Ground-active arthropod recovery in response to size of shrub plantations in a desertified grassland ecosystem

Rentao LIU[1*], Jianan LIU[1], Juan ZHAO[1], Weihua XI[2] and Zhimin YANG[3]

[1] Key Laboratory for Restoration and Reconstruction of Degraded Ecosystem in Northwestern China of Ministry of Education, Ningxia University, Yinchuan 750021, China

[2] School of Life Science, Shanxi Normal University, Linfen 041004, China

[3] School of Life Science, Inner Mongolia Normal University, Huhht 010000, China

*e-mail: liu_rt@nxu.edu.cn (*corresponding author*)

ARTICLE INFO

Regular research paper

Pol. J. Ecol. (2017) 65: 410–422

received after revision
June 2017

doi
10.3161/15052249PJE2017.65.3.008

key words

afforested plantation
arthropod activity
trophic group
crown size
desertified grassland

ABSTRACT

The ground-active arthropod diversity response to size of shrub plantations in desertified grassland ecosystems is largely unknown. In the study ground-active arthropods were collected by pitfall trapping beneath shrub canopy of very low, low, medium and high size, with adjacent mobile sandy land as a control. It was found that arthropod dominant taxa from mobile sandy land were significantly distinctive from those from plantations of different shrub size. A considerably lower Sørensen index (i.e., 0.25–0.48) was found between the arthropod communities from mobile sandy land and the canopy of either shrub size, than between those under low and medium/high shrub size (i.e., 0.62 to 0.69). The arthropod total abundance was significantly greater under the shrub canopy of very low size in comparison to that of low and medium shrub size and mobile sandy land, with the intermediate values under shrub canopy of high shrub size. Taxon richness and diversity of arthropod communities were distinctly lower under the shrub canopy of low size in comparison to very low, medium and high shrub size. The shrub size was found to have different effects on the density and richness distribution of arthropod trophic groups (i.e., predators, phytophagous, saprophagous, and omnivorous). It was concluded that shrub plantations could facilitate ground-active arthropod diversity recovery when they were afforested in mobile sandy land. There was a contrasting effect of shrub size on ground-active arthropod diversity recovery *versus* arthropod abundance when grazing was excluded.

INTRODUCTION

In desertified regions, the widespread afforested shrub plantations have been reported to control desertification with the restoration of degraded ecosystems (Wezel *et al.* 2000, Zhao *et al.* 2010). Callaway and Walker (1997) indicated some changes of abiotic properties along with shrub size since the physical protection was offered by shrub crown. Additionally, the shrub size was found to represent the food resource availability for the biotic communities (Schlinkert *et al.* 2015). Regarding terrestrial arthropods, they known to be are highly sensitive to plant community because plants, directly and indirectly, provide them with food and refuge (Samways 1992). The changes in environmental variables and food resources in relation to shrub size could have remarkable effects on activity distribution, and trophic groups of soil invertebrate community belowground (Doblas-Miranda *et al.* 2009). The linkages between aboveground and belowground ecosystems had a considerable influence on community-level process along with the restoration of degraded arid ecosystems (Wardle *et al*. 2004).

In southwest fringe of Mu Us sandy land, there was a wide range of afforested *Caragana* plantations that were planted by local government for desertification control and alleviation of its negative effects (Liu *et al*. 2013b). Aforementioned researches focused on the effects of shrub canopy in regard to plant species on soil properties and soil invertebrate activities (Liu *et al*. 2015). In practice, there was large area of afforested plantations of the same shrub species with distinctive shrub size including canopy crown, plant height and branches due to grazing and/ cutting management (Eldridge *et al*. 2013, Liu *et al*. 2013a, b). For example in the grazed shrub plantations, there was a detrimental effect of grazing (i.e., herbivore foraging activities) on shrub architectural and correlative plant height and plant productivity (Siemann *et al.* 1999). Likewise, there was a positive linkage between plant species diversity and shrub size with improved plant height and vegetation cover (Pugnaire and Lázaro 2000). It was reported that shrub crown gradients along with biomass production and distinct patterns in species distributions occurred understory (Moro *et al*. 1997). However, few studies were carried out on the activity density and diversity recovery of ground-active arthropods associated with present shrub size in desertified ecosystems. This point was directly correlated with the management of shrub plantations, biodiversity conservation and desertification control in desertified grassland ecosystems.

There were a vast number of studies regarding the effect of plant traits (shrub size) on the activity distribution, and community structure of soil arthropods. Johnson and Agrawal (2005) reported that variation in the arthropod community were most strongly associated with plant size and morphology. The abiotic conditions including the physical protection and the food resources offered by the shrub crown were correlated with the arthropod community distribution (Schlinkert *et al*. 2015). Lightfoot and Whitford (1989) indicated a positive correlation of arthropod abundances with shrub size, foliage density, foliage growth, and foliar nitrogen and water concentrations. Rhoades (1983) showed that there was a distinctive plant protection mechanism (better or less defense) of highly *versus* less productive plants in term of plant size from herbivores through defensive chemicals. In turn, Lightfoot and Whitford (1989) reported that the increased numbers of herbivores were found to provide more food for predators, thus showing considerably effects on web structures within soil ecosystems that played implications on ecological process of restored arid ecosystems.

In all, plant architecture was an important aspect (i.e., thermal cover, refuge) of arthropod assembly regarding enemy-free space as indicated by Lightfoot and Whitford (1989). Schultz *et al.* (1977) reported that the insects on creosote bush exhibited specialized adaptations, behaviorally and morphologically, to use the foliage as shelter from predators including highly cryptic background-matching on various foliar structural and coloration features. Schultz (1978, 1981) reported that there was a significant selection pressure of predation on the evolution of resource use strategies among phytophagous insects on creosote bush. Schlinkert *et al.* (2015) considered plant size as a comprehensive driver of species richness distribution of plant-related arthropods (i.e., pollinators, herbivores and their natural enemies). Together, these researches focused more on the arthropod groups including herbivores and/or predators, and/or the arthropod abundance and richness. However, there was largely unknown how shrub size mediated the density and diversity recovery of ground-active arthropods in shrub plantations of desertified ecosystem.

