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Effect of naturally vs manually managed restoration on ground-dwelling arthropod communities in a desertified region

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ABSTRACT

Both naturally and manually managed restoration can effectively improve degraded ecosystems; however, little is known about the option of restoration management for the recovery of ground-dwelling arthropod communities in desertified regions. Naturally restored grassland (termed here "grassland") and manually afforested shrubland (termed here "shrubland") were compared in relation to ground-dwelling arthropod communities; the adjacent mobile sand land was used as a control. Both types of restoration markedly improved soil and herbaceous properties, with the grassland characterized by high plant herbaceous richness and abundance in addition to low soil temperature, and the shrubland characterized by high soil fine-sand content and clay-plus-silt content as well as low coarse-sand content. Restoration management in different habitats resulted in the specific distribution of arthropod groups, with the Labiduridae and Anatolicas (Tenebrionidae) dominant in the mobile sand land and the Formicidae dominant at both restored sites. Total abundance was correlated with the dominant taxa, even for the Simpson index; both were significantly higher in the mobile sand land than in the restored sites, while no significant differences were found between the two types of restoration. Restoration management facilitated ground-dwelling arthropod diversity, including taxon richness, with markedly higher values in the restored sites compared with those in the mobile sand land. Furthermore, taxon richness and Shannon index were noticeable in the shrubland, with significantly higher values than in the grassland. Soil temperature, water content, and bulk density together explained the different structure of ground-dwelling arthropod communities at each site where the restored procedures were implemented. Overall, the manually afforested shrubland was found to contribute much more to the conservation of ground-dwelling arthropod diversity relative to the naturally restored grassland, where both restored strategies were used to facilitate the processes of fixation and recovery of desertified sand land.

1. Introduction

In arid and semiarid areas, sandy grassland is susceptible to land degradation and has undergone severe desertification, primarily due to heavy grazing combined with climate change (Li et al., 2004; Zhao et al., 2005). Grazing management (e.g., exclosure) is considered one of the main methods used that is aimed at the natural restoration of grassland ecosystems and desertification control (Mekuria et al., 2007; Parfitt et al., 2010). A widespread and important afforestation program, widely used in rehabilitating desertified ecosystems, has been reported as a manual measure for the stabilization of mobile sand land and the fast recovery of degraded arid ecosystems (Su and Zhao, 2003; Zhao et al., 1999). Both restoration strategies, i.e., natural and manual (labor-intensive), are expected to improve soil and vegetation systems, thus facilitating the recovery process of desertified ecosystems (Liu et al., 2013a; Okin et al., 2001; Su et al., 2005).

According to Hemerik and Brussaard (2002), during this recovery process, the naturally restored grassland can provide enough palatable food resources to benefit the ground-dwelling arthropod communities. As reported by Liu et al. (2012), a 15-year grazing-exclusion policy could facilitate the diversity recovery of soil faunal communities in a desertified steppe ecosystem, while, shrub afforestation was found to be beneficial for the restoration of soil faunal diversity and the stabilization of mobile sand lands

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(Liu et al., 2013a). The findings of Zhao and Liu (2013) indicated that the shrubs facilitated the aggregation of soil macro-arthropods; this was known as the "bug island" effect of shrubs. Overall, the microhabitats that resulted from the natural or manual types of restoration related to faunal assemblages, provided a relevant issue for research into arthropod survival, occurrence, and distribution (Andersen et al., 2002; Ayal, 2007; Blaum et al., 2009). As of now, the knowledge accumulated has been related to the restoration strategies for degraded ecosystems; there were very limited data on the comparable relationship between ground-dwelling arthropod communities and selective restoration management in desertified regions.

Over the past several decades, the Mu Us sandy land has undergone severe desertification, resulting in a strong call for desertification research in China (Xu et al., 2012). A restoration project was initiated by the local government, and grazing exclosure was established using fences constructed with concrete pilings and barbed wire. In the exclosure, all grazing by domestic herbivores was excluded, with the goal of allowing the natural vegetation to recover in the desertified grassland regions. Simultaneously, the local government implemented a large-area conservation program since the 1970s that included manually afforested plantations. Till now, plant cover by shrub *Caragana* plantations accounted for an area of about 24.3% of the county, with a mean density of 915–3015 plant hm^{-2}, indicating effective desertification control (Liu et al., 2013b). Guo (2009) and Tao et al. (2011) showed that there were many serious debates related to this shrub plantation program on issues such as water consumption and niche competition against herbaceous vegetation recovery in a water-limited desertified region. In the afforested shrubland, weeds dominated the vegetation community, and the palatable herbage plants did not recover correspondingly in practice with the stabilization of mobile sand land. Both the manual and natural restoration programs were vital for assessing the ecological and economic effects on the desertified grassland ecosystems (Wang et al., 2010; Zhao et al., 1999). Thus, it was necessary to determine the effectiveness of selective restoration procedures regarding ground-dwelling arthropod communities for the recovery of desertified grassland.

