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Temporal variations of ground-dwelling arthropods in relation to grassland salinization

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ABSTRACT

The richness and abundance of ground-dwelling arthropods were investigated by a space-for-time substitution approach from spring to autumn of 2012 in the Hexi Corridor region, Gansu Province, to understand the effects of grassland salinization on the temporal distribution of the ground-dwelling arthropod community. The results showed that: 1) grassland salinization had a serious damage to the ground-dwelling arthropod community. The magnitude of the decrease was spring > summer > autumn, resulting in obvious change on seasonal distribution pattern of the ground-dwelling arthropod community; 2) the abundance of predators, herbivores and decomposers decreased significantly in all three seasons with salinization development, with greater effects in spring than in summer and autumn; 3) with salinization development, the most abundant taxon was Formicidae. However, the second dominant family changed over the time of the study. For example, in the lightly salinized grassland, the second dominant families were Lycosidae in spring and autumn, they were gradually replaced by Tenebrionidae in spring and Gnaphosidae in autumn in the severely salinized grassland; and 4) changes in the ground-dwelling arthropod community were largely related to changes in the physical environment and resource availability during the process of grassland salinization. Our results suggest that plant density, vegetation cover and fine particles content played important roles in structuring the ground-dwelling arthropods during the process of grassland salinization.

1. Introduction

Worldwide, approximately 932 million ha soils occurring in more than 100 countries are estimated to be salt-affected, accounting for about 10% of the total dry land surface [1], and this situation is getting worse in many parts of the world [2]. Salinization not only results in soil degradation and severe decreases in land potential productivity [3], but it also has adverse effects on the eco-environmental and economic development [4]. Salinization, as one of the most serious types of land degradation, has become a major concern throughout the world [5,6].

Salt-affected soils occur mainly in arid and semiarid regions, where evaporation greatly exceeds precipitation and salts dissolved in the ground water reach and accumulate at the soil surface through capillary movement [6]. Seriously salinization can even lead to collapse of the ecosystem [6]. In previous studies, the focus has mainly been on the nature, causes and controls of soil salinization [7] and also on the characteristics of the soil [8], the vegetation and the microorganisms [4,8]. However, few studies have considered the effect of salinization on the ground-dwelling arthropod community.

Arthropods have great abundances and species richness in almost all habitats [9,10] and account for more than half of global biodiversity [11]. Arthropods act for instance as pollinators, seed predators, natural enemies of pests and decomposers of dung or litter in ecosystems [12,13], controlling the nutrient and energy flow through the trophic levels of the food chain [14]. Seasonally

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dependant biotic and abiotic factors such as resource availability, temperature and soil moisture, can have strong influences on the activity and the community composition of arthropods [15,16]. At present, temporal and seasonal changes in the arthropod community structure have been noted [15,16], however, they have arguably been less studied than spatial and treatment effects, especially in salted soil area.

According to the database of China's second national soil survey [17], the salinization of the soil affects an estimated 35 million ha in China, of which 29.3 million ha is considered grassland. In the middle reaches of the Hexi Corridor region in Gansu Province of China, the salt-affected grassland is estimated to be 1.4 million ha, which accounts for 79% of the total salt-affected soils [18]. In this region, water from the upper mountainous region led to results that the groundwater level was very shallow, the soil was salted. In previous studies, the characteristics of soil degradation and grassland vegetation [8] have been investigated. However, less information is available concerning the temporal distribution of the ground-dwelling arthropod community in relationship to the soil salinization in this region. Using pitfall traps, we investigated the composition and diversity of ground arthropods in the process of grassland salinization during the spring, summer and autumn, which corresponded to the main period of ground-dwelling arthropod activity. The goal of this study was to determine the ground-dwelling arthropod community, in order to analyze the changes in their seasonal distribution patterns and how these patterns were affected by grassland salinization. This study also discusses the factors that contributed to these observed distribution patterns.

2. Materials and methods

2.1. Study area

This experiment was conducted at the Linze Grassland Ecological Test Station (100°02′ E, 39°15′ N) in the middle reaches of the Hexi Corridor region at an average altitude of 1400 m above sea level in Gansu Province, PR China. The station is located at the southern edge of the alluvial fans of the Heihe River. The Heihe River runs down from the Qilian Mountains, and melt water from glaciers and snow cover is the principal source of surface runoff. The underground water table is at a depth of 0–2.5 m. This region is characterized by temperate continental arid monsoon climate, dry and hot in summer and cold in winter. The mean annual precipitation is approximately 122 mm, most of which occurs in summer and autumn, and which is only one-twentieth of the annual mean evaporation (2338 mm). The annual mean temperature is 7.1 °C, while the absolute maximum may reach 38 °C and the minimum −28 °C. The soils in this region are classified as salinized meadow soils and salinity soils [19].

The study grassland sites were fenced with goat proof wire mesh from 1989 to now and consequently goat grazing was excluded for 23 years. The study area was 200 ha. Evaporation in this region greatly exceeds precipitation and salts dissolved in the ground water reach and accumulate at the soil surface through capillary movement. Grasslands are of different salinization level due to the different depth of underground water table. Soil sand, silt and clay contents from 0 to 20 cm depth determined using the pipette method [20] were shown in Table 1.

Table 1
Soil sand, silt and clay contents (0–20 cm) in the process of grassland salinization. *LSG* lightly salinized grassland, *MSG* moderately salinized grassland, *HSG* heavily salinized grassland, *SSG* severely salinized grassland.