The aim of present study was to examine (1) how shrub size mediated the composition and abundance distribution of ground-active arthropods, (2) how ground-active arthropod diversity responded to shrub size. We hypothesized: (1) there was a distinctive difference in the composition, and activity abundance of ground-active arthropods between the shrub plantations of different shrub size; (2) the high shrub size harbored greater number of arthropod individuals relative to the low one; (3) the high shrub size contributed more to diversity recovery of ground-active arthropods than the low one.

METHODS

Study area

The present study was carried on in Yanchi county (37°04´–38°10´N and 106°30´–107°41´E, 1600 a.s.l meters on average), standing at the southwest fringe of Mu Us sandy land of Ningxia, China. The afforested shrub plantation was planted in the mobile sandy land including shrubs such as *Artemisia ordosica*, *Hedysarum scoparium* and *Caragana korshinskii*. Some shrub plantations were subjected to sheep grazing activities, resulting in the low and sparse shrub crown. Another shrub plantations were subjected to the plant-cutting with the goal for utilization and management. The other afforested shrub plantation was observed to increase its size with ageing of plants due to increasing of plant height, foliages, and branches under exclosure management (Liu *et al.* 2012). Different shrub size concerning plant height, foliage density, biomass and stem numbers was observed in the study area as shown by Wang (2013).

In the study area mean annual rainfall is 287 mm with potential pan-evaporation of 2710 mm. Mean annual temperature is 7.5°C, with the lowest and highest monthly values of -8.7°C in January and 22.4°C in July, respectively. Prevailing winds are mainly northwester lying in April and May, and mean annual wind velocity is 2.8 m s^{-1}. Annual sand dust, on average, blowing at wind velocities over 5.0 m s^{-1} occurs 323 times (climate data from Yanchi Meteorological Station, 1976 to 2010). Soil types are mainly Sierozem, Loess and Orthi-sandic Entisols with poor soil fertility and loose structure, which are very susceptible to wind erosion.

Experimental design

Four shrub size gradient (i.e., the very low = below 0.5 m^3 in shrub column, low = between 1.5 and 2 m^3, medium = between 3 and 5 m^3, and high = above 6 m^3) was selected for the afforested plantation of shrub *Caragana korshinskii*, with the adjacent mobile sandy land as a control. Three replicates sites were set for each habitat, including the control and the four shrub sizes. Each of the replicates occupied the area of 0.5–3 ha. Here, the very low, medium and high shrub size was due to the natural growth stages of plant life history under fenced exclosure. The low shrub size was due to the overgrazing activities by 2 sheep h m^{-2}. The detailed information for each afforested plantation and the control sites were shown in Table 1.

In each site four *C. koushinskii* shrubs in addition to the open spaces were selected as the sampling points. Together we obtained 120 sampling points totally [(4 shrubs+4 open spaces) × 3 replicates × 5 habitats]. The distance between two sampled plants in

Table 1.The background information for studied habitats.

Site/shrub size	Location	Altitude (m)	Grazing management	Shrub trait				
				Size (column, m^3)	Density (no. ha^{-1})	Height (cm)	Age (Year)	Aboveground biomass (kg)
Control (mobile sandy land)	N37°49´11″ E107°30´19″	1360	Overgrazing	-	-	-	-	
Very low	N37°46´55″ E107°22´21″	1352	Exclosure	<0.5	2500	30	9	0.64
Low	N37°49´36″ E107°30´18″	1429	Overgrazing	1.5 ~ 2	2000	98	27	1.96
Medium	N37°48´55″ E107°29´50″	1398	Light grazing	3 ~ 5	5000	131	18	1.54
High	N37°50´44″ E107°28´22″	1386	Exclosure	> 6	1667	165	39	1.90

terms of shrub belt was over 15 m (one every other belt) for the determination of trap independence. The similar sampling method was introduced in the mobile sandy land. The research was carried out in summer (i.e. late July) during the year 2013.

Measurements of shrub properties and ground-active arthropod sampling

In each sampling site, shrub height (i.e., m) and crown diameter (i.e., maximum width, and width perpendicular to the maximum; m) was determined by using steel tap. We calculated shrub volume (i.e., m^3) based on shrub height multiplying crown diameter.

At each sampling point, pitfall trap with plastic cup (7 cm diameter, 10 cm deep) was placed flush with the trap level on ground surface. All pitfall traps full of approximately 60 ml of 70% ethanol solution were left for 10 consecutive days (day and night) in the field. Traps were examined every three days during the 10-day sampling period. Totally, 120 pitfall traps was obtained for the sampling experiment. All captured arthropods stored in 75% alcohol were identified to the order and family levels based on classification keys of Zheng and Gui (2004) and Yin (2001) under a binocular microscope (40×) and later were classified into four throphic groups including predatory (Pr), phytophagous (Ph), saprophagous (Sa), and omnivorous groups (Om) based on their feeding lifestyle (Doblas-Miranda *et al*. 2009)

Data analysis

Within each replicate site, trap contents were pooled together by similar microhabitats (i.e., 4 traps beneath shrub canopy and 4 traps in open spaces) during the study period. We then obtained total abundance (number of individuals per four traps pooled per site), total taxon richness (the total number of taxonomic groups per four traps pooled per site). The Shannon's diversity index and associated evenness index were thus calculated. The similarity of arthropod community between sampling sites was compared by means of Sørensen index (i.e., a measure of proportional similarity ranging from 0 (no similarity) to 1 (identical)) in order to examine the presence/absence data of ground-active arthropod taxa.

