

# Ground-dwelling arthropod community response to native grassland conversion in a temperate desert of northwestern China

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**Abstract** Oases are common in desert regions of northwestern China and are major sites for human settlement. The implementation of oasis conservation planning has led to afforestation with appropriate shrubs and trees in the native grasslands surrounding inhabited oases. However, little is known about how this Land use change from native grassland to shrub and tree plantations influences the composition of ground-dwelling arthropod communities and the performance of their different trophic groups. To address this, we measured activity density, taxon richness, and relative abundance of four different ground arthropod trophic groups (spiders, beetle predators, beetle herbivores, and beetle detritivores) and several environmental variables affecting arthropod distributions (vegetation cover,

ground temperature, soil moisture, soil properties, and leaf litter) along an experimentally established land use change gradient of a mature shrub (*Haloxylon ammodendron*) plantation, a mature poplar (*Populus gansuensis*) plantation and a mature pine (*Pinus sylvestris*) plantation, as well as a native grassland from which all cultivated systems were converted. We found that converted shrub plantation had much lower activity density of predatory, herbivorous, and detritivorous beetles; similar activity density of spiders; and similar taxa richness of all four trophic groups relative to the native grassland. However, converted forest plantations regardless of tree species had much higher activity density of spiders, lower activity density of the three beetle groups, much higher richness of predatory beetles, and lower richness of herbivorous and detritivorous beetles. We also found a change in the composition of the ground arthropod community that was largely driven by changes in ground temperature and leaf litter mass. We conclude that conversion of native grassland to shrub and tree plantations can significantly affect ground-dwelling arthropod communities, reducing the activity of ground-dwelling beetle assemblages while increasing that of ground-dwelling spider assemblages. These findings are important for conserving native arthropod diversity in desert ecosystems.

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## Introduction

In recent decades, the diversity of ground-dwelling arthropods (termed “ground arthropods” hereafter) has rapidly declined due to anthropogenic activities (Millennium Ecosystem Assessment 2005; Uchida and Ushimaru

2014; Vergnes et al. 2014), especially global changes in land use and land cover, which constitute some of the most significant threats to their biodiversity (Downie et al. 1999; Perner and Malt 2003; Kremen et al. 2007; Koellner and Geyer 2013; Li et al. 2014). Changes in land use and land cover can significantly affect the distribution, composition, activity, and diversity of ground arthropods through habitat loss and fragmentation (Hoekstra et al. 2005; Herrmann et al. 2010). Ground arthropods are an important but relatively less studied component of terrestrial food webs. Although many studies have recently investigated the effects of land use/cover changes on the structure and diversity of ground arthropod communities in different terrestrial ecosystems across the globe (Downie et al. 1999; Perner and Malt 2003; Kremen et al. 2007; Negro et al. 2010), studies have rarely been conducted in the temperate desert ecosystems of China which have experienced significant land use/cover changes during the last several decades (Li et al. 2014).

Temperate deserts are the major terrestrial ecosystem in northwestern China and cover approximately 20 % of the country's land surface (Li et al. 2006). A typical desert ecosystem is composed of desert, oasis, and a transition zone between two. In the oases, irrigated agriculture that relies mainly on mountainous snowmelt and glacier melt is the primary type of land use (Wang et al. 2010). The desert areas are primarily characterized by gravel-covered dwarf shrub steppes (commonly termed "Gobi steppes"; Liu et al. 2012). The transition zones are generally occupied by sandy tall shrub-dominated grasslands. These sandy grasslands provide important habitat for native ground arthropods (Liu et al. 2010).

However, the sandy grasslands in the transition zones have been heavily grazed by livestock over the last 50 years in order to produce a greater amount of animal products to meet the demands of a booming human population. Overgrazing by livestock, in conjunction with climate change, has resulted in widespread degradation of the sandy grassland vegetation (Zhao et al. 2005) and the subsequent wind erosion of topsoil (Li et al. 2009). Consequently, many oases inhabited by humans have been seriously threatened by desertification, i.e., encroachment of moving sand into oases (Su et al. 2007). To protect oasis against desertification, local governments have implemented large-scale oasis conservation planning since the 1970s. One major strategy used for preventing the desertification of oases was the establishment of oasis shelterbelts via selective afforestation with native trees and shrubs in degraded areas surrounding inhabited oases (Cao 2011). Following the implementation of oasis conservation planning, vast areas of degraded sandy grasslands at the margins of many oases were converted into cultivated shrub and tree plantations. These established ecological

shelterbelts played an important role in maintaining the integrity and sustainability of oasis ecosystems through stabilization of the soil (Su et al. 2007).

When natural grasslands are converted into shrub and tree plantations, the vegetation type, cover, species composition, and diversity are completely altered (Li et al. 2009). These alterations may in turn cause further changes in microclimatic conditions, soil properties, and resource availability. These altered environmental conditions may stimulate an adaptive response in ground arthropods. In a previous study, we investigated the effects of converting natural grassland to farmland systems on the trophic structure and diversity of ground arthropod communities. However, how the conversion of native grassland to different types of shrub and tree plantations affects the trophic structure and diversity of ground arthropod communities has not yet been explored.

In this study, we used an experimentally established gradient of land use change in a typical temperate desert region as a model system. The established land use change gradient included a 21-year-old shrub (*Haloxylon ammodendron* (Mey.) Bunge) plantation, a 28-year-old broad-leaved poplar (*Populus gansuensis* C. Wang et H.L. Yang) forest plantation, a 33-year-old needle-leaved pine (*Pinus sylvestris* var. *mongolica* Litvin.) forest plantation, as well as a natural grassland from which all cultivated systems were converted (Wang et al. 2012). To characterize the responses of different trophic groups of ground arthropods to changes in land use, we measured the performance (activity density, taxon richness, and relative abundance) of four major trophic group assemblages (spiders, beetle predators, beetle herbivores, and beetle detritivores). Within the four habitats we also quantified a suite of environmental variables affecting arthropod distributions including vegetation cover (VC), ground temperature (GT), soil moisture, soil pH (pH), soil texture, and leaf litter mass (LM). Using these datasets, we aimed to evaluate the effects of converting native grasslands to shrub and tree plantations on the performance of these four trophic group assemblages and identifying the key factors driving variability in the composition of the investigated community.