Degree of salinization	Sand[a] (%)	Silt (%)	Clay (%)
LSG	12.6 ± 1.5	87.0 ± 1.3	0.4 ± 0.2
MSG	28.9 ± 3.7	71.1 ± 3.7	0
HSG	30.4 ± 1.6	69.6 ± 1.6	0
SSG	31.2 ± 2.6	65.2 ± 1.0	0

Values are means ± SE.
[a] Sand, 2–0.05 mm; Silt, 0.05–0.002 mm; Clay, < 0.002 mm.

2.2. Experimental design

For the present work, a space-for-time substitution approach was used [21]. According to the classification of salinization types and degrees [7], four types of salinized grasslands were selected including lightly (LSG, 200–400 mS/m), moderately (MSG, 400–800 mS/m), heavily (HSG, 800–1600 mS/m), and severely (SSG, > 1600 mS/m) salinized grasslands. The common species found among the differently salinized grasslands include *Phragmites communis* and *Legmus dasystachys*. Species unique to specific grassland types are *Kalidium gracile* to the moderately salinized grassland; *Achnetherum splendens* to the heavily salinized grassland; and *Nitraria tangutorum* to the severely salinized grassland [19]. For each of the four types of salinized grassland, three survey plots (10 × 10 m) at least 100 m apart with similar topographic conditions (open and flat field site) were established for measurements.

2.3. Sampling design

Sampling was conducted during the periods of 25–29 May, 27–31 July and 2–6 September, 2012, respectively, which corresponds to the main period of ground-dwelling arthropod activity in our study region. 15 pitfall traps (diameter: 8 cm, depth: 10 cm) filled with approximately 70 mL of 70% ethanol solution were buried flush with the ground surface in each plot (Fig. 1). The traps were checked every 2 days during each sampling period. At least 12 pitfall traps were recycled in each plot at the end of each sampling. Captured arthropod specimens (preserved in 75% ethyl alcohol) were counted and identified to the family level, as described by Yin [22].

Vegetation survey was carried out in August 2012, at the peak of vegetation cover and species richness. 7–9 random quadrats of

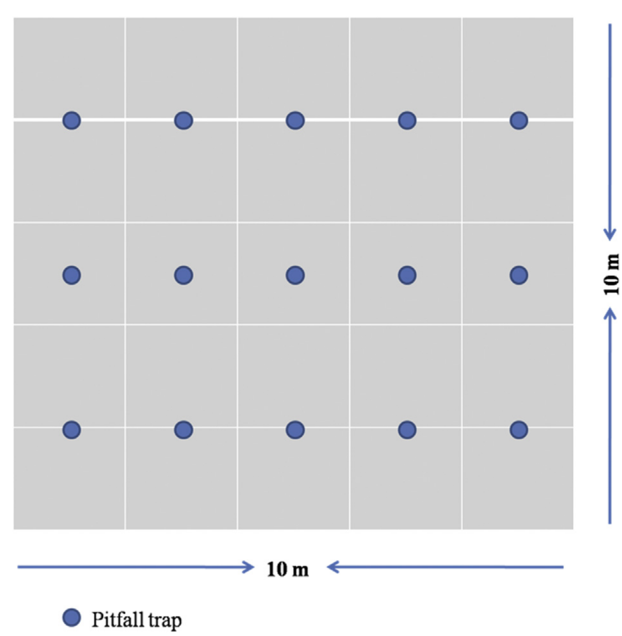

Fig. 1. Diagram showing the pitfall plot configuration.

herbs (0.5 × 0.5 m) except *A. splendens* which was measured in 10 × 10 m and shrubs (2 × 2 m) were placed in each plot to measure plant species richness (PR), density (PD) and vegetation cover (VC). We counted the number of plants per species (species density). Community density was calculated as the sum of species densities per plot. Aboveground plant biomass (AB) within the subplots was determined by clipping the plants at the ground level, drying at 65 °C for 72 h, then weighing. For *A. splendens* and *Nitraria tangutorum*, five or six plants were collected randomly and their dry mass was determined. Aboveground plant biomass was then calculated by multiplying community density with the mean size of these individuals.

2.4. Statistical analysis

At the community level, the total abundance (the total number of arthropods per trap averaged over all the traps per plot) was calculated, and the total taxonomic richness (the total number of families within the ground-dwelling arthropods, which was the sum of the families found in all traps per plot) was measured. All the captured arthropods were classified into three trophic groups based on their feeding habits, namely: predators, herbivores and decomposers (detritivores + omnivores). The abundance of the three main trophic groups of predators, herbivores and decomposers was calculated. The Kruskal–Wallis test was performed to determine whether or not there were differences among the four salinized grassland types using DPS software [23] because our data were not normally distributed.

In order to explore the differences in the community composition of ground-dwelling arthropods among the four salinized grassland types during the different seasons, we compared the arthropod communities found in the four types of salinized grassland using the Sørensen index, which is a measurement of proportional similarity ranging from 0 (no similarity) to 1 (identical). The Sørensen index is given by the equation $S = 2c/(a+b)$ [24] where a = number of species in one type of salinized grassland, b = number of species in another type of salinized grassland, and c = number of species common to the two types of salinized grassland.