We conducted descriptive statistics and significance tests assigned at $P < 0.05$ by using SPSS 15.0 software for Windows (SPSS Inc., Chicago, Illinois, USA). We also performed One-way ANOVA and Tukey's (HSD) post hoc tests for the determination of differences in all the measured variables. Normality and homogeneity of variances were tested before applying parametric tests.

RESULTS

A total of 4311 individual arthropods were captured by pitfall trapping, which included 10 orders and 34 families (Table 2). Among the dominant families were Carabidae, Melolonthidae, and Tenebrionidae within the order Coleoptera, and Formicidae within the order Hymenoptera, together comprising 78.2% of the total numbers. Particularly, the family Tenebrionidae was observed to dominate in all investigated habitats.

Composition and abundance distribution of arthropod dominant taxa

In the mobile sandy land, the dominant taxa belonged to Labiduridae (i.e., Dermaptera) and Tenebrionidae families, which together comprised 93.7% of the total numbers (Table 2). Along with the size of shrub plantation, we found the dominant taxa in the shrubland of very low size such as families Carabidae, Curculionidae, Formicidae, Melolonthidae, and Tenebrionidae to be replaced by the Tenebrionidae and Formicidae familes in the low size of shrubland, and by the Carabidae, Melolonthidae and Tenebrionidae, and Formicidae families in the medium size of shrubland, and by the Tenebrionidae and Formicidae familes in the high size of shrubland. The arthropods from these families comprised 88.8%, 78.9%, 80.2%, and 56.8% of totals in the very low, low, medium and high size of shrubland, respectively.

Common taxa and the similarity indices of ground-active arthropods between habitats of different shrub size

Greater number of common taxa was found between the shrub plantations of different

Table 2. Abundance (mean ± SE records per trap) distribution of ground-active arthropods in relation to shrub size. "-" no specimens found. The different letters indicate significant differences at $P < 0.05$ in the abundance of dominant arthropod families. Pr = Predators, Ph = Phytophagous group, Sa = Saprophagous group, Om = Omnivorous group.

Taxon	Trophic group	Mobile sandy land	Shrub size			
			Very low	Low	Medium	High
Oniscidae	Om	-	-	-	-	5.3±1.5
Phalangiidae	Pr	-	-	1.0±1.0	3.7±1.2	1.0±0.6
Salticidae	Pr	0.3±0.3	-	-	-	-
Lycosidae	Pr	-	-	1.0±1.0	-	1.0±0.6
Thomisidae	Pr	-	1.3±0.7	-	-	-
Gnaphosidae	Pr	0.3±0.3	2.0±0.0	-	-	-
Philodromidae	Pr	-	-	-	1.3±0.3	4.7±2.7
Liocranidae	Pr	-	-	-	3.3±1.2	2.0±0.6
Labiduridae	Pr	38.7±23.7	1.7±0.3	-	-	1.0±0.6
Arcypteridae	Ph	-	-	1.0±0.6	-	-
Coreidae	Ph	-	-	-	-	1.0±0.6
Scutelleridae	Ph	-	-	-	-	5.0±2.1
Lygaeidae	Ph	-	-	-	3.7±3.7	1.7±0.9
Carabidae	Pr	6.7±1.2b	77.0±30.0a	11.7±9.2b	27.7±2.2ab	27.7±10.8ab
Chrysomelidae	Ph	-	1.0±0.6	-	-	24.7±13.3
Buprestidae	Ph	0.3±0.3	2.7±0.3	-	-	4.0±0.0
Staphylinidae	Om	-	-	-	1.3±1.3	-
Elateridae	Ph	-	3.0±1.0	-	1.3±1.3	-
Glaphyridae	Ph	-	28.3±6.6	1.3±1.3	7.3±2.2	6.3±2.7
Melolonthidae	Ph	0.3±0.3d	98.0±11.5a	9.0±1.5d	65.0±14.6b	34.3±1.3c
Geotrupidae	Sa	-	11.7±5.4	2.3±1.9	1.0±1.0	3.7±0.9
Aphodiidae	Sa	-	-	3.0±1.2	-	3.0±1.7
Silphidae	Sa	-	1.0±1.0	-	-	3.3±1.7
Histeridae	Sa	-	-	-	-	2.7±0.9
Dermestidae	Sa	1.0±0.6	-	-	-	-
Tenebrionidae	Ph	99.0±52.3a	144.3±17.4a	57.0±18.9a	54.3±6.7a	60.0±7.9a
Curculionidae	Ph	-	51.3±10.3	4.0±2.1	19.7±7.5	18.7±2.9
Larval Tenebrionidae	Ph	-	-	-	-	1.7±0.3
Asilidae	Pr	-	-	1.0±0.6	-	-
Formicidae	Om	-	61.7±16.2	81.7±32.3	54.0±5.6	154.0±23.7
Megachilidae	Ph	-	-	-	-	1.0±0.6
Scoliidae	Ph	-	1.0±0.6	-	-	-
Sphecidae	Ph	-	1.0±0.0	-	1.7±0.3	-
Pompilidae	Ph	0.3±0.3	-	-	-	-
Larval Lepidoptera	Ph	-	-	1.7±0.3	5.3±3.4	9.0±4.0

shrub size (i.e., 7–12 common taxa) in comparison to that between the mobile sandy land and either shrubland (i.e., 5–6 common taxa) (Table 3). Likewise, the values of Sørensen index were found to be remarkably greater between habitats of different shrub size (i.e., ranging from 0.52 to 0.69) in comparison to that between the mobile sandy land and either shrubland (i.e., ranging from 0.25 to 0.48). Particularly, there was relatively greater value of Sørensen index between shrub plantation of low and mediumd/high size (i.e., ranging from 0.62 to 0.69).