## Materials and methods

### Study site

The study site is located in the western part of Gansu Province in northwestern China (39° 21'N, 100° 07'E; 1,384 m above sea level). This region has a continental arid desert climate characterized by a mean annual temperature of 7.6 °C (minimum monthly average of −10.7 °C in January and maximum monthly average of 23.8 °C in July)

and a mean annual precipitation of 117 mm, with the majority of rainfall occurring from June to September (Zhang and Shao 2014). The mean annual pan-evaporation is approximately 2,390 mm, twenty times more than the annual precipitation. Wind speed averages  $3.3 \text{ m s}^{-1}$  annually, and gales with wind velocities of  $\geq 17 \text{ m s}^{-1}$  occur on approximately 20 days during the spring (March to May) every year.

### Study system

The study region is a centuries-old artificial oasis zone that covers approximately  $6,000 \text{ km}^2$ . The oasis zone consists of several small and isolated artificial oases, three of which were chosen for this study. The three oases are spaced at least 1 km apart to avoid pseudoreplication (Hurlbert 1984). At the margins of each study oasis, we selected a natural sandy grassland and the adjacent afforested plots of a 21-year-old shrub (*H. ammodendron*) plantation, a 28-year-old Gansu Poplar (*P. gansuensis*) forest plantation, and a 33-year-old Mongol Scotch Pine (*P. sylvestris*) forest plantation as the study system. Distances between the four habitats in each oasis site ranged from 500 to 1,000 m.

The natural sandy grasslands sampled at the three oasis sites were dominated by the shrub species *Calligonum mongolicum*, *Nitraria sphaerocarpa*, and *Nitraria sibirica* along with herbaceous species such as *Agriophyllum squarrosum*, *Bassia dasyphylla*, *Halogeton glomeratus*, and *Pugionium cornutum*. The shrub plantations sampled at the three oasis sites were planted with seedlings in 1988 and were irrigated during the first 3 years after planting and then received no further irrigation. Once established, these deep-rooted shrubs can survive on current-year precipitation and shallow groundwater (Tian et al. 2014). The understory herbaceous layer of the shrub plantations was dominated by herbaceous species, such as *Salsola ruthenica*, *H. glomeratus*, and *B. dasyphylla*. The poplar plantations sampled at the three oasis sites were planted with saplings in 1980 and were irrigated annually with  $12,000\text{--}15,000 \text{ m}^3$  water per hectare. The average trunk diameter at breast height (1.3 m high) was  $24.9 \pm 3.1 \text{ cm}$  (mean  $\pm$  standard error) and the average tree height was  $19.2 \pm 1.9 \text{ m}$ , with the existing stand density of  $2,340 \pm 350$  stems per hectare. The understory herbaceous layer of the poplar plantations was dominated by *Calamagrostis epigejos* and *B. dasyphylla*. The pine plantations sampled at the three oasis sites were planted with saplings in 1975 and were irrigated annually with  $10,000\text{--}12,000 \text{ m}^3$  water per hectare. The average trunk diameter at breast height was  $18.2 \pm 2.4 \text{ cm}$  and the average tree height was  $14.1 \pm 1.6 \text{ m}$ , with an existing stand density of  $2,210 \pm 142$  stems per hectare. The understory herbaceous layer of the pine plantations was

dominated by *Chenopodium album*, *Setaria viridis*, and *Ixeris denticulata*. No pesticides or fertilizers were applied to any of the plantations or natural grasslands.

### Sampling of ground beetles and spiders

We conducted a field survey of ground beetles and spiders using pitfall trapping. At each oasis site, three plots ( $30 \times 30 \text{ m}$ ) were established at least 150 m apart in each of the four habitats. In each plot, five pitfall traps were placed beneath the shrubs/trees (3 traps) and in the open areas between shrubs/trees (2 traps). Thus, we placed 45 pitfall traps in each of the four habitats across the three oasis sites, for a total of 180 pitfall traps. Each trap (10-cm diameter, 12-cm height) consisted of two plastic cups, an outer permanent cup buried in the ground and a removable inner cup. Ethylene glycol was added to each trap to a depth of approximately 5 cm. This acted as a killing agent and preservative. There were three trapping periods during the growing season of 2010: May 6–20, July 4–18, and September 8–22 (total of forty-five 24-h periods). The contents of each trap were collected at the end of each sampling interval. All collected beetles and spiders were preserved in 70 % alcohol before sorting and identification. A large number of juveniles with no recognizable markings of any genital structures were trapped, and it was difficult to identify these to the species level. Therefore, all specimens were identified to the family/subfamily level based on the relevant literature (Song et al. 1999; Yin 2001; Zheng and Gui 1999). All identified families of ground beetles and spiders (including both juveniles and adults) were classified into four trophic groups: spiders (generalist predators), predatory beetles, herbivorous beetles, and detritivorous beetles. The classifications were based on our field investigations (Liu et al. 2010) and published information (Hu 1984; Lawrence and Britton 1991; Wise 1993; Ren and Yu 1999; Uetz et al. 1999). Analyses were conducted using the pooled data from a total of 45 trapping days over the three sampling periods.

### Measurements of vegetation cover, leaf litter, microclimate, and soil properties

To determine relationships between the investigated ground arthropod community composition and environmental variables, we measured a suite of environmental variables that are known to affect ground arthropod distributions. These include aboveground vegetation characteristics (woody VC and herbaceous VC), microclimatic conditions [GT and soil moisture content (SMC)], soil properties [soil texture, pH, and bulk density (BD)], and leaf litter quantity and quality (mass, carbon contents, and nitrogen concentrations).

For both forest plantation habitats, the percentage cover of trees in each plot was determined using the crown projection method (Gao et al. 2011). For both the native grassland and shrub plantation habitats, the percentage cover of shrubs in each plot was determined using the line intercept method (Mueller-Dombois and Ellenberg 1974). For all four habitats, the percentage cover of the understory herbaceous layer in each plot was estimated visually using five 1-m<sup>2</sup> subplots (located at the four corners and center of each plot), and the amount of leaf litter on the ground within these subplots was quantified by collecting litter. The collected litter from each plot was air-dried for 2 weeks, oven-dried at 60 °C for 48 h, and weighed. A portion of the litter samples was used to analyze nitrogen and carbon contents. After litter was removed, soil cores within these five subplots were taken with a depth of 20 cm using a cylindrical 100-cm<sup>3</sup> stainless-steel soil auger. The five cores from each plot were bulked in the field and mixed thoroughly to form one composite sample for analyses of pH, BD, and particle size distribution. pH was determined in 1:2.5 (w/v) soil solutions. BD was measured using 100-cm<sup>3</sup> rings. Particle size distribution was determined using a Microtrac S3500 Particle Size Analyzer (Microtrac Inc., USA) by dividing the soil into three size classes: coarse sand (2–0.25 mm), fine sand (0.25–0.05 mm), and silt plus clay (<0.05 mm), which were expressed as a percentage of soil weight.