Canonical correspondence analysis (CCA) was applied to quantify and test the association between ground-dwelling arthropod community composition variation and environmental properties. Families with fewer than three occurrences were deleted from the data matrix [25]. The environmental variables used in the CCA included soil EC, pH, CS (clay plus silt content), SOC, SWC, TN, AN, AB, plant density (PD), VC, PR. To avoid overfitting of the environmental variables in the regression model, the most discriminating variables were selected by the 'forward selection' procedure. Statistical tests were run using the Monte Carlo permutation test (999 permutations) of CANOCO for Windows 4.5 [26]. To meet the requirements for normality and homogeneity of variance, data on the ground-dwelling arthropod abundance and environmental variables were log (x+1) transformed prior to analysis.

3. Results

3.1. Vegetation characteristics

As shown in Fig. 2, the vegetation cover ($F = 10.38$, $p < 0.05$), community density ($F = 10.38$, $p < 0.05$), species richness ($F = 9.39$, $p < 0.05$)and aboveground biomass ($F = 10.38$, $p < 0.05$) decreased significantly with salinization development. In comparison with LSG, in SSG the vegetation cover, community density, species richness and aboveground biomass decreased by 92.8%, 96.7%, 64.7% and 81.1%, respectively.

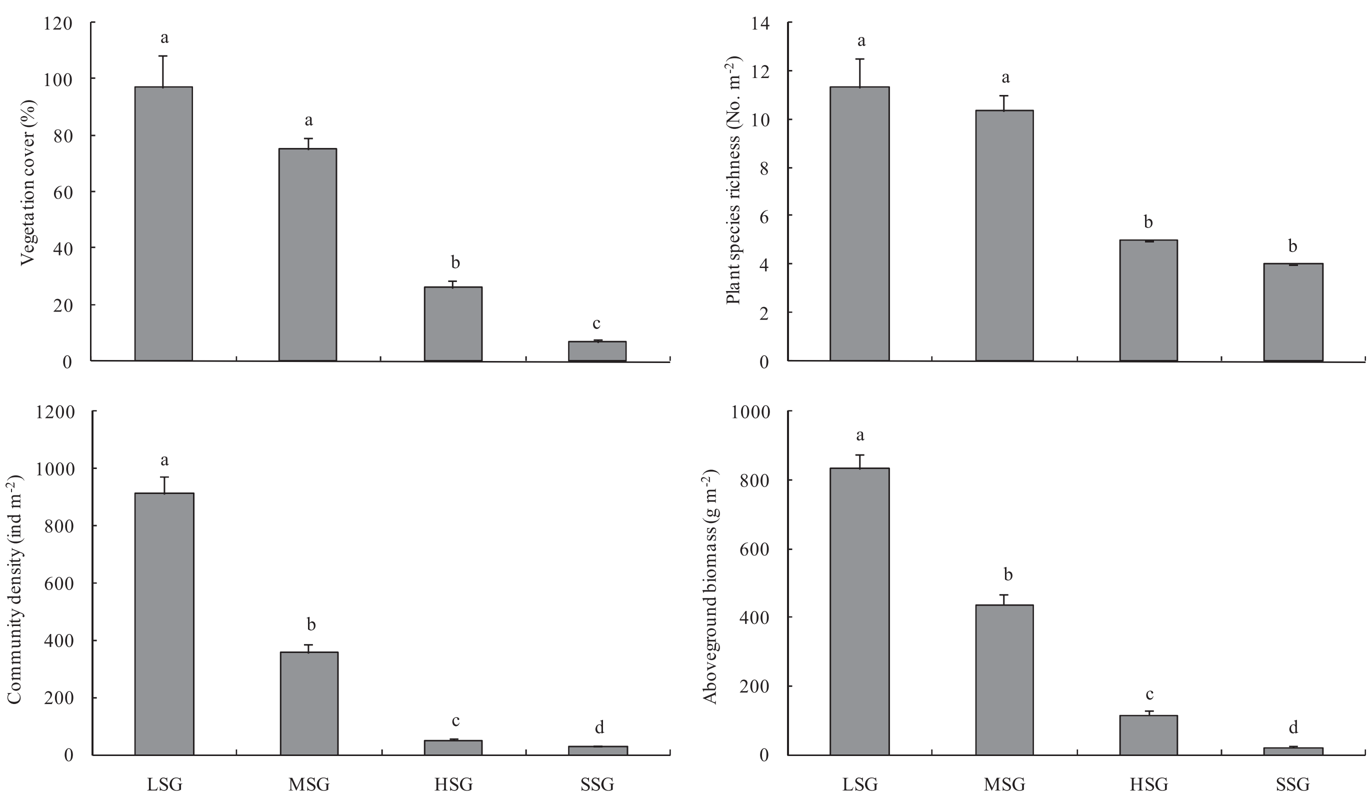

Fig. 2. Vegetation cover, plant species richness, community density and aboveground biomass in the process of grassland salinization. Means (±SE) with different letters indicate significant differences among the four types of salinized grasslands ($P < 0.05$ from Kruskal–Wallis test). *LSG* lightly salinized grassland, *MSG* moderately salinized grassland, *HSG* heavily salinized grassland, *SSG* severely salinized grassland.

3.2. The ground-dwelling arthropod community structure

In the four combined types of salinized grasslands, a total of 15,324 individuals within 32 ground-dwelling arthropod families were collected. Within these families, 27 were recorded in LSG, 26 in MSG, 21 in HSG, and 13 in SSG (Table 2). Arthropod abundances ranked as follows in the four types of salinized grasslands: Hymenoptera (LSG = 67.1% of total; MSG = 62.1%; HSG = 76.4%; SSG = 65.6%), Araneae (LSG = 17.0%; MSG = 17.8%; HSG = 7.9%; SSG = 17.9%) and Coleoptera (LSG = 9.2%; MSG = 9.5%; HSG = 11.0%; SSG = 13.5%).