Ecological indices of ground-active arthropod assembly

The total arthropod abundance was found to be significantly ($P < 0.01$) greater in very low shrub size in comparison to the mobile sandy land and low, medium and high shrub size (Fig. 1). Whereby, the taxon richness ($P = 0.000$), Shannon index ($P < 0.001$) and evenness index ($P < 0.05$) were found to be significantly greater in either shrub size in comparison to the mobile sandy land.

Notably, there was distinctive pattern of the taxon richness, Shannon index and evenness index between shrub of different size. With regard to the taxon richness, the high shrub size harbored greatest values in comparison to very low, low and medium shrub size (Fig.1). There was a significantly ($P <0.05$) lower taxon richness in low shrub size relative to very low and medium shrub size. Similarly, there was a significantly ($P < 0.05$) lower Shannon index in low shrub size relative to very low, medium and high shrub size, whereas there were no significant ($P > 0.05$) differences observed between very low, medium and high shrub size. Also, there were no significant ($P > 0.05$) differences in the evenness index observed between either shrub size.

Trophic structure of ground-active arthropods

Both the density and richness of predatory and phytophagous groups were found to indicate a similar trend – they increased at the primary stage, then decreased at the second stage, and after that they increased again to the high shrub size (Fig. 2). Particularly there were significant ($P < 0.05$) differences in the taxon richness of predators and in the density and taxon richness of phytophagous groups between the five habitats.

The distribution of activity density and taxon richness of saprophagous groups shifted significantly from mobile sandy land to the high shrub size (Fig. 2). The density of saprophagous groups was found to be significantly ($P < 0.05$) lower in mobile sandy land and medium shrub size relative to the other plantations of very low, low and high shrub size. The taxon richness of saprophagous groups was found to be significantly ($P < 0.001$) different between the five habitats, followed by high > low > very low shrub size > mobile sandy land > medium shrub size.

Both the density and richness of omnivorous group were also found to indicate a similar trend: they increased significantly ($P < 0.05$) from the primary stage, then kept

Table 3. Number of common arthropod taxa and similarity (Sørensen index values) between the habitats of different shrub size.

	Site	Mobile sandy land	Shrub size: Very low	Low	Medium	High
Shrub size	Mobile sandy land		0.48	0.30	0.25	0.30
	Very low	6		0.52	0.58	0.55
	Low	6	7		0.69	0.63
	Medium	6	9	9		0.62
	High	5	11	11	12	

Note: the numbers on the left of diagonal line = the number of common taxa; the numbers on the right of diagonal line = the values of Sørensen index.

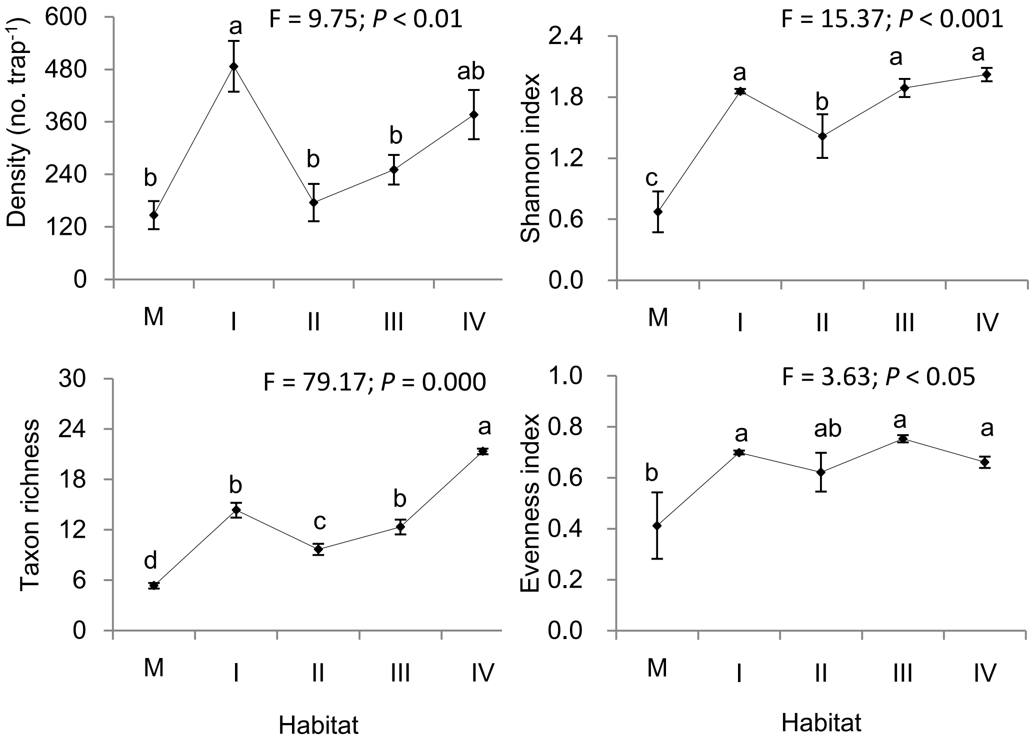

Fig. 1. The abundance, taxon richness, Shannon index and evenness index of ground-active arthropods communities in habitats of different shrub size. Values were represented by means±SE. Different letters indicate significant differences at $P < 0.05$. Habitat: M = mobile sandy land, I = very low shrub size, II = low shrub size, III = medium shrub size, IV = high shrub size.

stable until the medium shrub size, and after that they increased significantly ($P < 0.05$) to the high shrub size (Fig. 2).

DISCUSSION

In the present study we found four arthropod families (Carabidae, Mellonthidae, Tenebrionidae and Formicidae) to be dominant groups within ground-active arthropod communities. This finding was in agreement with the results of studies from other shrubland ecosystems in Horqin sandy land (Zhao and Liu 2013) and Mu Us sandy land (Liu *et al.* 2013b) and also in the Gobi desert ecosystem of western China (Liu *et al.* 2012). These four dominant taxa were reflective of desert and semi-desert arthropods characterized by a strong adaptation to xeric environmental conditions as indicated by Ren and Yu (1999). Particularly, the arthropods from common family Tenebrionidae were found to dominate each habitat, regardless of mobile sandy land or afforested plantation, which confirmed the aforementioned results.