Time domain reflectometry (TRIME-FM, IMKO Micromoduletechnik GmbH, Ettlingen, Germany) was used to measure volumetric SMC at a depth of 20 cm at five randomly chosen locations in each plot. The daily maximum GT at these five locations was measured at 14:00 h with a surface thermometer (WQG-15, Hebei, China). Observations of SMC and GT were carried out on three consecutive days during each of the three sampling periods.

#### Statistical analysis

In this study, we used a repeated measure two-way ANOVA (with two factors: oasis and habitat) to evaluate the effects of land use change on the following response variables: (1) the activity density (the number of individuals per trap), taxon richness (the number of families per plot), and the Pielou's evenness index of the ground arthropod community; (2) the activity density, taxon richness, and relative abundance of the four trophic groups as well as the activity density of the eight dominant families whose abundance comprised approximately 1 % of the total catch; and (3) the measured environmental variables. A Tukey's honestly significant difference test was used to compare differences in the means of these response variables between habitats (significance level at  $P < 0.05$ ). Prior to analysis, data were log-transformed to normalize

data distributions. These statistical analyses were carried out using the SPSS 16.0 software package (SPSS Inc., Chicago, IL, USA).

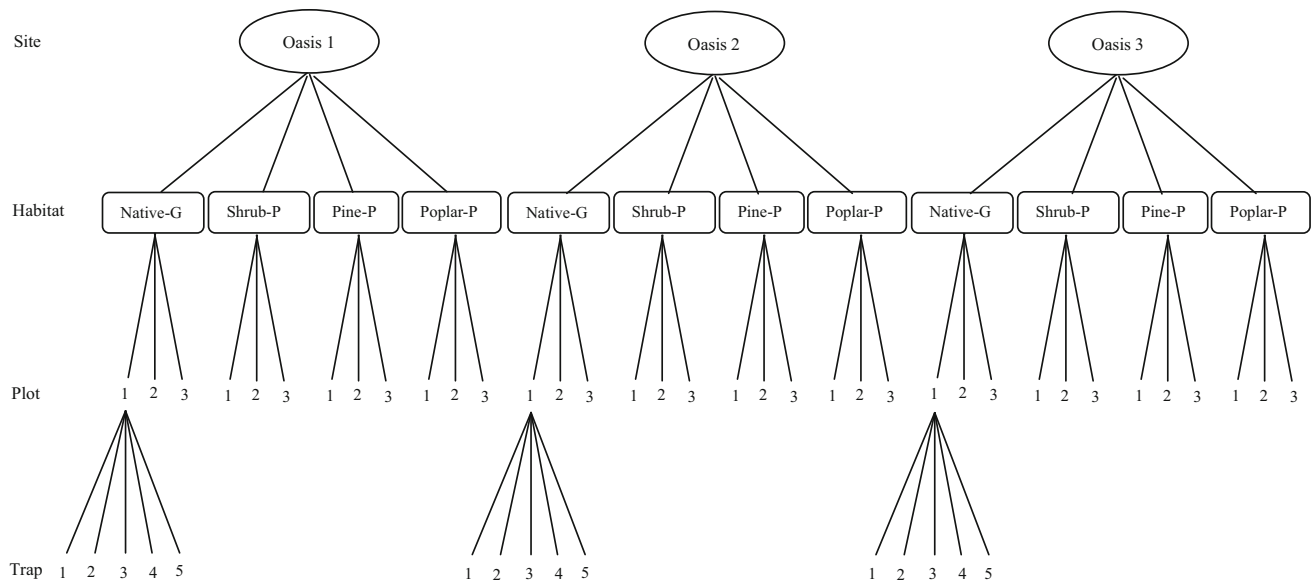
Differences in the family composition (Bray–Curtis dissimilarity) of ground arthropods among the four habitats were assessed using permutational multivariate analysis of variance (PERMANOVA; Anderson et al. 2008).  $P$  values were obtained through pair-wise PERMANOVA tests (999 permutations) with  $\log(x + 1)$  transformed data for the analysis. Data were transformed to lessen the effect of numerically dominant taxa in analyses. All PERMANOVA analyses were performed using the PERMANOVA+ package for PRIMER (Anderson et al. 2008).

Canonical correspondence analysis (CCA) was used to examine the relationships between the composition of the ground arthropod community and the measured related environmental variables. The data were first analyzed by detrended correspondence analysis (DCA), showing that CCA is an appropriate ordination approach in our case (length of gradient <3). In this analysis, a data matrix consisting of 23 families and 9 environmental variables, including VC, LM GT, SMC, pH, BD, coarse sand content (CSC), fine sand content (FSC), and silt + clay content (SCC), was built to examine the relative importance of each environmental variable in explaining the variance in the community composition. We used partial CCA to evaluate the relative contribution of each environmental variable in explaining variance in the data, which was depicted by the inertia from the conditional effect. This value indicates the magnitude of additional explanatory power each variable contributes when it is added to the model (Lepš and Šmilauer 2003). The partial CCA and the Monte Carlo permutation tests were performed to determine the conditional effects of VC, LM, GT, SMC, pH, BD, CSC, FSC, and SCC, respectively, when the effects of several other variables are held constant. All data were  $\log(x + 1)$  transformed prior to analysis. CCA was carried out using the CANOCO 4.5 software package (Fig. 1).

#### Results

##### Changes in environmental variables following conversion of native grasslands to plantations

The conversion of native grasslands to plantations significantly altered the environmental conditions of ground arthropods habitats, but there are large differences in the degree of alterations (Table 1). Overall, converting native grassland to shrub plantation did not affect the cover of the understory herbaceous layer, but it did significantly increase the cover of shrub vegetation. Changing native grassland to shrub plantation did not significantly alter



**Fig. 1** Field sampling design in this study (*Native-G* native grassland, *Shrub-P* shrub plantation, *Pine-P* pine plantation, *Poplar-P* poplar plantation)