Ground-dwelling arthropods play an ecologically important role in terrestrial ecosystems, for example, (1) as pollinators; (2) as important components of food chains and nutrient cycles; and (3) in altering soil structure and fertility in arid and semiarid regions (Lobry de Bruyn, 1999). The taxa can also be considered bioindicators used to assess the effectiveness of different restoration strategies in desertified arid soils. Furthermore, the biotic interactions in soils can regulate the structure and function of aboveground and belowground communities (Wardle et al., 2004; Jiang et al., 2007). These interactions between belowground and aboveground subecosystems have a considerable influence on community- and ecosystem-level processes (Wardle et al., 2004) during the recovery of degraded arid ecosystems. However, arthropod responses to the selective restoration procedures were largely unknown when these restoration procedures were implemented to reverse desertification in northwestern China. Therefore, with the focus on the ground-dwelling arthropods, it is

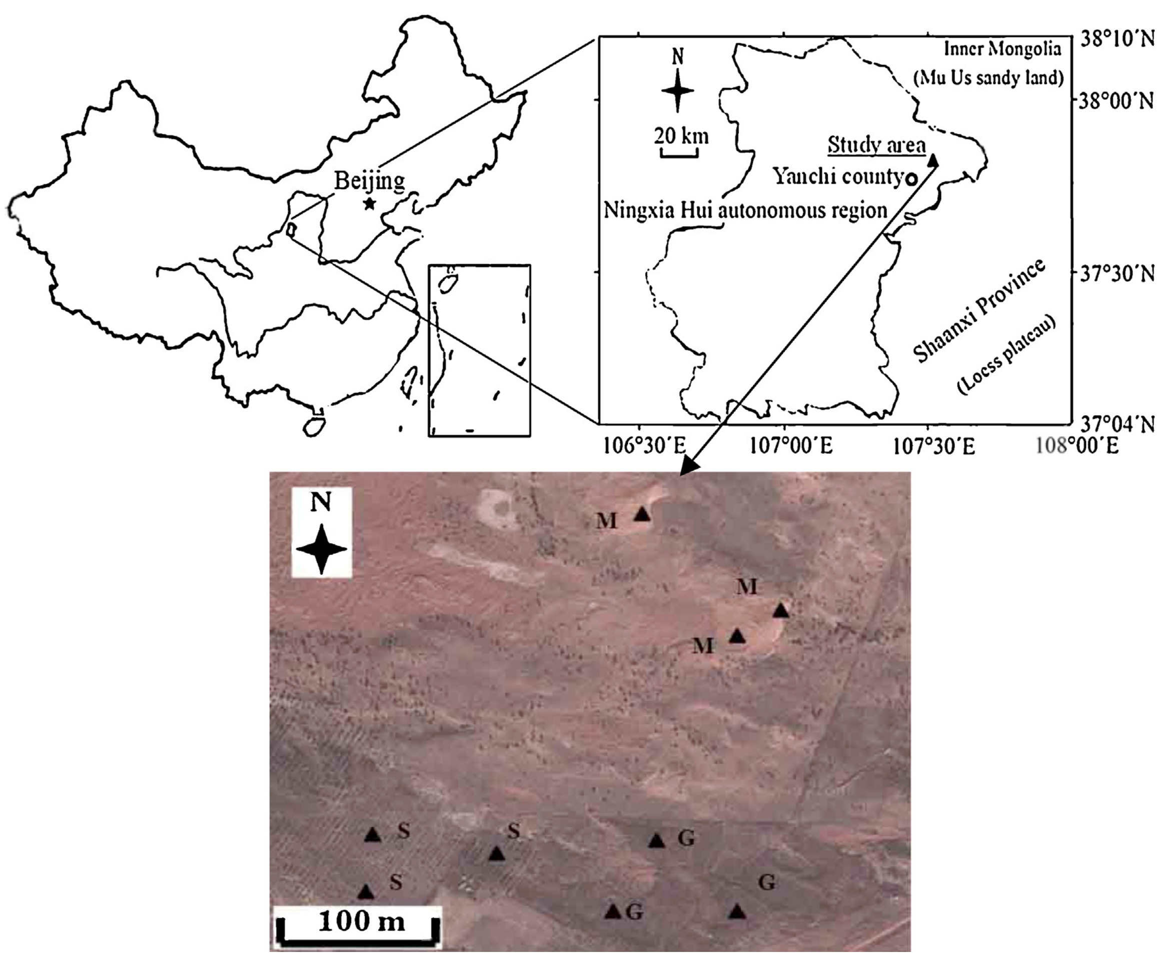

Fig. 1. Location of sampling sites (triangle) in a desertified steppe of Ningxia, northwestern China (from Imagery ©2014 DigitalGlobe, CNES/SPOT Image, Landsat, Google Earth). M – mobile sand land, S – manually afforested shrubland, G – naturally restored grassland.

expected that the findings obtained from this study will have strong implications on the selection of suitable procedures for ecosystem restoration and desertification control in arid and semiarid systems.

The aims of the present study were: (1) to compare ground-dwelling arthropod communities in both restored grassland and afforested-plantation habitats; (2) to determine the relationship between the community structures of ground-dwelling arthropods and environmental parameters; and (3) to assess the impact of selective restoration on a ground-dwelling arthropod community. This study can supply data that will give profound insight into the effectiveness of arthropod-diversity recovery and related food-web structure and terrestrial-ecosystem functioning, with the stabilization of mobile sand land. The results can also be used for the determination of selective restoration procedures for the efficient recovery process of degraded ecosystems and for desertification control, and, thus, for developing a monitoring program to evaluate restoration success in arid and semi-arid Mu Us soils in northern China.