The development of salinization had a significant effect on the abundance ($F = 9.97$, $p < 0.05$) and taxa richness ($F = 9.31$, $p < 0.05$) of the ground-dwelling arthropods. The abundance and taxa richness decreased significantly with salinization development. In comparison to LSG, MSG, HSG, and SSG the abundance decreased by 42.8%, 77.6%, and 93.4%. The taxonomic richness decreased by 52% in SSG as compared to LSG.

The arthropod families recorded were classified into three trophic guilds (Table 2). The abundance of the three trophic groups was significantly affected by the salinization development. Arthropod abundances ranked as follows in the four types of salinized grasslands: decomposer (LSG = 67.6%; MSG = 62.1%; HSG = 78.2%; SSG = 75.0%); predator (LSG = 19.7%; MSG = 19.6%; HSG = 8.3%; SSG = 17.9%) and herbivore (LSG = 12.6%; MSG = 18.3%; HSG = 13.5%; SSG = 7.2%).

3.3. The temporal variations of ground-dwelling arthropods

Arthropod abundance decreased significantly in all three seasons with the salinization development (Fig. 3). In comparison with LSG, arthropod abundance in MSG, HSG and SSG decreased in spring by 50.7%, 90.8% and 97.7%, respectively; by 20.2%, 49.2%, and 86.9% in summer; and by 57.5%, 86.9%, and 92.4% in autumn. The change in taxon richness differed between seasons with salinization development. The richness decreased by 77.4% in spring and 61.7% in summer, and there was no significant difference in autumn in SSG compared to LSG.

The abundance and taxon richness were also significantly influenced by the season (Fig. 3). For LSG and MSG, the higher abundance of arthropods were recorded in spring, while for HSG and SSG, the greater quantities were in summer. The taxon richness was higher in spring and lower in autumn for LSG. An opposite result was observed for SSG which had greater richness in autumn, lower in spring and an intermediate value in summer. In autumn, in LSG the richness decreased by 49.1% and increased by 100% in SSG compared to the results observed in spring.

With salinization development, Formicidae were the most abundant arthropods in all of the four types of salinized grasslands of the study. The second dominant family changed over time of the study. In LSG, for example, the second dominant families were Lycosidae in spring and autumn and they were gradually replaced by Tenebrionidae in spring and Gnaphosidae in autumn in SSG.

The abundance of all trophic groups decreased significantly in all three seasons with salinization development (Fig. 4). The decomposer group was the dominant trophic group for all of the four types of salinized grasslands over the time of the study. The abundance of all the three trophic groups was significantly influenced by the change in seasons. For LSG and MSG, the higher abundance of predators was recorded in spring which occurred in autumn for HSG and SSG. The higher abundance of herbivores was recorded in spring for LSG, MSG, and HSG, while this occurred in

Table 2
Abundance (ind/trap; mean ± SE) and taxa composition of ground-dwelling arthropod communities in the process of grassland salinization. P = predators; H = herbivorous; D = decomposers. *LSG* lightly salinized grassland, *MSG* moderately salinized grassland, *HSG* heavily salinized grassland, *SSG* severely salinized grassland.

		Abundance (ind/trap) ± SE				Guild
		LSG	MSG	HSG	SSG	
Araneae	Gnaphosidae	2.13 ± 0.07	2.41 ± 0.69	2.34 ± 0.57	1.10 ± 0.30	P
	Linyphiidae	0.51 ± 0.10	0.04 ± 0.02	0.26 ± 0.15	0.51 ± 0.20	P
	Lycosidae	27.73 ± 3.78	14.52 ± 5.00	0.24 ± 0.05	0.25 ± 0.13	P
	Nesticidae	0.29 ± 0.09	0.29 ± 0.10	0.10 ± 0.03	0	P
	Philodromidae	0.02 ± 0.02	0	0	0	P
	Salticidae	0.05 ± 0.05	0.09 ± 0.09	0.05 ± 0.03	0.25 ± 0.08	P
	Thomisidae	0.02 ± 0.02	0.11 ± 0.05	0.03 ± 0.03	0	P
	Zodariidae	0.82 ± 0.23	1.36 ± 0.14	0.27 ± 0.06	0.05 ± 0.03	P
Pseudoscorpiones	Pseudoscorpiones	0	0	0.07 ± 0.07	0	P
Coleoptera	Carabidae	3.27 ± 0.75	1.35 ± 0.46	0.03 ± 0.03	0	P
	Chrysomelidae	4.97 ± 0.48	3.27 ± 2.11	0.05 ± 0.05	0.42 ± 0.12	H
	Cicindelidae	0.02 ± 0.02	0.42 ± 0.36	0.02 ± 0.02	0	P
	Coccinellidae	0	0	0.02 ± 0.02	0	P
	Curculionidae	1.62 ± 0.96	3.83 ± 1.71	3.63 ± 0.42	0.09 ± 0.05	H
	Elateridae	0.61 ± 0.19	0.40 ± 0.30	0	0	H
	Lampyridae	0.02 ± 0.02	0	0	0	P
	Melolonthidae	3.66 ± 0.86	0.59 ± 0.49	0.03 ± 0.03	0	H
	Scarabaeidae	0.07 ± 0.07	0.02 ± 0.02	0	0	H
	Silphidae	1.04 ± 0.30	0.04 ± 0.04	0	0	D
	Staphylinidae	1.90 ± 0.24	0.14 ± 0.07	0	0	P
	Tenebrionidae	0	0	0.79 ± 0.79	1.14 ± 0.43	D
Diptera	Tipulidae	0.04 ± 0.04	0.04 ± 0.04	0	0	D
Hemiptera	Lygaeidae	0.07 ± 0.04	0.21 ± 0.21	0	0	H
	Pentatomidae	7.10 ± 2.30	0.02 ± 0.02	0	0	H
Homoptera	Cicadelloidea	0.28 ± 0.05	0.25 ± 0.03	0.52 ± 0.03	0.06 ± 0.06	H
	Delphacidae	0	0	0.07 ± 0.07	0.04 ± 0.04	H
Hymenoptera	Formicidae	124.29 ± 29.81	65.75 ± 22.45	31.75 ± 1.82	7.99 ± 1.93	D
Lepidoptera	Noctuidae	0.05 ± 0.05	0.15 ± 0.12	0.02 ± 0.02	0	H
Orthoptera	Acridoidea	0.66 ± 0.24	0.66 ± 0.17	0.85 ± 0.32	0.21 ± 0.02	H
	Grylloidea	4.13 ± 1.12	9.88 ± 1.40	0.44 ± 0.19	0.06 ± 0.06	H
	Gryllotalpidae	0	0.02 ± 0.02	0	0	H
Thysanoptera	Thripidae	0.18 ± 0.11	0.05 ± 0.05	0	0	H