**Table 1** Summary of the measured main environmental variables within the four studied habitats

Variables	Native grassland	Shrub plantation	Poplar plantation	Pine plantation	$F_{3, 35}$
<b>Vegetation characteristics</b>					
Shrub/tree canopy cover (%)	26.9 ± 3.9 <sup>a</sup>	77.3 ± 2.6 <sup>b</sup>	64.1 ± 5.8 <sup>b</sup>	76.6 ± 6.7 <sup>b</sup>	32.91***
Herbaceous plant cover (%)	9.6 ± 3.5 <sup>a</sup>	7.8 ± 3.6 <sup>a</sup>	2.3 ± 2.9 <sup>b</sup>	1.2 ± 3.3 <sup>b</sup>	77.71***
<b>Microclimate</b>					
Ground temperature (°C)	37.5 ± 0.4 <sup>a</sup>	34.3 ± 0.6 <sup>a</sup>	23.4 ± 0.1 <sup>b</sup>	23.9 ± 0.2 <sup>b</sup>	1,113.46***
Soil moisture (%)	2.2 ± 0.1 <sup>b</sup>	2.9 ± 0.1 <sup>b</sup>	5.6 ± 0.2 <sup>a</sup>	5.3 ± 0.3 <sup>a</sup>	282.94***
<b>Soil properties</b>					
pH <sub>water</sub>	9.2 ± 0.1 <sup>a</sup>	8.1 ± 0.1 <sup>b</sup>	8.4 ± 0.1 <sup>b</sup>	8.2 ± 0.1 <sup>b</sup>	95.99***
Bulk density (g cm <sup>-3</sup> )	1.58 ± 0.02 <sup>a</sup>	1.52 ± 0.02 <sup>a</sup>	1.41 ± 0.04 <sup>b</sup>	1.32 ± 0.02 <sup>b</sup>	18.25**
Coarse sand (2–0.25 mm, %)	25.1 ± 1.5 <sup>a</sup>	21.5 ± 1.3 <sup>a</sup>	3.2 ± 0.2 <sup>b</sup>	3.0 ± 0.3 <sup>b</sup>	254.05***
Fine sand (0.25–0.05 mm, %)	75.6 ± 1.6 <sup>b</sup>	77.0 ± 1.3 <sup>b</sup>	92.6 ± 0.4 <sup>a</sup>	89.7 ± 0.4 <sup>a</sup>	44.08***
Silt + clay (< 0.05 mm, %)	0.5 ± 0.1 <sup>d</sup>	1.5 ± 0.1 <sup>c</sup>	4.0 ± 0.3 <sup>b</sup>	7.2 ± 0.4 <sup>a</sup>	362.12***
<b>Litter quantity and quality</b>					
Litter mass (g m <sup>-2</sup> )	21.8 ± 1.9 <sup>d</sup>	38.4 ± 5.1 <sup>c</sup>	275.3 ± 17.2 <sup>b</sup>	3,377.0 ± 77.6 <sup>a</sup>	953.53***
Litter carbon (%)	37.8 ± 2.4 <sup>c</sup>	28.2 ± 1.2 <sup>d</sup>	42.9 ± 0.4 <sup>b</sup>	46.9 ± 0.5 <sup>a</sup>	74.47***
Litter nitrogen (%)	1.9 ± 0.1 <sup>a</sup>	1.9 ± 0.1 <sup>a</sup>	1.3 ± 0.1 <sup>c</sup>	1.5 ± 0.1 <sup>b</sup>	28.72**
C: N ratio	20.3 ± 2.8 <sup>b</sup>	15.2 ± 0.5 <sup>c</sup>	34.1 ± 2.1 <sup>a</sup>	31.2 ± 1.3 <sup>a</sup>	91.58***

Means (±SE) with different letters indicate significant differences between habitats (\*  $P < 0.05$ ; \*\*  $P < 0.01$ ; \*\*\*  $P < 0.001$ )

GT and soil moisture regimes, but it did lead to large changes in some of the soil variables (pH and SCC) as well as some of the litter variables (LM, litter carbon content, and C:N ratio). However, native grassland conversion resulted in consistent and significant changes in all of the vegetation variables, all of the microclimate variables, all of the soil variables, and all of the litter

variables in both of the tree plantations (Table 1). On average, the cover of woody vegetation, SMC, FSC, SCC, LM, litter carbon content, and C:N ratio were significantly higher while the cover of herbaceous vegetation, GT, pH, BD, CSC, and litter nitrogen content were significantly lower in both tree plantations compared to native grassland (Table 1).



## Changes in community composition and diversity following conversion of native grasslands to plantations

A total of 14,651 individuals representing 23 families of ground beetles and spiders were collected from 36 sampling plots within the four habitats across the three oasis sites. There were 13 families in the native grassland, 12 families in the shrub plantation, and 14 families each in the poplar and pine plantations (Table 2). In the native grassland, the three most abundant families were Tenebrionidae, Curculionidae, and Carabidae, whereas in the shrub plantation the most abundant families were Tenebrionidae, Gnaphosidae, and Lycosidae. However, the most abundant families were Lycosidae, Gnaphosidae, and Carabidae in the poplar plantation and Nesticidae, Linyphiidae, and

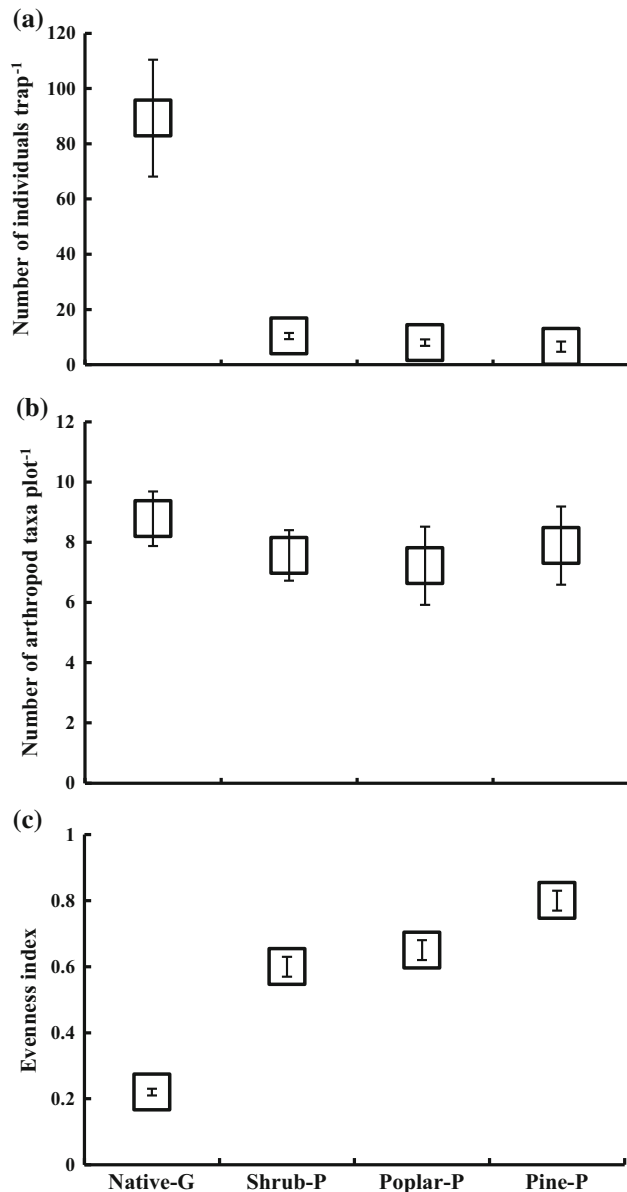
Gnaphosidae in the pine plantation (Table 2). The conversion of native grasslands to plantations had a significant negative effect on the total activity density ( $F_{3,179} = 203.56$ ,  $P < 0.0001$ ) and a significant positive effect on the Pielou's evenness index ( $F_{3,179} = 122.97$ ,  $P < 0.0001$ ). However, it did not affect the overall taxa richness ( $F_{3,179} = 1.42$ ,  $P = 0.2709$ ) of the ground arthropod community (Fig. 2).