2. Materials and methods

The study was conducted in northern Yanchi County (37°04′–38°10′N and 106°30′–107°41′E, elevation 1450 m), located at the southwestern fringe of Mu Us sandy land in the Ningxia Hui Autonomous Region of China (Fig. 1). The region has a temperate, continental, semiarid, monsoonal climate with a mean multi-annual precipitation of 289 mm; 70% of the total precipitation occurs between June and September. Mean multi-annual potential pan-evaporation is 2014 mm per year. Mean multi-annual temperature is 8.1 °C, with lowest and highest monthly mean temperatures of −8.7 °C in January and 22.4 °C in July, respectively. Mean annual wind velocity is 2.8 m s^{-1}, and prevailing winds are mainly northwest in April and May. Sand dust-blowing at velocities over 5.0 m s^{-1} occurs at an average of 323 times per year. Wind erosion often occurs from April to mid-June, before the rainy season begins (climate data from Yanchi Meteorological Station, 1976–2010). At the study site, the main soil types are sierozem, loess, and orthi-sandic entisols, all of which are of low fertility, loose structure, and are very susceptible to wind erosion (Liu et al., 2013b).

The predominant vegetation in the mobile sand land was *Agriophyllum squarrosum* (Table 1). Together with the gradual stabilization of the mobile sand land by manually afforested shrubs, e.g., *Caragana*, shrubland plantations formed, and herbaceous vegetation was created by *Salsola collina*,*Artemisia scoparia*, *Corispermum mongolicum*, *Echinops gmelini*, and *Euphorbia humifusa*. At the sites where natural restoration was imposed, the herbaceous vegetation was found to be dominated by *Pennisetum centrasiaticum*, *Aneurolepidium dasystachys*, *Cleistogenes gracilis*, *Astragalus melilotoides*, *Thermopsis lanceolata*, and *Lespedeza potaninii*.

2.1. Experimental design

Three replicate plots (30 m × 30 m), at least 50 m apart from each other, were established for each type of restoration, e.g., naturally restored grassland (i.e., "grassland", G), and manually afforested shrubland (i.e., "shrubland", S) in a 10-year-old fenced site with mobile sand land as a control (i.e., C) (Fig. 1). In each plot, five sampling points, 7–10 m apart from each other, were set for arthropod, soil, and vegetation determination. In the shrubland, the shrub belts were 8 m apart from each other, and the sampling points were set beneath the canopy of shrubs within every two belts, in light of the existence of a "bug island" (Zhao and Liu, 2013).

2.2. Arthropod sampling

At each sampling point, a pitfall trap (7 cm diameter, 10 cm depth), filled with approximately 70 ml of 70% ethanol solution, was placed in the soil, with the opening of the trap level with the

Table 1
The abundance (mean ± SE, individuals m^{-2}) and height (mean ± SE, cm) of herbaceous vegetation for each site. M – mobile sand land, S – manually afforested shrubland, G – naturally restored grassland.

Plant species	M		S		G	
	Abundance	Height	Abundance	Height	Abundance	Height
Agriophyllum squarrosum	51.7 ± 11.5	6.6 ± 1.0				
Artemisia scoparia			83.3 ± 24.2	47.1 ± 4.3	333.4 ± 69.8	19.4 ± 1.4
Astragalus melilotoides			2.7 ± 0.0	28.2 ± 0.0	2.4 ± 0.9	29.1 ± 0.8
Leymus secalinus	5.0 ± 3.0	17.4 ± 2.1	36.6 ± 19.0	36.4 ± 4.1	13.8 ± 11.3	33.7 ± 9.0
Oxytropis psamocharis			1.0 ± 0.0	7.3 ± 0.8	6.5 ± 2.3	7.0 ± 0.4
Echinochloa crusgalli					6.3 ± 2.8	3.6 ± 0.7
Sophora alopecuroides			2.3 ± 0.8	27.6 ± 12.6	3.1 ± 0.9	21.3 ± 3.2
Echinops gmelinii			13.1 ± 4.1	28.9 ± 2.8	25.0 ± 6.0	14.6 ± 1.3
Pennisetum centrasiaticum			2.0 ± 0.0	10.0 ± 0.0	16.0 ± 7.1	10.6 ± 2.4
Polygala tenuifolia			2.7 ± 0.0	8.5 ± 0.0	2.8 ± 0.2	7.9 ± 1.6
Cleistogenes gracilis			10.0 ± 0.0	16.7 ± 0.0	4.4 ± 1.7	5.6 ± 0.7
Salsola collina			24.8 ± 7.2	12.6 ± 0.8	9.7 ± 2.4	2.4 ± 0.3
Cuscuta chinensis			1.0 ± 0.0	5.0 ± 0.0	1.0 ± 0.0	7.8 ± 0.3
Parthenocisus tricuspidata			5.5 ± 2.5	1.8 ± 0.7	21.2 ± 5.7	0.7 ± 0.2
Lespedeza potaninii			2.0 ± 0.0	16.0 ± 0.0	9.4 ± 3.2	18.0 ± 0.7
Heteropappus altaicus			3.6 ± 1.4	18.0 ± 6.0	3.9 ± 1.6	9.0 ± 2.5
Scorzonera divaricata			2.5 ± 1.5	19.3 ± 1.7	34.5 ± 33.5	12.7 ± 1.3
Cynanchum komarovii					1.3 ± 0.3	18.0 ± 2.0
Corispermum hyssopifolium	2.0 ± 0.0	10.0 ± 0.0	3.0 ± 0.0	9.7 ± 0.0	47.3 ± 46.3	4.2 ± 1.2
Euphorbia esula			3.8 ± 0.5	17.6 ± 2.4	5.3 ± 1.8	15.9 ± 5.0
Setaria viridis	3.5 ± 1.5	3.0 ± 0.0	7.7 ± 0.0	15.8 ± 0.0	10.0 ± 0.0	3.7 ± 0.0
Gueldenstaedtia verna			2.0 ± 0.0	6.3 ± 0.0	2.0 ± 1.0	4.2 ± 1.8
Oxytropis aciphylla					1.0 ± 0.0	1.5 ± 0.0
Thlaspi arvense			4.1 ± 0.4	18.9 ± 2.6	1.5 ± 0.5	9.6 ± 1.6
Allium mongolicum			1.0 ± 0.0	11.0 ± 0.0	5.0 ± 0.0	10.5 ± 0.0
Poaceae sp.					7.0 ± 0.0	3.3 ± 0.0
Artemisia sp.					1.0 ± 0.0	12.0 ± 0.0
Unkown sp.			6.0 ± 0.0	5.5 ± 0.0		

