0.00	0.02	0.01

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	Peshert	Peshert	Chapar	Chapar	Gonbad	Gonbad
Agropyron elongatum (Host) P.Beauv.	0.13	0.00	0.00	0.00	0.00	0.00
Agropyron pectiniforme Roem. & Schult.	1.13	0.87	0.00	0.00	0.00	0.00
Agropyron tauri Boiss. & Balansa	0.00	0.07	0.00	0.00	0.00	0.00
Aizoanthemum hispanicum (L.) H.E.K.Hartmann	0.00	0.00	0.20	0.13	0.04	0.05
Ajuga chamaecistus Ging. ex Benth.	0.00	0.07	0.00	0.00	0.00	0.00
Allium atroviolaceum Boiss.	0.07	0.00	0.00	0.00	0.00	0.00
Alyssum minus Rothm.	0.87	0.67	0.00	0.00	0.07	0.00
Alyssum montanum Pall.	0.53	0.07	0.00	0.00	0.00	0.00
Anagallis arvensis L.	0.00	0.00	0.47	0.00	0.00	0.00
Arenaria gypsophiloides L.	0.20	0.00	0.00	0.00	0.00	0.00
Artemisia sieberi Besser	**14.40**	**6.20**	0.00	0.00	0.00	0.00
Astragalus aureus Willd.	0.00	1.33	0.00	0.00	0.00	0.00
Astragalus lineatus Lam.	0.00	0.13	0.00	0.00	0.00	0.00
Astragalus sp.	4.40	0.60	0.00	0.00	0.00	0.00
Bromus danthoniae Trin.	0.33	0.00	0.00	0.00	0.00	0.00

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	Peshert	Peshert	Chapar	Chapar	Gonbad	Gonbad
Bromus madritensis L.	0.53	0.00	0.13	0.00	0.00	0.00
Bromus tectorum L.	1.27	1.20	0.00	0.00	0.00	0.00
Bupleurum falcatum L.	0.00	0.07	0.00	0.00	0.00	0.00
Cakile maritima Scop.	0.20	0.07	0.00	0.00	0.01	0.01
Calendula palestina Boiss.	0.00	0.00	0.40	0.87	0.00	0.00
Carduus nutans L.	0.00	0.00	4.40	0.07	0.00	0.00
Centaurea ovina Pall. Ex Willd.	0.07	0.27	0.00	0.00	0.00	0.00
Ceratocephala testiculata (Crantz) Besser	0.93	0.27	0.00	0.00	0.00	0.00
Chrozophora tinctoria (L.) Juss.	0.27	0.00	0.00	0.00	0.00	0.00
Convolvulus commutatus Boiss.	0.53	1.20	0.00	0.00	0.00	0.00
Cousinia commutate Bunge	1.80	0.07	0.00	0.00	0.00	0.00
Crepis sancta (L.) Bornm.	0.20	0.07	0.00	0.00	0.00	0.00
Crucianella filifolia Regel & Schmalh.	0.00	0.00	0.80	0.00	0.00	0.00
Cynodon dactylon (L.) Pers.	0.00	0.00	0.07	0.27	0.00	0.00
Descurainia sophia (L.) Webb ex Prantl	0.13	0.07	0.00	0.00	0.12	0.06
Euphorbia helioscopia L.	1.33	0.53	0.00	0.00	0.00	0.00

	Peshert	Peshert	Chapar	Chapar	Gonbad	Gonbad
Euphrasia pectinate Ten.	0.00	0.00	0.13	0.00	0.00	0.00
Eurotia ceratoides (L.) C.A.Mey.	0.87	0.00	0.00	0.00	0.11	0.00
Falcaria vulgaris Bernh.	0.07	0.00	0.00	0.00	0.00	0.00
Festuca ovina L.	**9.33**	1.13	0.00	0.00	0.00	0.00
Fumaria vaillantii Loisel.	0.07	0.00	0.13	0.00	0.00	0.00
Glyceria maxima (Hartm.) Holmb.	0.07	0.73	0.00	0.00	0.00	0.00
Halocnemum strobilaceum (Pall.) M.Bieb.	0.00	0.00	3.27	2.40	**35.90**	**34.75**
Hordeum murinum L.	0.07	0.00	**11.47**	0.00	0.08	0.02
Hypericum scabrum L.	0.27	0.40	0.00	0.00	0.00	0.00
Isatis cappadocica Desv.	0.07	0.00	0.00	0.00	0.00	0.00
Lepidium draba L.	0.00	0.00	0.47	0.00	0.10	0.01
Lolium temulentum Bertero ex Steud.	0.00	0.00	0.13	0.07	0.00	0.00
Malva neglecta Wallr.	0.00	0.00	7.33	0.53	0.06	0.00
Malva sylvestris L.	0.00	0.00	3.33	2.20	0.00	0.00
Medicago minima (L.) Bartal.	0.00	0.00	0.00	**8.13**	0.00	0.00
Medicago radiata L.	0.00	0.00	0.00	1.13	0.00	0.00
Medicago sativa L.	0.00	0.00	0.00	0.00	1.70	0.00