PERMANOVA analyses showed a significant effect of converting native grassland to plantations on the composition of the ground arthropod community ( $F = 54.98$ ,  $P < 0.0001$ ). Pairwise comparisons showed significant differences in communities between the native grassland and the shrub plantation ( $t = 5.22$ ,  $P < 0.0001$ ), between the native grassland and the poplar plantation ( $t = 8.85$ ,

**Table 2** The activity density (the number of individuals per trap) of 23 families (dominant families in bold) of ground-dwelling beetles and spiders within the four habitats across three oasis sites

Trophic group/family	Native grassland	Shrub plantation	Poplar plantation	Pine plantation	$F_{3,179}$
<b>Spiders</b>					
Araneidae	0.19 ± 0.06 (26)	0.00 ± 0.00	0.00 ± 0.00	0.17 ± 0.13 (23)	3.64*
<b>Gnaphosidae</b>	0.89 ± 0.15 (120)	1.39 ± 0.23 (188)	1.18 ± 0.17 (159)	0.93 ± 0.27 (126)	1.53n.s.
<b>Linyphiidae</b>	0.02 ± 0.02 <sup>b</sup> (3)	0.11 ± 0.05 <sup>b</sup> (15)	0.13 ± 0.04 <sup>b</sup> (18)	1.74 ± 0.39 <sup>a</sup> (235)	29.47***
<b>Lycosidae</b>	0.31 ± 0.09 <sup>b</sup> (42)	0.91 ± 0.27 <sup>b</sup> (123)	4.87 ± 0.42 <sup>a</sup> (657)	0.44 ± 0.11 <sup>b</sup> (59)	60.62***
<b>Nesticidae</b>	0.00 ± 0.00 <sup>b</sup>	0.00 ± 0.00 <sup>b</sup>	0.14 ± 0.06 <sup>b</sup> (19)	1.93 ± 0.44 <sup>a</sup> (261)	30.30***
Philodromidae	0.17 ± 0.13 (23)	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	2.22n.s.
<b>Salticidae</b>	0.84 ± 0.30 <sup>a</sup> (113)	0.22 ± 0.06 <sup>b</sup> (30)	0.00 ± 0.00 <sup>b</sup>	0.31 ± 0.16 <sup>b</sup> (42)	6.15**
Thomisidae	0.00 ± 0.00	0.00 ± 0.00	0.02 ± 0.02 (3)	0.02 ± 0.02 (3)	1.00n.s.
<b>Beetle predators</b>					
<b>Carabidae</b>	2.62 ± 0.57 <sup>a</sup> (354)	0.39 ± 0.11 <sup>b</sup> (53)	0.54 ± 0.16 <sup>b</sup> (73)	0.26 ± 0.08 <sup>b</sup> (35)	17.39***
Cicindelidae	0.00 ± 0.00 <sup>b</sup>	0.00 ± 0.00 <sup>b</sup>	0.20 ± 0.05 <sup>a</sup> (27)	0.00 ± 0.00 <sup>b</sup>	19.13***
Coccinellidae	0.00 ± 0.00 <sup>b</sup>	0.06 ± 0.03 <sup>b</sup> (8)	0.02 ± 0.02 <sup>b</sup> (3)	0.30 ± 0.05 <sup>a</sup> (41)	21.14***
Histeridae	0.00 ± 0.00 <sup>b</sup>	0.00 ± 0.00 <sup>b</sup>	0.35 ± 0.16 <sup>a</sup> (47)	0.00 ± 0.00 <sup>b</sup>	5.50**
Pselaphidae	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.02 ± 0.02 (3)	1.01n.s.
Staphylinidae	0.13 ± 0.04 <sup>b</sup> (18)	0.19 ± 0.10 <sup>b</sup> (26)	0.19 ± 0.07 <sup>b</sup> (26)	0.43 ± 0.09 <sup>a</sup> (58)	5.16**
<b>Beetle herbivores</b>					
<b>Curculionidae</b>	2.97 ± 1.27 <sup>a</sup> (401)	0.19 ± 0.18 <sup>b</sup> (26)	0.11 ± 0.11 <sup>b</sup> (15)	0.00 ± 0.00 <sup>b</sup>	57.28***
Dynastidae	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.02 ± 0.03 (3)	1.01n.s.
Melolonthidae	0.25 ± 0.12 <sup>a</sup> (34)	0.13 ± 0.08 <sup>b</sup> (18)	0.00 ± 0.00 <sup>c</sup>	0.02 ± 0.02 <sup>c</sup> (3)	11.39***
Scarabaeidae	0.00 ± 0.00	0.00 ± 0.00	0.04 ± 0.05 (6)	0.00 ± 0.00	2.00n.s.
Silvanidae	0.00 ± 0.00 <sup>b</sup>	0.06 ± 0.06 <sup>a</sup> (8)	0.00 ± 0.00 <sup>b</sup>	0.00 ± 0.00 <sup>b</sup>	4.51*
Trogossitidae	0.00 ± 0.00 <sup>b</sup>	0.00 ± 0.00 <sup>b</sup>	0.19 ± 0.18 <sup>a</sup> (26)	0.02 ± 0.03 <sup>b</sup> (3)	9.48***
<b>Beetle detritivores</b>					
Geotrupidae	0.02 ± 0.03 (3)	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	1.01n.s.
Silphidae	0.22 ± 0.20 (30)	0.15 ± 0.14 (20)	0.06 ± 0.08 (8)	0.00 ± 0.00	2.76n.s.
<b>Tenebrionidae</b>	80.67 ± 19.96 <sup>a</sup> (10,800)	6.57 ± 1.14 <sup>b</sup> (887)	0.00 ± 0.00 <sup>c</sup>	0.00 ± 0.00 <sup>c</sup>	1,742.42***
Total	11,267	1,402	1,087	895	

Means (±SE) with different letters indicate significant differences between habitats (n.s., not significant; \*  $P < 0.05$ ; \*\*  $P < 0.01$ ; \*\*\*  $P < 0.001$ ). Numbers in the parentheses are total number of individuals captured by pitfall trapping per habitat



**Fig. 2** The effects of converting native grasslands into different types of shrub and tree plantations on the activity density, taxon richness, and the Pielou's evenness index of the ground-dwelling arthropod community. Means ( $\pm$ SE) with different letters indicate significant differences between habitats

$P < 0.0001$ ), and between the native grassland and the pine plantation ( $t = 7.73$ ,  $P < 0.0001$ ).