ground surface. Arthropod sampling was conducted in the summer of 2012, at the time of peak growth of vegetation. The sampling periods consisted of 15 consecutive trapping days (day and night). Traps were checked every three days during the sampling period, and ethanol solution was added as needed. At the end of the sampling period, the specimens were collected, preserved in 75% ethanol, and identified to order and family levels under a microscope, based on the relevant literature (Zheng and Gui, 2004; Yin, 2001).

2.3. Determination of vegetation and soil physicochemical properties

Adjacent to each sampling point, 1 m × 1 m quadrats were set, and five quadrats were obtained for each replicate plot. The number of plant species (PS), their density (PD, individuals m^{-2}), the overall ground vegetation cover (VC, %), and the mean vegetation height (PH, cm), were determined. Vegetation cover was estimated visually using sample images for VC values ranging from 0 to 100% at 10% intervals. Vegetation height was the mean height of all plants inside the quadrates (Zhang et al., 2004). In each replicate shrubland plot, canopy size was also determined by measuring its height and diameter.

At each sampling point, two soil cores were obtained from the 0–10 cm layers using a cylindrical 100-cm^3 stainless-steel soil auger. All soil samples were brought to the laboratory for the analysis of soil physicochemical properties. Soil bulk density (BD $g\,cm^{-3}$) was determined by volume/dry weight ratio, and water content (SW%) was determined gravimetrically by drying soil samples at 60 °C for 48 h. Soil texture was determined by the dry sieve method (Li et al., 2009), i.e., dividing the soil into three particle sizes: coarse sand (>2 mm, CS, %), fine sand (2–0.05 mm, FS, %) and silt plus clay (<0.05 mm, CPS, %), expressed as percentage of soil weight. For each quadrate, soil temperature (ST, °C) was determined during the growing season using a portable thermometer with conductivity wires (Sato Keiryoki MFG Co. Ltd., Japan).

2.4. Data analysis

Preliminary data analysis of arthropod abundance showed no significant differences between the five sampling points in each plot. Trap contents from the five sampling points were averaged for each plot. Total abundance was expressed as the number of individuals per trap. Then total taxonomic richness and Shannon diversity index were calculated together with the Simpson index. Least significant difference (LSD) tests and Tukey–Kramer HSD (honest significant difference) comparisons were used in order to test differences between means for each class within each factor. All statistical analyses were performed using SPSS 16.0 for Windows (SPSS Inc., Chicago, IL). Before applying parametric tests, we tested for normality and homogeneity of variances. For all tests, statistically significant differences were assigned at $p < 0.05$.

Ordination techniques were used to determine the relative contribution of the measured environmental variables to community composition (Lepš and Šmilauer, 2003). The taxon abundance data were first analyzed by detrended correspondence analysis (DCA, length of gradient <4), suggesting that redundancy analysis (RDA) was an appropriate approach. Partial RDA and the Monte Carlo permutation test were used to determine the conditional effect of soil temperature with the remaining variables as covariables, that of soil water content with the remaining variables as covariables, that of soil bulk density with the remaining variables as covariables, that of plant height with the remaining variables as covariables, etc. DCA and partial RDA were carried out using CANOCO software for Windows 4.5 (Microcomputer Power, Ithaca, NY). Before RDA, the Hellinger transformation was applied to remove the issue of double zeros in the data matrix and to improve analysis. The data and Monte Carlo reduced model tests with 499 unrestricted permutations were used to statistically evaluate the significance.

3. Results

3.1. Responses of environmental variables to restoration management

Soil particle distribution showed significant ($p < 0.05$) differences between sampling sites (Table 2). Soil coarse-sand content and fine-sand content followed an opposite pattern, with significantly ($p < 0.05$) higher coarse-sand content and lower fine-sand content in the mobile sand land and grassland in comparison with shrubland. However, soil clay-plus-silt content indicated significantly ($p < 0.01$) higher values in both grassland and shrubland in comparison with the mobile sand land. Soil temperature, water content, and bulk density decreased significantly ($p < 0.05$) through the stabilization of the mobile sand land regardless of type of restoration, while an opposite pattern was found for plant richness and cover, with significantly ($p < 0.01$) higher values in the restored sites in comparison with the mobile sand land (Table 2). Noticeably, the grassland harbored significantly ($p < 0.01$) higher total plant abundance, while the shrubland facilitated plant height, relative to the other sites. The shrub plantations were correlated with canopy size; the mean shrub height was 0.56 ± 0.07 m and the canopy area (length × width) was 0.83 ± 0.16 m^2 ($n = 15$).