summer for SSG. The higher abundance of decomposers was recorded in spring for LSG, while for MSG, HSG and SSG this occurred in summer. Groups among seasons showed significant differences in all the types of salinized grasslands only for herbivores and decomposers. In HSG there was no significant difference among seasons for predators.

3.4. The temporal variations for community similarities

The Sørensen similarity analysis showed that LSG, MSG, HSG and SSG operated in tandem in order to exhibit a similar pattern in the taxa composition in all three seasons (Table 3). The low Sørensen similarity index between SSG and LSG and MSG indicated that the communities in SSG differed considerably from those in LSG and MSG during spring and summer seasons.

The mean values of the Sørensen similarity index between sampling periods were 0.83 (range: 0.78–0.89) (Table 4), indicating that the taxa in the communities did not vary among the three sampling seasons.

Additionally, the variation ranges of similarity indices among the three sampling seasons (Sørensen: 0.78–0.89) (Table 4) were considerably smaller than those among salinization types (Sørensen: 0.54–0.93) (Table 3). This indicated that the influence of salinization degree on the community composition is stronger than that of the seasonal influence.

3.5. CCA analysis

The CCA showed that all 11 of the examined environmental variables explained 86.2% of the variation in the ground-dwelling arthropod community composition (Fig. 5). For data of soil physico-chemical properties see Ref. [8]. A Monte-Carlo permutation test indicated that all the canonical axes were significant ($F = 2.65$, $p < 0.01$). The first axis explains the 46.6% of the variation, and is related mainly to soil EC ($r = 0.95$, $p < 0.01$), SOC ($r = -0.91$, $p < 0.01$), TN ($r = -0.92$, $p < 0.01$), AN ($r = -0.93$, $p < 0.01$), SWC ($r = -0.80$, $p < 0.01$), CS ($r = -0.71$, $p < 0.05$), BD ($r = 0.60$, $p < 0.05$), PD ($r = -0.97$, $p < 0.01$), VC ($r = -0.94$, $p < 0.01$), PR ($r = -0.93$, $p < 0.01$) and AB ($r = -0.97$, $p < 0.01$). Melolonthidae ($r = -0.72$, $p < 0.01$), Carabidae ($r = -0.83$, $p < 0.01$), Chrysomelidae ($r = -0.72$, $p < 0.01$), Silphidae ($r = -0.66$, $p < 0.05$), Elateridae ($r = -0.69$, $p < 0.01$), Tenebrionidae ($r = -0.75$, $p < 0.01$), Thripidae ($r = -0.58$, $p < 0.05$), Zodariidae ($r = -0.76$, $p < 0.01$), Nesticidae ($r = -0.78$, $p < 0.01$), Lycosidae ($r = -0.88$, $p < 0.01$), Grylloidea ($r = -0.68$, $p < 0.01$), Formicidae ($r = -0.83$, $p < 0.01$), Staphylinidae ($r = -0.68$, $p < 0.05$) are more related with the first axis, while no variable is