#### Changes in the performance of trophic groups following conversion of native grasslands to plantations

The activity density of the four trophic groups was significantly affected by the conversion of native grasslands to plantations (spiders:  $F_{3,179} = 17.07$ ,  $P < 0.0001$ ; beetle predators:  $F_{3,179} = 8.14$ ,  $P = 0.0012$ ; beetle herbivores:  $F_{3,179} = 65.18$ ,  $P < 0.0001$ ; and beetle detritivores:

$F_{3,179} = 1,746.18$ ,  $P < 0.0001$ ). Converting native grassland to shrub plantation significantly decreased the activity density of beetle predators ( $-330\%$ ), beetle herbivores ( $-770\%$ ), and beetle detritivores ( $-1,104\%$ ) but had little effect on the activity density of spiders. However, converting native grassland to either of the two tree plantations significantly increased the activity density of spiders ( $+130\%$  in poplar plantation and  $+162\%$  in pine plantation), reduced the activity density of beetle predators ( $-112\%$  in poplar plantation and  $-175\%$  in pine plantation) and beetle herbivores ( $-900\%$  in poplar plantation and  $-3,100\%$  in pine plantation), and led to a local extinction of beetle detritivores (Fig. 3a).

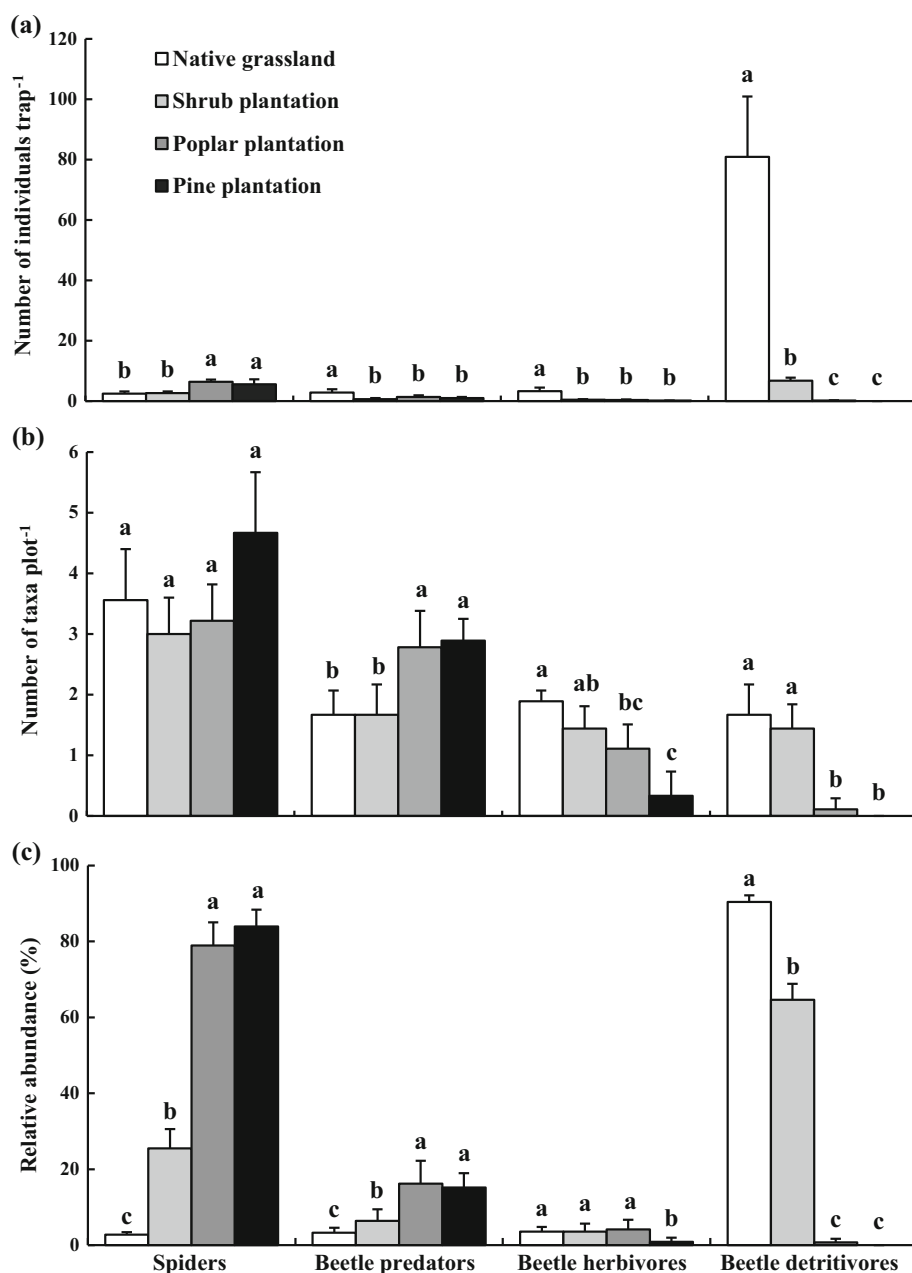
The conversion of native grasslands to plantations did not greatly affect the taxa richness of spiders ( $F_{3,179} = 3.21$ ,  $P = 0.0612$ ), but it had a significant effect on the richness of beetle predators ( $F_{3,179} = 5.19$ ,  $P = 0.0093$ ), beetle herbivores ( $F_{3,179} = 9.16$ ,  $P = 0.0007$ ), and beetle detritivores ( $F_{3,179} = 47.41$ ,  $P < 0.0001$ ). Converting native grassland to shrub plantation did not affect the taxa richness of the three beetle groups, whereas converting native grassland to either of the two tree plantations significantly increased the taxa richness of beetle predators ( $+66\%$  in poplar plantation and  $+73\%$  in pine plantation), reduced the richness of beetle herbivores ( $-70\%$  in poplar plantation and  $-473\%$  in pine plantation) and beetle detritivores ( $-1400\%$  in poplar plantation and more in pine plantation), and did not alter spider diversity (Fig. 3b).