3.2. Population-level responses to restoration management

A total of 578 individuals belonging to 41 taxonomic groups (8 orders and 34 families plus additional larval groups) were collected during the study period (Table 3). Family *Labiduridae*

Table 2
Environmental parameters at each site.

	Soil						Herbaceous vegetation			
	Particle distribution %			Bulk density $g\,cm^{-3}$	Temperature °C	Water content%	Species richness	Density No. m^{-2}	Height cm	Cover %
	>0.25 mm	0.25–0.05 mm	<0.05 mm							
M	26.3 ± 3.0a	73.3 ± 3.0b	0.4 ± 0.0b	1.4 ± 0.0a	35.2 ± 0.7a	4.7 ± 0.7a	2.7 ± 0.9b	232 ± 40b	8.3 ± 0.9b	7.3 ± 2.3b
S	12.9 ± 1.1b	82.5 ± 1.0a	4.6 ± 0.6a	1.3 ± 0.0b	27.1 ± 0.4b	2.4 ± 0.5b	8.0 ± 1.8b	160 ± 35b	30.1 ± 9.2a	25.0 ± 2.6a
G	22.4 ± 2.7a	71.1 ± 0.7b	3.5 ± 0.4a	1.3 ± 0.0ab	24.7 ± 0.2c	0.8 ± 0.1b	19.0 ± 2.3a	447 ± 64a	11.5 ± 0.9b	26.0 ± 4.0a
F	8.1*	9.4*	23.8**	6.0*	146.5***	15.6**	22.2**	9.6*	4.9($p = 0.05$)	11.5**

M – mobile sand land, S – manually afforested shrubland, G – naturally restored grassland.
Different letters in the column means significant differences between sampling sites.
* $p < 0.05$,
** $p < 0.01$,
*** $p < 0.001$.

Table 3
The abundance (mean ± SE, individuals $trap^{-1}$) of the taxonomic group for each site.

Taxa	Code	M	S	G
Mite	1	0.00 ± 0.00	0.00 ± 0.00	0.07 ± 0.07
Salticidae	2	0.33 ± 0.33	0.00 ± 0.00	0.00 ± 0.00
Theridiidae	3	0.00 ± 0.00	0.25 ± 0.25	0.00 ± 0.00
Lycosidae	4	0.00 ± 0.00	0.50 ± 0.14	0.00 ± 0.00
Oxyopidae	5	0.00 ± 0.00	0.17 ± 0.08	0.00 ± 0.00
Gnaphosidae	6	0.33 ± 0.33	0.25 ± 0.00	0.00 ± 0.00
Philodromidae	7	0.00 ± 0.00	2.00 ± 0.25	0.67 ± 0.37
Clubionidae	8	0.00 ± 0.00	0.08 ± 0.08	0.07 ± 0.07
Liocranidae	9	0.00 ± 0.00	0.00 ± 0.00	0.13 ± 0.13
Thomisidae	10	0.00 ± 0.00	0.00 ± 0.00	0.13 ± 0.07
Labiduridae	11	38.67 ± 23.69	0.00 ± 0.00	0.00 ± 0.00
Tettigoniidae	12	0.00 ± 0.00	0.00 ± 0.00	0.13 ± 0.07
Aphididae	13	0.00 ± 0.00	0.00 ± 0.00	0.07 ± 0.07
Cicadellidae	14	0.00 ± 0.00	0.25 ± 0.25	0.00 ± 0.00
Membracidae	15	0.00 ± 0.00	0.08 ± 0.08	0.00 ± 0.00
Lygaeidae	16	0.00 ± 0.00	0.50 ± 0.14	0.20 ± 0.12
Pyrrhocoridae	17	0.00 ± 0.00	0.00 ± 0.00	0.07 ± 0.07
Coreoidea	18	0.00 ± 0.00	0.08 ± 0.08	0.00 ± 0.00
Scutelleridae	19	0.00 ± 0.00	0.08 ± 0.08	0.13 ± 0.13
Anthocoridae	20	0.00 ± 0.00	0.08 ± 0.08	0.00 ± 0.00
Carabidae	21	6.67 ± 1.20	1.25 ± 0.38	1.20 ± 0.23
Chrysomeloidea	22	0.00 ± 0.00	0.17 ± 0.08	0.07 ± 0.07
Buprestidae	23	0.33 ± 0.33	0.00 ± 0.00	0.00 ± 0.00
Anatolica[a]	24	96.67 ± 53.80	5.92 ± 4.23	0.00 ± 0.00
Blap[a]	25	1.00 ± 0.58	3.25 ± 0.25	0.00 ± 0.00
Gonocephalum[a]	26	1.33 ± 1.33	0.58 ± 0.36	0.00 ± 0.00
Crypticus[a]	27	0.00 ± 0.00	0.17 ± 0.17	0.00 ± 0.00
Melolonthidae	28	0.33 ± 0.33	0.25 ± 0.14	1.87 ± 0.52
Curculionidae	29	0.00 ± 0.00	0.58 ± 0.33	0.00 ± 0.00
Dermestidae	30	1.00 ± 0.58	0.00 ± 0.00	0.00 ± 0.00
Silphidae	32	0.00 ± 0.00	0.00 ± 0.00	0.33 ± 0.33
Tenebrionidae larvae	31	0.00 ± 0.00	0.00 ± 0.00	1.73 ± 0.55
Meloidae larvae	33	0.00 ± 0.00	0.00 ± 0.00	0.13 ± 0.07
Chrysomelidae larvae	34	0.00 ± 0.00	0.17 ± 0.17	0.13 ± 0.07
Curculionidae larvae	35	0.00 ± 0.00	0.08 ± 0.08	0.00 ± 0.00
Formicidae	36	0.00 ± 0.00	6.25 ± 2.14	14.47 ± 3.09
Pompilidae	37	0.33 ± 0.33	0.00 ± 0.00	0.00 ± 0.00
Sco1iidae	38	0.00 ± 0.00	0.58 ± 0.36	0.00 ± 0.00
Sphecidae	39	0.00 ± 0.00	0.00 ± 0.00	0.07 ± 0.07
Apinae	40	0.00 ± 0.00	0.08 ± 0.08	0.00 ± 0.00
Lepidoptera larvae	41	0.00 ± 0.00	0.25 ± 0.14	0.07 ± 0.07