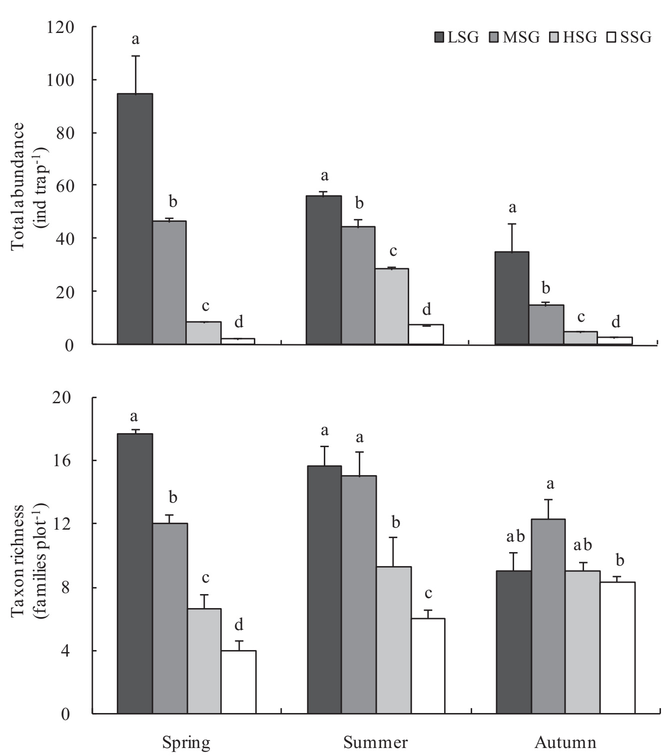

Fig. 3. Total abundance and taxon richness of ground-dwelling arthropods in the process of grassland salinization. Means (±SE) with different letters within each season indicate significant differences among the four types of salinized grasslands ($P < 0.05$ from Kruskal–Wallis test). *LSG* lightly salinized grassland, *MSG* moderately salinized grassland, *HSG* heavily salinized grassland, *SSG* severely salinized grassland.

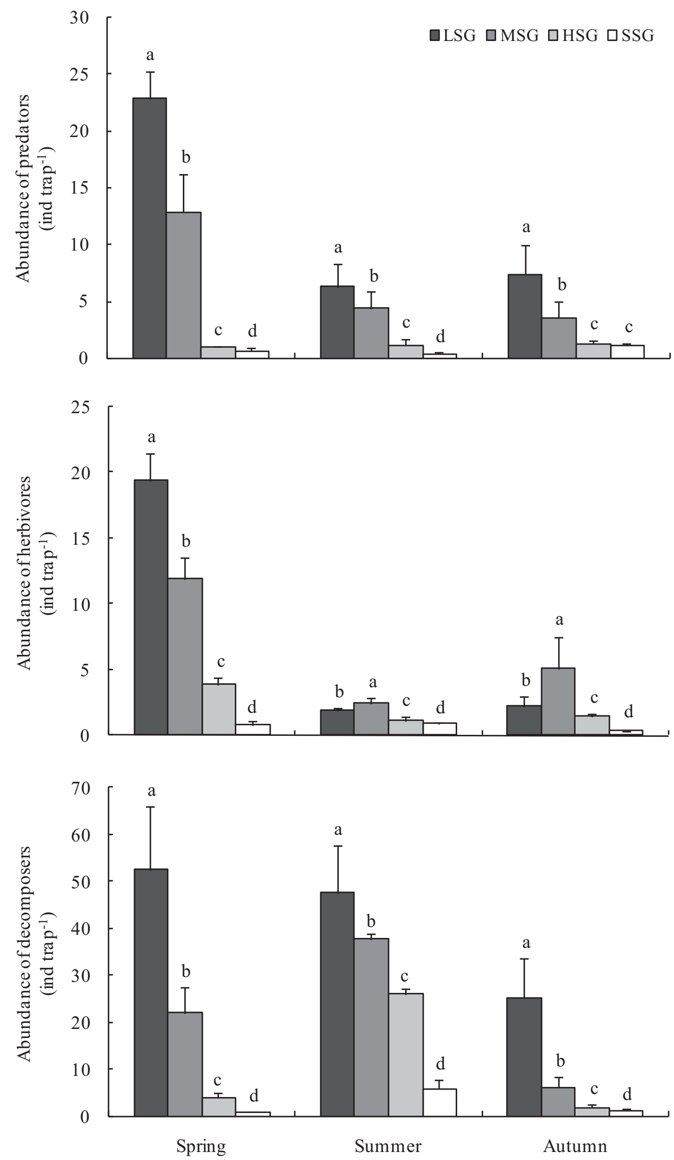

Fig. 4. Abundance of three trophic groups in the ground-dwelling arthropod community in the process of grassland salinization. Means (±SE) with different letters within each season indicate significant differences among the four types of salinized grasslands ($P < 0.05$ from Kruskal–Wallis test). *LSG* lightly salinized grassland, *MSG* moderately salinized grassland, *HSG* heavily salinized grassland, *SSG* severely salinized grassland.

Table 3
Sørensen similarity index values for comparing community composition of ground-dwelling arthropods among four salinized grassland types within seasons. *LSG* lightly salinized grassland, *MSG* moderately salinized grassland, *HSG* heavily salinized grassland, *SSG* severely salinized grassland.

	LSG	MSG	HSG	SSG
Spring				
LSG	1	0.87	0.61	0.30
MSG		1	0.67	0.33
HSG			1	0.63
SSG				1
Summer				
LSG	1	0.85	0.61	0.46
MSG		1	0.67	0.46
HSG			1	0.7697
SSG				1
Autumn				
LSG	1	0.67	0.62	0.67
MSG		1	0.80	0.64
HSG			1	0.58
SSG				1
Across three seasons				
LSG	1	0.93	0.69	0.54
MSG		1	0.75	0.59
HSG			1	0.78
SSG				1