In the mobile sandy land, it was found that the family Labiduridae dominated the habitats with severely reduced nutrient availability, food resources and shelter as was previously indicated by Liu *et al.* (2009). At the primary stage with regard to the stabilization of mobile sandy land and desertification control, the shrub plantation was found to be correlated with the extent to which shrub size affected the taxa composition of ground-active arthropods as showed by Johnson and Agrawal (2005) and Schlinkert *et al.* (2015). After the primary stage, the dominant families shifted remarkably from five families in very low shrub size toward two families, i.e., Tenebrionidae and Formicidae in low shrub size. Then these both families were added by the other two families (i.e., Carabidae and Melolonthidae) in medium shrub size, and finally reached the minimum number of

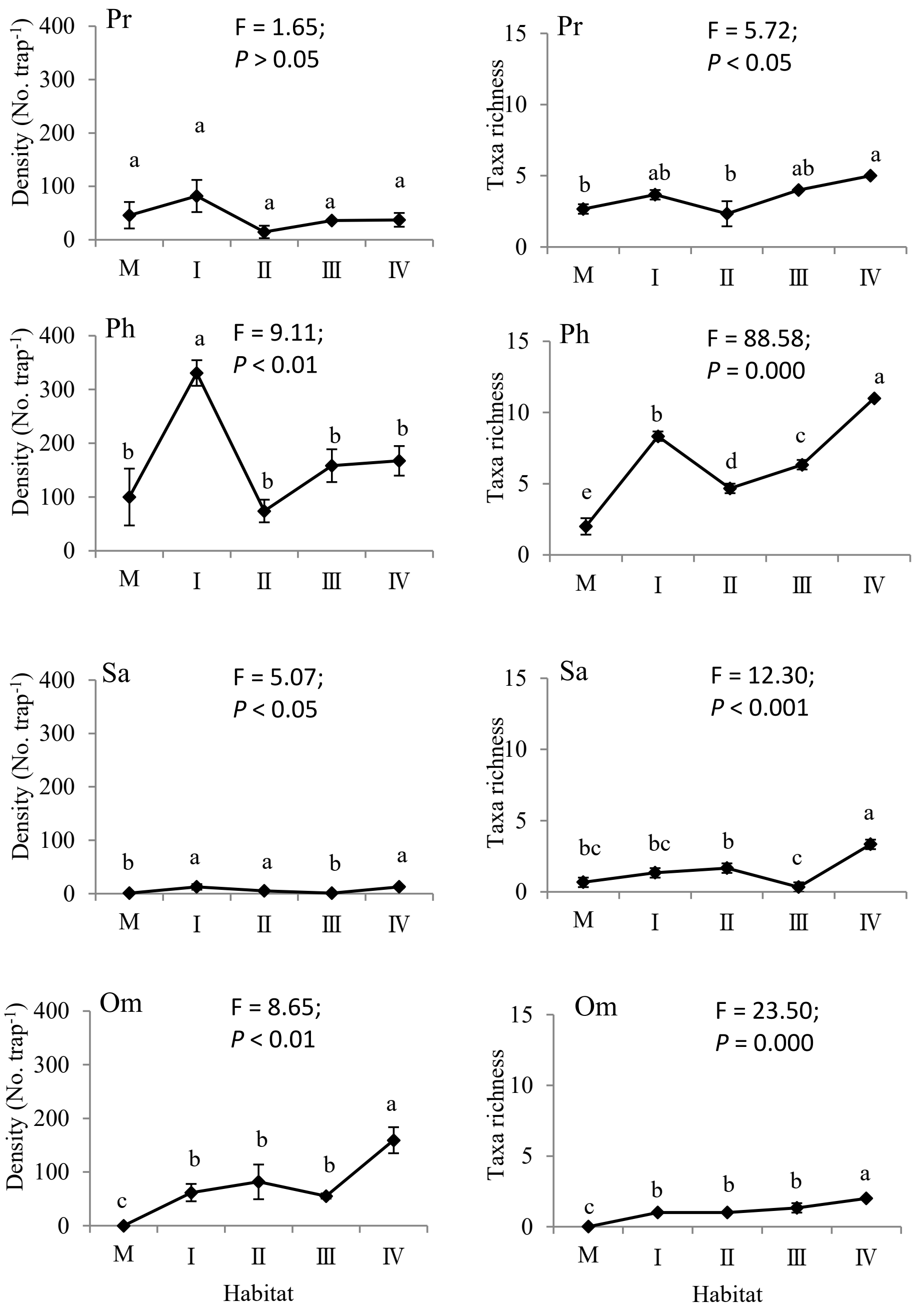

Fig. 2. Density and taxon richness of arthropod trophic groups in habitats of different shrub size. Values were represented by means±SE. Different letters indicate significant differences at $P < 0.05$. Pr = Predators, Ph = Phytophagous group, Sa = Saprophagous group, Om = Omnivorous group. Habitat: M = mobile sandy land, I = very low shrub size, II = low shrub size, III = medium shrub size, IV = high shrub size.

dominant families (i.e., Tenebrionidae and Formicidae) in high shrub size. This finding was mostly in agreement with our first hypothesis. The differences in the dominant taxa between mobile sandy land and shrub plantations confirmed a strong adaptation of particular macrofauna to specific living conditions in these habitats (Liu *et al.* 2009).