M – mobile sand land, S – manually afforested shrubland, G – naturally restored grassland.
[a] Represents the genus of family *Tenebrionidae*.

(order: *Dermaptera*), genus *Anatolicas* (family *Tenebrionidae*, *Coleoptera*), and family *Formicidae* (*Hymenoptera*), were found to be predominant in the overall ground-dwelling arthropod assemblage (Fig. 2). Together, they comprised 84.07% of the total number of individuals.

The three predominant groups were found to be considerably affected by the restoration treatment (Fig. 2). *Labiduridae* (*Dermaptera*) taxa were found to be predominant only in the mobile sand land, with no individuals found in the restored sites. Likewise, the *Anatolica* (*Tenebrionidae*) taxa were found only in the mobile sand land and shrubland, but not in the naturally restored sites. The ants (i.e., *Formicidae*) taxa, however, were found only in the shrubland and grassland, with significantly ($p < 0.05$) higher abundance in grassland in comparison with shrubland.

3.3. Community-level responses to restoration management

Total abundance, taxon richness, the Shannon index and the Simpson index, were all found to be significantly ($p < 0.05$) affected by the restoration treatments (Fig. 3). Total abundance and the Simpson index decreased significantly ($p < 0.05$) whereas taxon richness and the Shannon index increased significantly ($p < 0.05$) after the mobile sand land was stabilized and restored, irrespective of the type of management. Furthermore, the shrub plantation effect was found to be distinctively elevated by taxon richness and the Shannon index, with significantly ($p < 0.05$) higher values in shrubland than in grassland.

3.4. Relative contributions of environmental factors to taxonomical composition

RDA analysis showed that all the environmental variables including soil properties (temperature, moisture, coarse sand, fine sand, silt plus clay, and bulk density) explained 96% of the total variation in the data, with axes 1 and 2 accounting for 80.7 and 15.0% of the total variation, respectively (Fig. 4). Partial RDA showed that different environmental variables differed in their influence on the community composition of ground arthropods (Table 4). From all the ten environmental variables, only soil temperature ($p = 0.002$), moisture ($p = 0.012$), and bulk density ($p = 0.024$) were found to be significant under the Monte Carlo permutation test, whereas those of the remaining variables were not significant under the Monte Carlo permutation test (in all cases $p > 0.05$). Soil temperature, moisture, and bulk density accounted for 56.2%, 24.9%, and 11% of the total 100% variation explained by RDA, respectively, while the other variables that were not significant under the Monte Carlo permutation test accounted for the rest (only 8%) (Table 4).

4. Discussion

The present study elucidates the importance of restoration measures in soil amelioration and herbaceous recovery (Tables 1, 2). The management of restoration increased soil clay-plus-silt content due to increased vegetation cover and decreased surface roughness, as found by Li et al. (2000) and Pei et al. (2008), in comparison to the adjacent mobile sand land. In the shrubland, the higher soil fine-sand content and clay-plus-silt content were correlated with the contribution of "fertile islands" by shrubs that could improve soil texture as well as increase soil organic matter and nutrients, thus ameliorating soil fertility (Garner and Steinberger, 1989). Despite a narrow range (1.27–1.39 g cm^{-3}), soil bulk density in the surface decreased significantly after

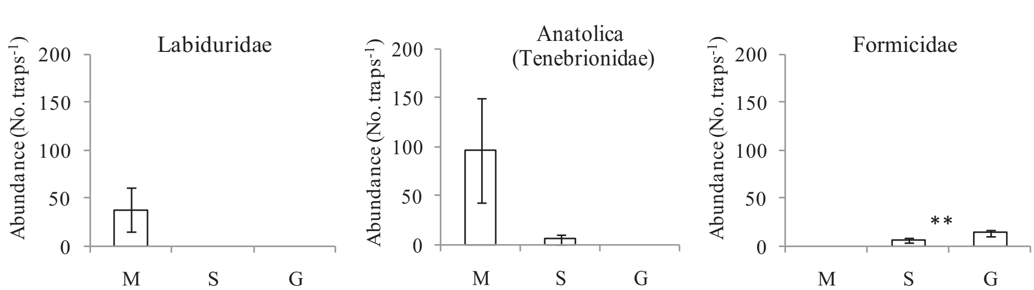

Fig. 2. The mean abundance (individuals per trap) of dominant groups in each site. M – mobile sand land, S – manually afforested shrubland, G – naturally restored grassland. **Significant differences between sampling sites at $p < 0.01$.