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	Peshert	Peshert	Chapar	Chapar	Gonbad	Gonbad
Melilotus officinalis (L.) Lam.	0.00	0.00	0.20	0.00	0.00	0.00
Minuartia litwinowii Schischk.	0.00	0.00	0.40	0.07	0.00	0.00
Minuartia verna (L.) Hiern	0.20	0.20	0.00	0.00	0.00	0.00
Myosotis olympica Boiss.	0.20	0.00	0.00	0.00	0.00	0.02
Noaea mucronata (Forssk.) Asch. & Schweinf.	0.00	0.80	0.00	0.00	0.37	0.37
Nonea caspica (Willd.) G.Don	0.00	0.00	0.13	0.87	0.00	0.00
Nonea lutea Bory & Chaub.	0.00	0.00	0.13	0.07	0.00	0.00
Peganum harmala L.	0.00	0.00	0.13	2.93	0.00	0.00
Phalaris tuberosa L.	0.00	0.00	6.40	0.00	0.00	0.00
Phleum paniculatum Huds.	0.33	0.07	0.00	0.00	0.00	0.00
Plantago coronopus L.	0.00	0.00	0.27	**5.27**	0.00	0.00
Poa annua L.	0.00	0.00	0.13	0.07	0.00	0.00
Poa bulbosa L.	0.07	0.20	0.00	0.00	0.00	0.00
Polygonum aviculare L.	0.00	0.00	0.33	0.47	0.00	0.00
Polygonum hydropiper L.	0.00	0.00	0.67	0.27	0.00	0.00
Puccinellia distans (Jacq.) Parl.	0.00	0.00	**16.73**	0.07	0.00	2.75
Salicornia europaea L.	0.00	0.00	0.00	0.00	0.00	0.38

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	Peshert	Peshert	Chapar	Chapar	Gonbad	Gonbad
Salsola aucheri (Moq.) Bunge ex Iljin	0.00	0.00	5.00	0.00	0.00	0.00
Salsola turcomanica Litv.	0.00	0.00	0.00	0.00	0.00	0.38
Scandix aucheri Boiss.	0.00	0.00	1.20	0.00	0.00	0.00
Scorzonera radicosa Boiss.	0.07	0.00	0.00	0.00	0.00	0.00
Secale montanum Guss.	0.07	0.00	0.00	0.00	0.00	0.00
Sedum cespitosum (Cav.) DC.	0.07	0.47	0.00	0.00	0.00	0.00
Setaria viridis (L.) P.Beauv.	0.00	0.00	0.07	0.07	0.00	0.00
Sinapis arvensis L.	0.00	0.20	0.00	0.00	0.00	0.00
Sinapis alba L.	0.00	0.13	0.00	0.00	0.00	0.00
Sonchus oleraceus L.	0.00	0.00	0.27	0.00	0.00	0.00
Spergularia diandra (Guss.) Heldr.	0.00	0.00	0.07	0.20	0.00	0.00
Stachys inflate Benth.	1.13	2.00	0.00	0.00	0.00	0.00
Stachys turcomanica Trautv.	0.27	2.07	0.00	0.00	0.00	0.00
Stipa hohenackeriana Trin. & Rupr.	7.93	1.00	0.00	0.00	0.00	0.00
Taraxacum officinale F.H.Wigg.	0.00	0.00	0.13	0.07	0.02	0.06
Teucrium polium L.	0.40	0.87	0.00	0.00	0.00	0.00

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	Peshert	Peshert	Chapar	Chapar	Gonbad	Gonbad
Traxacum montanum (C.A.Mey.) DC.	0.13	0.67	0.00	0.00	0.00	0.00
Verbascum aucheri (Boiss.) Hub.-Mor.	0.00	0.07	0.00	0.00	0.11	0.00
Ziziphora clinopodioides L.	0.33	0.00	0.00	0.00	0.00	0.00
Ziziphora tenuior L.	0.33	0.00	0.00	0.00	0.00	0.00

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