On the one hand, to largely extent these new dominant taxa (i.e., Carabidae, Melolonthidae, Curculionidae, and Formicidae) in shrub plantations from the stabilization of mobile sandy land could be considered as indicators of restoration process of desertified ecosystems as indicated by Andersen and Sparling (1997) and Burger *et al.* (2003). The low number of common taxa and low similarity between the mobile sandy land and afforested shrub plantations confirmed this result. For example, Liu *et al.* (2009) reported that the family Labiduridae could be an indicator of mobile sandy land in Horqin sandy land. Whiles, Andersen and Sparling (1997) and Whitford (2000) considered arthropods from the family Formicidae as indicators of restoration success of vegetation in degraded ecosystems.

In addition, these abundant and diverse dominant taxa along with shrub size were commonly considered in biological surveys, and they characterized multiple trophic levels in desertified ecosystems (Williams 1993, Burger *et al.* 2003). The number of dominant taxa was found to indicate a negative relation to their dominance of total individuals. It was suggested that the varying number of arthropod taxa was associated with resource capacity in each afforested plantation as results of shrub size (Schlinkert *et al.* 2015). The shrub size represented food resource availability for biotic communities as indicated by Lightfoot and Whitford (1989). Johnson and Agrawal (2005) suggested that the abiotic conditions including physical protection and food resources offered by shrub crown were associated with arthropod community distribution.

However, there was a high similarity in the composition of ground-active arthropods between the latter three shrub plantations from low to high shrub size. Particularly, there was relatively greater Sørensen indices between shrub plantations of low shrub size and medium and/or high size (i.e., Sørensen indices = 0.69). It was suggested that there was probably a critical line beginning from low shrub size (i.e., 1.5–2 m^3 in shrub volume) that exerted influences on the ground-active arthropod distribution as indicated by Schlinkert (2014). Thereafter, the taxa composition could maintain a relative consistency that facilitated the recovery of community structure together with the formation of well-organized food web of ground-active arthropods along with shrub afforestation (Wardhaugh *et al.* 2012).

Together, the total abundance, and the diversity indices (i.e., taxon richness, Shannon index and evenness index) of ground-active arthropods was found to be significantly greater in shrub plantations of very low shrub size relative to mobile sandy land. This finding was consistent with studies from Mazía *et al.* (2006), Liu *et al.* (2011), J.L. Liu *et al.* (2012), and Zhao and Liu (2013) which demonstrated a facilitative effect of shrub canopy on the activity abundance and diversity of ground-active arthropods. However, there was a significantly greater total abundance in the afforested plantation of very low shrub size in comparison to the latter three shrub plantations, as contrasted the second hypothesis. Also, there were no significant differences in total abundance observed between the latter three shrub plantations and also between these plantations and mobile sandy land. These findings contrasted Lightfoot and Whitford (1989) who indicated that shrub characteristics representing shrub size were positively correlated with arthropod abundances.

Riihimaeki *et al.* (2006) reported that the improved living conditions along with increased shrub size could be attractive for diverse arthropods to dwell in shrub plantations. Schlinkert *et al.* (2015) reported a comprehensive driver of plant-related arthropod richness that was induced by plant size. In this case, the competition on the limited resources by diverse arthropod taxa beneath canopy crown of high shrub size could result in a decreased abundance of dominant taxa (Takeda and Abe 2001, Kruess and Tscharntke 2002). In addition, the trampling effect of grazing was probably important reason explaining the low number of ground-active arthropods in the afforested plantation of low shrub size as indicated by Lenoir and Lennartsson (2010).

However, the arthropod diversity indices (i.e., taxon richness, Shannon index, and evenness index) were observed to be consistently greater in the four afforested plantations relative to mobile sandy land. This finding was characterized by a facilitative effect of shrub canopy on the diversity conservation of ground-active arthropods (JL. Liu *et al.* 2012). With regard to taxon richness, there was a marked lower value in shrub plantations of low shrub size in comparison to the other shrub size, which was followed by low values of Shannon index and evenness index. These results were inconsistent with Lightfoot and Whitford (1989) who indicated that shrub characteristics representing shrub size were positively correlated with arthropod richness. There was probably a detrimental effect of grazing activities by sheep on ground-active arthropod richness in the afforested plantation of low shrub size in practice relative to the other shrub size (Lenoir and Lennartsson 2010).

Interestingly, no significant differences in taxon richness were found between the afforested plantation of very low and medium shrub size, whereas a significantly greater value was found in the afforested plantation of high shrub size relative to the other shrub size. This result was partially consistent with our third hypothesis. There was probably a threshold of taxon richness along with shrub size (i.e., above 6 m^3 in shrub volume), which was partially in line with the findings from Schlinkert *et al.* (2015) and Alan *et al.* (2016).

However, there were no significant differences in the Shannon index and evenness index between the afforested plantation of very low, medium and high shrub size except the low shrub size. There was a similar effect of afforested shrub plantations on ground-active arthropod diversity, particularly restricted or 'specialised' beneath shrub canopy, irrespective of shrub size, which contrasted the third hypothesis. This result was inconsistent with the pattern of taxon richness between the shrub plantations of different shrub size, also contrasting Siemann *et al.* (1999), Southwood *et al.* (1979), and Schlinkert *et al.* (2015). It was suggested that shrub size was not necessarily a key factor taken into account in arthropod diversity recovery of desertified grassland ecosystems in terms of implementation plan of afforested shrub plantations for desertification control. The other factors including livestock grazing activities, and shrub-cutting and shrub age also played a role in the arthropod composition and diversity recovery of shrub plantations in the mobile sandy land (Liu *et al.* 2013a, b).