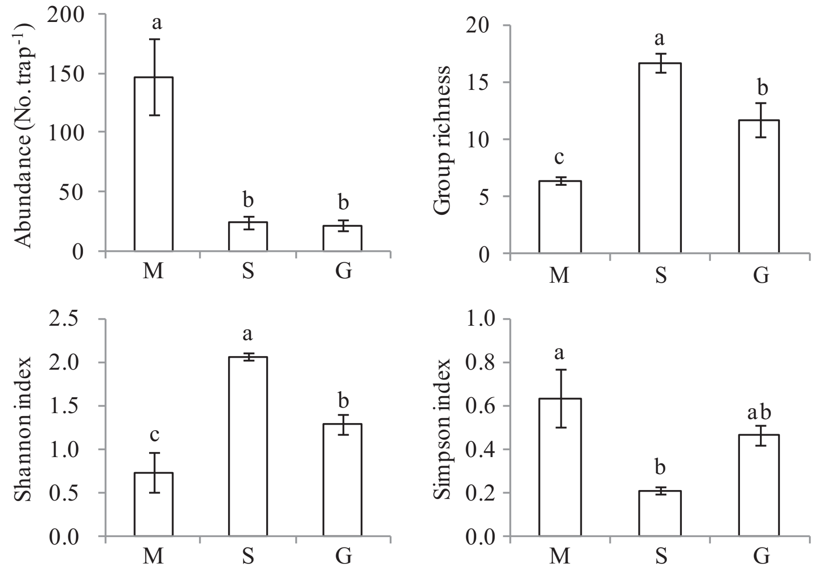

Fig. 3. Abundance, group richness, Shannon index, and Simpson index of arthropod communities at each site. Different letters indicate significant differences between sampling sites at $p < 0.05$. M – mobile sand land, S – manually afforested shrubland, G – naturally restored grassland.

restoration, which was in agreement with Su et al. (2005) and Pei et al. (2008). The decrease in soil moisture content and temperature at the restored sites was presumably due to significantly greater canopy density that provided shade from drop-down rainfall in the summer rainfall season (Stockton and Gillete, 1990), particularly in naturally restored grassland with markedly higher plant species richness, density, and vegetation cover. The naturally restored grassland sites increased the availability of potential palatable food resources for grazers

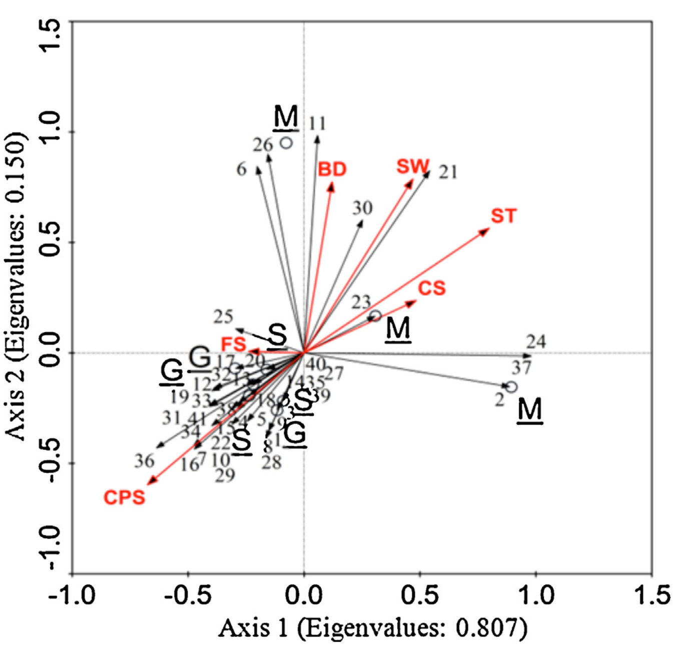

Fig. 4. Redundancy analysis (RDA) showing the relationship between arthropod composition and environmental variables. In the biplot, the arthropod groups are represented by numbers (full names of arthropod groups are given in Table 2). Three microhabitat types are represented: M – mobile sand land, S – manually afforested shrubland, and G – naturally restored grassland. Environmental variables (SW – soil moisture content, ST – soil temperature, CS – coarse-sand content, FS – fine-sand content, CPS – silt-and-clay content, BD – bulk density) are represented as arrows and the strength of their impacts were directly proportional to the length of the arrow lines.

(i.e., arthropods) that can be linked to the nature of grassland (Siemann, 1998). However, the mean height of herbaceous plants was greater beneath the shrub canopy in comparison with the grassland and mobile sand land. This was presumably due to the rich soil nutrients from a specific "fertile island" provided by shrubs for the growth of herbaceous plants beneath the shrub canopy (Liu et al., 2013b).