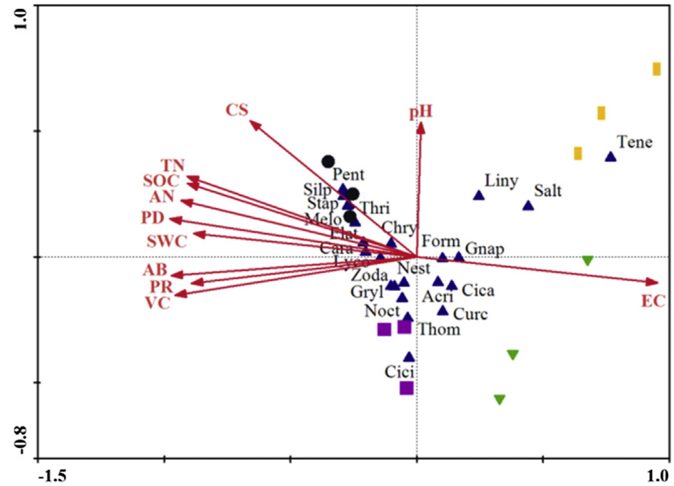

Fig. 5. Biplot of the first two CCA axes for showing the association of ground-dwelling arthropod community composition with environmental variables. *Circle* lightly salinized grassland, *square* moderately salinized grassland, *diamond* heavily salinized grassland, *box* severely salinized grassland. Ground-dwelling arthropods are represented by *triangles*. The families are labeled by the *first four letters* of the family name: Tenebrionidae (Tene), Cicindelidae (Cici), Carabidae (Cara), Chrysomelidae (Chry), Curculionidae (Curc), Elateridae (Elat), Melolonthidae (Melo), Pentatomidae (Pent), Lycosidae (Lyco), Gnaphosidae (Gnap), Nesticidae (Nest), Salticidae (Salt), Zodariidae (Zoda), Linyphiidae (Liny), Thomisidae (Thom), Grylloidea (Gryl), Formicidae (Form), Cicadelloidea (Cica), Silphidae (Silp), Staphylinidae (Stap), Noctuidae (Noct), Acridoidea (Acri) and Thripidae (Thri). Variables (*EC* soil electrical conductivity, *SWC* soil water content, *pH* soil pH, *CS* clay plus silt content, *SOC* soil organic carbon, *TN* total nitrogen, *AN* available nitrogen, *PR* richness index, *PD* plant density, *VC* vegetation cover, *AB* aboveground plant biomass) were represented as arrows and the strength of their impact was directly proportional to the length of the arrow lines. For data of soil physico-chemical properties (EC, SWC, pH, CS, SOC, TN, AN) see Ref. [8].

related with the second axis. Among these environmental variables, plant density ($p = 0.001$), vegetation cover ($p = 0.002$) and fine particles content ($p = 0.025$) explained the largest statistically significant amount of variation in the Monte Carlo permutation test, and plant density, vegetation cover and fine particles content explain 79.7% of the variance in the ground-dwelling arthropod community composition.

4. Discussion

Our results demonstrate that the ground-dwelling arthropod communities showed high variations in the process of grassland salinization, according to their abundance and taxa richness. The abundance and taxa richness decreased significantly with salinization development (Table 2). However, the results showed that the four types of salinized grasslands were very similar in composition. This suggested that the ground-dwelling arthropod composition did not change qualitatively in the process of grassland salinization (Table 3). There were, however, observed changes in the dominant groups and in the distribution of the trophic guilds with the seasonal variations.

Our results have demonstrated that grassland salinization can significantly alter vegetative characteristics (Fig. 2) as well as soil physico-chemical properties, except for soil pH [8]. The Pearson correlation matrix (Table 5) showed that the abundance and richness of the communities were not significantly correlated with soil pH. The abundance and richness of the communities were significantly negatively correlated with soil EC and positively correlated with SOC, TN, AN, fine particles content, SWC, aboveground biomass, plant density and vegetation cover. This is consistent with the findings of previous studies in other ecosystems demonstrating that changes in soil properties and vegetation characteristics interact to play important roles in structuring ground-dwelling arthropod communities [17,27,28]. However, the forward selection procedure of the CCA revealed that plant density, vegetation cover and fine particles content (silt plus clay content) were the most important factors determining the ground-dwelling arthropod community composition, as they were the main contributors to the total variation, as explained by the CCA. This is consistent with other studies suggesting that soil texture, resource availability and temperature have important impacts on the structure of ground-dwelling arthropod communities [29–34]. There are at least three possible pathways by which to profoundly alter the microhabitats and the availability of resources for ground-dwelling arthropods. First, vegetation cover [35] and the amount of leaf litter [36] present aspects of the productivity of habitats that can influence the availability of refuges from predation, foraging success, and providing essential food source for herbivores and decomposers [37,38]. Second, soil temperature is an important factor that controls many biogeophysical and biogeochemical processes. It is controlled not only by atmospheric and soil conditions, but also by vegetation cover and density. Studies have shown that the monthly mean of the daily maximum soil surface temperature decreased with increased vegetation cover and density during the growing season from May to September, while the monthly mean of the minimum soil surface temperature increased with increased vegetation cover and density [39,40]. Third, finely textured soils are known to be more favorable for ground-dwelling arthropod growth and survival due to their greater water holding capacity and nutrient availability, as well as providing better protection. These ecological functions combine to create a microhabitat with less secure oviposition, resource availability and shelter with an increase in salinity, thereby reducing the activity and the colonization

Table 4
Sørensen similarity index values in taxonomical composition between sampling periods in the four ground-dwelling arthropod communities.

	Spring	Summer	Autumn
Spring	1		
Summer	0.81	1	
Autumn	0.89	0.78	1

Table 5
Correlation coefficients between ground arthropod communities and vegetation and soil factors.