In regard to trophic groups, there were a similar trend in both density and richness of predator and phytophagous groups, which characterized a bottom-up effect of predator- phytophage relations within food chains (Lynam *et al.* 2017). Notably, at the primary stage from the mobile sandy land to the very low shrub size, there was a significantly greater density and richness of phytophagous groups. Shrub canopy could facilitate phytophagous groups as indicated by Rhoades (1983) and Schlinkert *et al.* (2015). Rhoades (1983) showed that plant size could be one of key factors that determined better or less defense from herbivores by defensive chemicals on highly versus less productive plants. Schlinkert *et al.* (2015) reported that plant size could be a comprehensive driver of species richness distribution of plant-related arthropods (i.e., pollinators, herbivores and their natural enemies).

The density distribution of saprophagous groups was represented by that of family Geotrupidae that was ascribed to the faeces and excrement remaining in the fields as a result of their biological attributes (Whitford 2000). The significantly greater richness of saprophagous groups in the low shrub size was attributive of grazing activities that gave much excrement in the field (by observation). Otherwise, the greatest richness of saprophagous groups observed in the high shrub size was attributive of biological crust observed on the ground that attracted more specific saprophagous groups (Lalley *et al.* 2006). However, there was a similar trend between the density and richness of omnivorous groups from the mobile sandy land through the very low to the high shrub size. It was in agreement with the aforementioned result that shrub canopy could facilitate the omnivorous groups. What's more, the greatest density and richness of omnivorous groups in the high shrub size was a reflective of improved living conditions beneath high shrub canopy. It could facilitate the arthropod abundant taxa and soil biological crust (by observation), and also could attract diverse taxa to occur here (Zhao and Liu 2013). All these results implied that the high shrub size was beneficial for the recovery of trophic groups in the desertified grassland ecosystems (Riihimaeki *et al.* 2006).

CONCLUSIONS

The surveyed habitats were dominated by the desert Carabidae, Formicidae, Melolonthidae, and Tenebrionidae families. The arthropod dominant taxa from mobile sandy land were significantly distinctive from those from plantations of different shrub size. Shrub canopy could facilitate ground-active arthropod diversity recovery when they were afforested in mobile sandy land. There was a similar ground-active arthropod diversity distribution between afforested plantations of four shrub sizes when grazing was excluded. However, the distribution pattern of total abundance and the diversity indices differed in response to shrub size in desertified regions. Shrub size was found to indicate different effects on trophic structure within ground-active arthropod communities. These findings allowed conservation biologists to look beyond the single ecological indices (i.e., total abundance or diversity indices) on the management and conservation of shrub plantation in desertified grassland ecosystems.

ACKNOWLEDGEMENTS: This research was supported by the Ningxia Natural Science Foundation of China (NZ15025), Fok Ying Tung Education Foundation (151103), Ningxia "Science and Technology Project for Overseas" Program (2016494), CAS "Light of West China" Program (XAB2016AW02), and National Natural Science Foundation (41661054; 41661026). We thank the two anonymous reviewers for their valuable comments on the manuscript.

REFERENCES

Alan B.C., Kwok A.B., Eldridge A.D.J. 2016 – The influence of shrub species and fine-scale plant density on arthropods in a semiarid shrubland – Rangeland. J. 38: 381–389.

Andersen A.N., Sparling G.P. 1997 – Ants as indicators of restoration success: relationship with soil microbial biomass in the Australian seasonal tropics – Restor. Ecol. 5: 109–112.

Burger J.C., Redak R.A., Allen E.B., Rotenberry J.T., Allen M.F. 2003 – Restoring arthropod communities in coastal sage scrub – Conserv. Biol. 17: 460–467.

Callaway R.M., Walker L.R. 1997 – Competition and facilitation: a synthetic approach to interactions in plant communities – Ecology, 78: 1958–1965.

Doblas-Miranda E., Sánchez-Piñero F., González-Megías A. 2009 – Different microhabitats affect soil macroinvertebrate assemblages in a Mediterranean arid ecosystem – Appl. Soil Ecol. 41: 329–335.

Eldridge D.J., Soliveres S., Bowker M.A., Val J. 2013 – Grazing dampens the positive effects of shrub encroachment on ecosystem functions in a semi-arid woodland – J. Appl. Ecol. 50: 1028–1038.

Johnson M.T.J., Agrawal A.A. 2005 – Plant genotype and environment interact to shape a diverse arthropod community on evening primrose (*Oenothera biennis*) – Ecology, 86: 874–885.

Kruess A., Tscharntke T. 2002 – Contrasting responses of plant and insect diversity to variation in grazing intensity – Biodivers. Conserv. 106: 293–302.

Lalley J.S., Viles H.A., Henschel J.R., Lalley V. 2006 – Lichen-dominated soil crusts as arthropod habitat in warm deserts – J. Arid Environ. 67: 579–593.

Lenoir L., Lennartsson T. 2010 – Effects of timing of grazing on arthropod communities in semi-natural grasslands – J. Insect Sci. 10:1–24.

Lightfoot D.C., Whitford W.G. 1989 – Interplant variation in creosotebush foliage characteristics and canopy arthropods – Oecologia, 81: 166–175.

Liu J.L., Li F.R., Liu C.A, Liu Q.J. 2012 – Influences of shrub vegetation on distribution and diversity of a ground beetle community in a Gobi desert ecosystem – Biodiver. Conserv. 21: 2601–2619.

Liu R.T, Zhao H.L, Zhao X.Y., Drake S. 2009 – Soil macrofaunal response to sand dune conversion from mobile dune to fixed dune in Horqin Sandy Land, North China – Eur. J. Soil Biol. 45: 417–422.

Liu R.T., Chai Y.Q., Xu K. 2012 – Changes of soil and herbaceous properties during the growth of afforested *Caragana* plantation in desertified steppe – Chin. J. Appl. Ecol. 23: 2937–2942.

Liu R.T., Chai Y.Q., Yang X.G. 2013a – Effect of shrub-cutting and grass-reseeding on the ground-active arthropod community in desertified steppe – Chin. J. Appl. Ecol. 24: 211–217.