Different microhabitats related to the restored management on the mobile sand land also greatly affected the distribution of ground-dwelling arthropods. In the present study, the *Labiduridae* and *Anatolicas* (*Tenebrionidae*) taxa were found to dominate the mobile sand land, being the most abundant; however, after undergoing restoration, the abundance of these two groups markedly decreased, and even disappeared (for example, *Labiduridae*), whereas the abundance of another group (i.e., ants) markedly increased. The different ground-dwelling arthropod groups were found to be present under xeric conditions due to their specific selection and adaptation (Liu et al., 2009, 2011). For example, *Labiduridae* and *Anatolicas* (i.e., desert *Tenebrionidae*), typical desert arthropods, were found to dominate under dry conditions (Ren and Yu, 1999; Liu et al., 2011). Thus, both can be regarded as indicators for the mobile sand land, with high temperature fluctuation and low vegetation cover. The ant (i.e., *Formidae*) taxa can be regarded as indicators for the restored sites, with rich quantity and quality of potential food resources and improved soil properties (Lobry de Bruyn, 1999).

The observed distribution of ground-dwelling arthropod assemblages along the habitat gradients could be elucidated by the results of redundancy analysis (RDA) (Fig. 4) (Kennedy et al., 2004; ter Braak and Smilauer, 2002). The taxonomic-group arrows that point in approximately the same direction as an environmental-factor arrow indicate a strong positive correlation (the longer the arthropod-group arrow, the stronger the relationship). For example, the arrows for *Labiduridae* (code 11 in Table 3) and *Anatolicas* (Tenebrionidae, code 24 in Table 3) pointed in approximately the same direction as those of the soil water content and temperature in the mobile sand land, which was in agreement with the discussion mentioned above. The arrows for *Formicidae* (code 36 in Table 3) pointed in approximately the same direction as that of the soil clay-plus-silt content (CPS) in both shrubland and grassland.

Table 4
Redundancy analysis (RDA) of the taxa abundance data for quantifying the conditional effects of the measured environmental variables on taxa composition using forward selection with Monte Carlo permutation test.

Variables	Initial conditional effects	MCR (%)	*F*	*P*
ST	0.562	56.2	8.966	0.002**
SW	0.253	24.8	8.162	0.012*
BD	0.110	11.0	7.121	0.024*
CPS	0.020	3.0	1.723	0.248
FS	0.010	1.0	1.077	0.362
CS	0.000	0.0	0.026	0.968
Total		96.0		

ST – soil temperature, SW – soil moisture content, BD – soil bulk density, CS – soil coarse-sand content, FS – fine-sand content, CPS – silt-and-clay content.

Regarding the community structure of the ground-dwelling arthropods, a marked change in taxon richness and the Shannon index of ground-dwelling arthropods was found from the mobile sand lands to restored sites. This suggested that the microhabitat, which improved by restoration measures, provided suitable living conditions and enough resources to support abundant groups and, thus, diversity, similar to the findings by Noemí-Mazía et al. (2006) and Doblas-Miranda et al. (2009). These results were also in accord with previous studies of Liu et al. (2012, 2013a),) that were conducted in naturally restored grassland and manually afforested shrubland. Those studies showed that the improved living conditions could facilitate the recovery of faunal community diversity in sandy grassland. In addition, the microhabitats beneath the shrub canopy, which acted as an “arthropod island” (Zhao and Liu, 2013), could explain the relatively higher group richness and Shannon index in the manually afforested shrubland compared with the naturally restored grassland. However, total abundance and the Simpson index were considerably lower in restored sites compared with the mobile sand land. This result was due to the dominant distribution of Labiduridae and Anatolicas (Tenebrionidae), with only a few kinds of other taxa (total of only 8 arthropod groups) found in the mobile sand land, as mentioned above (Table 3).

Redundancy analysis (RDA) can be used to assess the relative importance of the measured environmental factors in structuring ground-dwelling arthropod communities in a desertified region (ter Braak and Smilauer, 2002). The RDA plot illustrated that the six environmental variables (i.e., temperature, moisture, coarse sand, fine sand, silt plus clay, and bulk density) together accounted for 96% of the total variation in arthropod-community composition. Soil water content, temperature, and bulk density had significant influences on the arthropod community. These results were consistent with other studies that suggested that abiotic factors had an important impact, both direct and indirect, on the distribution and diversity of ground arthropod communities (Decaëns et al., 1998; Ziesche and Roth, 2008).

5. Conclusions

Natural and manual restoration management could improve soil and herbaceous vegetation properties. Diverse restoration measures caused distinctive habitats related to specific taxonomic groups (i.e., indicators) for each site. Correspondingly, total abundance was found to be correlated with the dominant groups, even for the Simpson index, both of which decreased markedly with the stabilization of the mobile sand land. However, the restoration measures indicated facilitative effects on ground-dwelling arthropod diversity, including taxon richness, which were more pronounced in the shrubland compared with the grassland. Overall, soil temperature, water content, and bulk density entirely accounted for the differences in ground-dwelling arthropod communities between sampling sites when the restoration procedures were implemented. It was suggested that both restoration measures were an option for the fixation and recovery process of desertified sand land. Based on our study, more field quantitative data on ground-dwelling arthropod communities (which can be useful bioindicators) are needed in order to be able to determine restoration management efficiency.

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