Item	Vegetation factors				Soil factors						
	Biomass	Density	Cover	Richness	EC	SOC	TN	AN	CS	SWC	pH
Richness	0.96**	0.95**	0.95**	0.88**	−0.83**	0.98**	0.98**	0.98**	0.83**	0.87**	−0.43
Abundance	0.95**	0.95**	0.92**	0.76**	−0.79**	0.95**	0.95**	0.95**	0.75**	0.88**	−0.42

EC, soil electrical conductivity (mS m^{-1}), SOC, soil organic C concentration (g kg^{-1} soil), TN, soil total N concentration (g kg^{-1} soil), AN, soil available N concentration (mg kg^{-1} soil), CS, clay plus silt content, SWC, soil water content (%). *$P < 0.05$, **$P < 0.01$. For data of soil factors (EC, SWC, pH, CS, SOC, TN, AN) see Ref. [8].

of ground-dwelling arthropods.

The composition and structure of the ground-dwelling arthropod community exhibited pronounced temporal variations between the sampling periods. The richness and abundance in all three seasons decreased significantly with grassland salinization development except for richness during autumn. The magnitude of the decrease was spring > summer > autumn. The results suggest that grassland salinization caused serious damage to the ground-dwelling arthropod community, and resulted in obvious changes in the seasonal distribution pattern of the ground-dwelling arthropod community. However, the patterns differed among the four salinized grasslands (Fig. 4). For example, in LSG and MSG, the abundance of ground-dwelling arthropods was spring > summer > autumn, while in HSG and SSG, it was summer > spring > autumn. The present results also show that the effects of seasons on the ground-dwelling arthropod community differed among the salinization stages, with larger effects in the heavy and severe salinization stages than in the moderate salinization stage. The difference could be simply attributed to the variation in temperature and resource quantity and quality. The difference in the following aspects could reflect the differences in temperature and resource quantity and quality. First, seasonality is a feature of most ecosystems [41]. The temporal variation in the four types of salinized grasslands may be related to variations in temperature as indicated by Wu et al. [42]. In the Hexi Corridor region, the monthly mean temperature was higher in May and August than in September. The microclimate of the grassland ecosystem also exhibits seasonal dynamics. Second, larger and higher plants may contribute more resources (leaf and litter) that can support more herbivore and decomposer arthropods, and at the same time may also provide greater numbers of secure oviposition sites for female arthropods [43]. In this study, plant density, cover and aboveground biomass decreased significantly with salinization development. Large amounts of litter were found in LSG and MSG, while almost no litter was observed in HSG and SSG (data not shown). Thus, variations in the monthly temperature, food resources and secure oviposition sites may explain the seasonal variation of ground-dwelling arthropods in grassland salinization. The results of the present study also showed that grassland salinization had significant effects on the dominant families and the trophic functional group structure of the ground-dwelling arthropod community, which are important indicators of healthy ecosystem function [44]. With salinization development, the most abundant taxon (Formicidae) did not change. However, the second dominant family changed over the time of the study. For example, in LSG, the second dominant families were Lycosidae in spring and autumn, they were gradually replaced by Tenebrionidae in spring and Gnaphosidae in autumn in SSG. The abundance of the three trophic groups decreased significantly in all three seasons. These results were in accordance with other studies [15,16], suggesting specific responses of ground-dwelling arthropods to seasonal changes. The variation of birth/death dynamic and diapause among ground-dwelling arthropod groups can provoke changes in abundance of ground-dwelling arthropods throughout the year [45]. The variation of trophic guilds can modify the patterns of food webs and increased the complexity of routes for nutrient recycling [46]. These changes mean degradation succession of the ground-dwelling arthropod community in grassland salinization.

Our results reinforces the predominance of the productivity hypothesis and thermal limitation hypothesis to account for the variation in ground-dwelling arthropods in the process of grassland salinization, as had previously been suggested for ants [47] and other arthropods [32,42]. The productivity-diversity hypothesis proposes that the availability of growth-limiting resources limits the diversity of biotic communities, and the thermal limitation hypothesis suggests that the effect of temperature on insect development, growth, and behavior regulates the abundance of individuals in an assemblage [47]. In our study, the changes in the composition of communities among the three sampling periods were smaller than those among the four types of salinized grasslands. These results suggested that the ground-dwelling arthropod community composition was relatively stable to sampling period within each type of salinized grassland. The possible reasons are that the various resources were sufficient for ground-dwelling arthropods within each habitat and the competitive exclusion may not have occurred [48].

In conclusion, salinization resulted in a significant decrease in the abundance and richness of the ground-dwelling arthropods. However, LSG, MSG, HSG and SSG operated in tandem to exhibit a similar pattern in the taxa composition in all three seasons. The abundance of predators, herbivores and decomposers decreased significantly in all three seasons with salinization development. Also with salinization development, the most abundant taxa exhibited no change, however, the second dominant family changed over the time of the study. The dynamics of the composition, abundance and richness with salinization development showed that plant density, vegetation cover and fine particles content played important roles in determining the distribution of ground-dwelling arthropods in the process of grassland salinization. The ground-dwelling arthropod community also varied temporally in terms of its composition, abundance and richness. The seasonal variation can be explained by the influence of the monthly temperature, food resources and secure oviposition sites. The temporal response of taxonomic groups to sampling period differed among the four salinized grasslands and the effect of the salinized grassland type on the ground-dwelling arthropods was greater than sampling period.

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