Liu R.T., Zhao H.L., Zhao X.Y., Drake S. 2011 – Facilitative effects of shrubs in shifting sand on soil macro-faunal community in Horqin Sand Land of Inner Mongolia, Northern China – Eur. J. Soil Biol. 47: 316–321.

Liu R.T., Zhu F., Song N.P., Yang X.G., Chai Y.Q. 2013b – Seasonal distribution and diversity of ground arthropods in microhabitats following a shrub age sequence in desertified steppe – PLoS ONE, 8(10):e77962.

Liu R.T., Zhu F., Steinberger Y. 2015 – Effect of shrub microhabitats on aboveground and belowground arthropod distribution in a desertified steppe ecosystem – Pol. J. Ecol. 63: 534–348.

Lynam C.P., Llope M., Möllmannd C., Helaouët P., Bayliss-Brown G.A., Stenseth N.C. 2017 – Interaction between top-down and bottom-up control in marine food webs – PNAS USA, 114: 1952–1957.

Mazía C.N., Chaneton E.J., Kitzberger T. 2006 – Small-scale habitat use and assemblage structure of 6 ground dwelling beetles in a Patagonian shrub steppe – J. Arid Environ. 67: 177–194.

Moro M.J., Pugnaire F.I., Haase P, Puigdefábregas J. 1997 – Effect of the canopy of *Retama sphaerocarpa* on its understorey in a semiarid environment – Funct. Ecol. 11: 425–431.

Pugnaire F.I., Lázaro R. 2000 – Seed bank and understorey species composition in a semi-arid environment: the effect of shrub age and rainfall – Annu. Bot. 86: 807–813.

Ren G.D., Yu Y.Z. 1999 – The darkling beetles of Chinese desert and semidesert (Coleoptera: Tenebrionidae) – Hebei University Publishing House, Baoding.

Rhoades D.F. 1983 – Herbivore population dynamics and plant chemistry (In: Variable Plants and Herbivores in Natural and Managed Systems, Eds: R.F. Denno, M.S. McClure) – Academic Press, New York, NY, pp. 155–220.

Riihimaeki J., Vehvilaeinen H., Kaitaniemi P., Koricheva J. 2006 – Host tree architecture mediums the effect of predators on herbivore survival – Ecol. Entomol. 31: 227–235.

Samways M.J. 1992 – Some comparative insect conservation issues of north temperate, tropical, and south temperate landscape – Agric. Ecosyst. Environ. 40: 137–154.

Schlinkert H., Westphal C., Clough Y., László Z., Ludwig M., Tscharntke T. 2015 – Plant size as determinant of species richness of herbivores, natural enemies and pollinators across 21 Brassicaceae species – PLoS ONE, 10(8): e0135928.

Schlinkert H. 2014 – Plant size gradient in Brassicaceae. figshare, http://figshare.com; 10.6084/m9. figshare.1246843.

Schultz J.C. 1978 – Competition, predation, and the structure of phytophilous insect communities: A study of convergent evolution – Dissertation, Univ. of Washington, Seattle, WA.

Schultz J.C. 1981 – Adaptive changes in antipredator behavior of a grasshopper during development – Evolution, 35: 175–179.

Schultz J.C., Otte D., Enders F. 1977 – Larrea as a habitat component for desert arthropods (In: Creosote Bush: Biology and Chemistry of Larrea in New World Deserts, Eds: T.J. Mabry, J.H. Hunziker, D.R.Jr. Defeo) – US/IBP Synthesis Series 6. Dowden, Hutchinson & Ross, Inc., Stroudsburg, PA.

Siemann E., Haarstad J., Tilman D. 1999 – Dynamics of plant and arthropod diversity during old field succession – Ecography, 22: 406–414.

Southwood T.R.E, Brown V.K., Reader P.M. 1979 – The relationships of plant and insect diversities in succession – Biol. J. Linn. Soc. 12: 327–348.

Takeda H., Abe T. 2001 – Templates of food–habitat resources for the organization of soil animals in temperate and tropical forests – Ecol. Res. 16: 961–973.

Wang X.Y. 2013 – Biomass model of *Caragana* shrubs of different ages in desertified steppe – J. Biomath. 28: 377–383.

Wardhaugh C.W., Stork N.E., Edwards W. 2012 – Feeding guild structure of beetles on Australian tropical rainforest trees reflects microhabitat resource availability – J. Anim. Ecol. 8: 1086–1094.

Wardle D.A., Bardgett R.D., Klironomos J.N. *et al*. 2004. – Ecological linkages between aboveground and belowground biota – Science, 304: 1629–1633.

Wezel A., Rajot J.L., Herbrig C. 2000 – Influence of shrubs on soil characteristics and their function in Sahelian agro-ecosystems in semi-arid Niger – J. Arid Environ. 44: 383–398.

Whitford W.G. 2000 – Keystone arthropods as webmasters in desert ecosystems (In: Invertebrates as webmasters in ecosystems, Eds: D.C. Coleman, P.F. Hendrix) – CABI Publishing, London, pp. 25–42.

Williams K.S. 1993 – Use of terrestrial arthropods to evaluate restored riparian woodlands – Restor. Ecol. 1: 107–116.

Yin W.Y. 2001 – Pictorial Keys to Soil Faunas of China – Science Press, Beijing.

Zhao H.L., Liu R.T. 2013 – The "bug island" effect of shrubs and its formation mechanism in Horqin Sand Land, Inner Mongolia – Catena, 105: 69–74.

Zhao X.Y., Luo Y.Y., Wang S.K., Huang W.D, Lian J. 2010 – Is desertification reversion sustainable in northern China? A case study in Naiman county, part of a typical agro-pastoral transitional zone in Inner-Mongolia, China – Global Environ. Res. 14: 63–70.

Zheng L.Y., Gui H. 2004 – Insect Classification – Nanjing Normal University Press, Nanjing.