The conversion of native grasslands to plantations had a significant effect on the relative abundance of spiders ( $F_{3,179} = 530.60$ ,  $P < 0.0001$ ), beetle herbivores ( $F_{3,179} = 10.25$ ,  $P = 0.0004$ ), beetle predators ( $F_{3,179} = 5.39$ ,  $P = 0.0081$ ), and beetle detritivores ( $F_{3,179} = 548.59$ ,  $P < 0.0001$ ). Converting native grassland to shrub plantation significantly increased the relative abundance of spiders and beetle predators, reduced that of beetle detritivores, and did not affect that of beetle herbivores. In contrast, converting native grassland to the poplar plantation significantly increased the relative abundance of spiders and beetle predators, reduced that of beetle detritivores, and did not affect that of beetle herbivores, whereas converting native grassland to the pine plantation significantly increased the relative abundance of spiders and beetle predators and reduced that of both herbivorous and detritivorous beetles (Fig. 3c).

#### Changes in the activity of dominant taxa following conversion of native grasslands to plantations

The three dominant beetle families and five dominant spider families in the ground arthropod community responded differently to the conversion of native grasslands to plantations (Tenebrionidae:  $F_{3,179} = 1,742.42$ ,  $P < 0.0001$ ; Carabidae:

**Fig. 3** The effects of converting native grasslands into different types of shrub and tree plantations on the performance of four different trophic groups (spiders, beetle predators, beetle herbivores, and beetle detritivores) of ground-dwelling arthropods. Means ( $\pm$ SE) with different letters indicate significant differences between habitats



$F_{3,179} = 17.13$ ,  $P < 0.0001$ ; Curculionidae:  $F_{3,179} = 57.28$ ,  $P < 0.0001$ ; Lycosidae:  $F_{3,179} = 60.62$ ,  $P < 0.0001$ ; Linyphiidae:  $F_{3,179} = 29.47$ ,  $P < 0.0001$ ; Nesticidae:  $F_{3,179} = 30.30$ ,  $P < 0.0001$ ; Gnaphosidae:  $F_{3,179} = 1.53$ ,  $P = 0.2408$ ; and Salticidae:  $F_{3,179} = 6.15$ ,  $P = 0.004$ ). Four groups were identified according to their response to changes in land use. The first response group included one spider family (Salticidae) and three beetle families (Tenebrionidae, Carabidae, and Curculionidae) that exhibited a consistent reduction in activity density in both shrub and tree plantations relative to the native grassland. The second response group included one spider family, Lycosidae, that displayed a significant increase in activity density only in the poplar

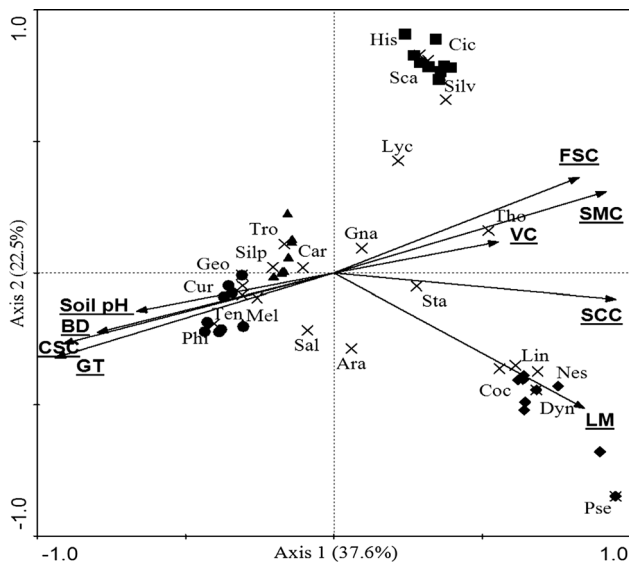
plantation. The third response group included two spider families, Linyphiidae and Nesticidae, which presented a significant increase in activity density only in the pine plantation and was unchanged in the shrub or poplar plantations relative to the native grassland. The fourth response group included one spider family, Gnaphosidae, whose activity density did not differ between habitats (Table 2).

The relative contribution of environmental variables to variation in community composition

The CCA to determine the relative contribution of environmental variables to variation in community composition



showed that the first two axes explained 60.1 % of the variation in the family–environmental space. This indicates a strong association between the investigated community composition and the measured environmental variables. In the CCA biplots (Fig. 4), the first axis indicates an obvious environmental gradient of increasing VC (correlation coefficient:  $r = 0.55$ ,  $n = 36$ ,  $P < 0.0001$ ), LM ( $r = 0.83$ ,  $n = 36$ ,  $P < 0.0001$ ), SMC ( $r = 0.90$ ,  $n = 36$ ,  $P < 0.0001$ ), FSC ( $r = 0.81$ ,  $n = 36$ ,  $P < 0.0001$ ), and SCC ( $r = 0.94$ ,  $n = 36$ ,  $P < 0.0001$ ) as well as decreasing GT ( $r = -0.92$ ,  $n = 36$ ,  $P < 0.0001$ ), BD ( $r = -0.78$ ,  $n = 36$ ,  $P < 0.0001$ ), pH ( $r = -0.65$ ,  $n = 36$ ,  $P < 0.0001$ ), and CSC ( $r = -0.90$ ,  $n = 36$ ,  $P < 0.0001$ ). This separated the community between the native grassland + shrub plantation sites with higher GT, pH, SBD, and CSC and the tree plantation sites with higher VC, LM, SMC, FSC, and SCC. The second axis was only significantly related to LM



**Fig. 4** Canonical correspondence analysis ordination diagram of the first two axes showing the relationship between environmental variables and community composition. Habitat types are represented by symbols: *filled circle* native grassland, *filled diamond* shrub plantation, *filled triangle* poplar plantation, and *filled square* pine plantation. Arthropod families are represented by *x* and are labeled by the first three or four letters of the family names: Araneidae (Ara), Gnaphosidae (Gna), Linyphiidae (Lin), Lycosidae (Lyc), Nesticidae (Nes), Philodromidae (Phi), Salticidae (Sal), Thomisidae (Tho), Carabidae (Car), Cicindelidae (Cic), Coccinellidae (Coc), Histeridae (His), Pselaphidae (Pse), Staphylinidae (Sta), Curculionidae (Cur), Dynastidae (Dyn), Melolonthidae (Mel), Scarabaeinae (Sca), Silvanidae (Silv), Trogossitidae (Tro), Geotrupidae (Geo), Silphidae (Silp), and Tenebrionidae (Ten). Degree of correlation of environmental variables (VC vegetation cover, LM litter mass, GT ground temperature, SMC soil moisture content, pH soil pH, BD soil bulk density, CSC coarse sand content, FSC fine sand content, SCC silt + clay content) with the axes are shown as vectors. Relative contribution to a family space is expressed by length of the arrow lines. Longer arrow lines indicate greater relative contribution

( $r = 0.49$ ,  $n = 36$ ,  $P = 0.001$ ), which separated the community between the poplar plantation and the pine plantation along a gradient with LM.

Partial CCA further revealed that the relative contribution of these nine environmental variables differed considerably. Of these nine variables, only the conditional effects of GT, LM, pH, and BD were statistically significant in the Monte Carlo permutation test ( $P < 0.05$  in all cases). These four variables explained 35.5 % (GT), 23.5 % (LM), 3.2 % (pH), and 2.6 % (BD) of the variation in the community composition, whereas a total of 5.3 % of the variation in the community composition was explained by the remaining variables that were not significant in the Monte Carlo permutation test ( $P > 0.05$  in all cases). These results indicate that GT and LM are the most important determinants of the community composition change (Table 3).

## Discussion

Using an experimentally established land use change gradient in a temperate desert ecosystem, we investigated the effects of replacing native grasslands with different types of cultivated shrub and tree plantations on the trophic structure and diversity of ground arthropod communities. Despite the lack of species-level identification for specimens in our study, the family-level taxonomic information can still be useful for species conservation. The results reported here regarding the differential responses of different trophic groups and their dominant taxa to changes in land use are important for developing management strategies for the conservation of native arthropod diversity in desert ecosystems.

Our results show that conversion of native grasslands to shrub and tree plantations can significantly affect the composition of the investigated ground arthropod community. The fact that total taxa richness was not affected while total activity density and evenness indices were significantly affected by the conversions suggests that compositional changes were largely a result of replacement or altered dominance of certain taxa within the community rather than changes in the number of taxa per se. Li et al. (2014) reported a similar result in a previous study on the composition of ground arthropod communities following the conversion of native grassland to irrigated farmland in the same study area. A recent study on the effects of two global change drivers (rising temperature and nitrogen deposition) on an insect herbivore community in a sub-alpine grassland found that changes in the herbivore community composition caused by climate change resulted primarily from replacement or altered dominance of certain species rather than changes in the number of species per se (de Sassi et al. 2012).

**Table 3** Canonical correspondence analysis (CCA) quantifying the relative contribution of the selected nine environmental variables in explaining the variation in ground-dwelling arthropod community compositions (proportional to the inertia values)

Variables	Inertia conditional effects	MCR (%)	<i>F</i>	<i>P</i>
Vegetation cover	0.017	1.17	1.03	0.435
Litter mass	0.343	23.51	18.92	0.001
Ground temperature	0.518	35.50	18.73	0.001
Soil moisture	0.021	1.44	1.31	0.185
Soil pH	0.047	3.22	2.74	0.001
Bulk density	0.038	2.60	2.30	0.006
Coarse sand content	0.016	1.10	0.97	0.463
Fine sand content	0.008	0.55	0.48	0.904
Silt + clay content	0.014	0.96	0.86	0.609
Total	1.022	70.05		

Inertia from the conditional effects is used to derive the multivariate correlation ratio (MCR), which represents the proportion of variation explained by each individual environmental variable. The sum of all unconstrained eigenvalues = 1.459

Partial CCAs evaluated the relative importance of the nine selected environmental variables (VC, LM, GT, SMC, pH, BD, CSC, FSC, and SCC) in shaping the ground arthropod community composition. The results show that GT, LM, pH, and BD were more important in explaining community composition variation than the other factors. This is consistent with the findings of other studies in arid and semi-arid ecosystems (Slobodchikoff 1983; Parmenter et al. 1989; Stapp 1997; Pétillon et al. 2008; Ruggiero et al. 2009; Yang et al. 2011; Liu et al. 2014). In particular, GT and leaf LM were identified as the most important drivers of the community composition (Table 3). Thus, GT and leaf LM can be used as good predictors of land use change effects on ground arthropod communities. These results appear to support the conclusion that altered GT and leaf litter production resulting from the conversion of native grasslands to plantations will have particularly significant impacts on the assemblage of ground arthropod communities in this desert ecosystem.

As predicted, the direction and strength of land use change effects on ground arthropods varied among trophic groups as well as among dominant taxa within trophic groups. Compared to the native grassland, we found that established shrubland had a significantly lower activity density of predatory beetles, herbivorous beetles, and detritivorous beetles; a similar activity density of spiders; and similar richness for all four trophic groups. This observation suggests that converting native grassland to shrub plantation tended to reduce the activity of predatory, herbivorous, and detritivorous beetle assemblages, but it may not affect the activity of spiders or the richness of the four trophic groups. In the shrub plantation, the lower activity density of beetle predators was mainly due to carabid beetles, the lower activity density of beetle herbivores was

mainly caused by curculionid beetles, and the lower activity density of beetle detritivores was mainly due to tenebrionid beetles. In desert ecosystems, carabid beetles are important predators (Ren and Yu 1999) and many species in this family are key natural enemies of pests such as aphids and slugs (Bohan et al. 2000; Suenaga and Hamamura 2001; Winder et al. 2005; Hatteland et al. 2011), whereas tenebrionid beetles are a major component of the detrital food web (Ren and Yu 1999; Liu et al. 2012). Remarkably, reduced activities of these two beetle assemblages due to conversion of native grassland to shrub plantation are likely to have negative consequences on ecological functions of desert ecosystems such as predator-mediated pest control (Riechert and Lockley 1984; Nyffeler and Benz 1987; Young and Edwards 1990; Bianchi et al. 2010), detritivore-mediated decomposition of dung and dead plant material (Kajak 1995; Lawrence and Wise 2000; Moore et al. 2004; Wu and Sun 2010), and herbivore-mediated seed dispersal (Estrada and Coates-Estrada 1991; Shepherd and Chapman 1998; Andresen and Feer 2005; Santos-Heredia et al. 2010).

Similarly, we found a much higher activity density of spiders and a much lower activity density for the three beetle assemblages in both forest plantations as compared to native grassland. This observation suggests that converting native grassland to irrigated forest plantations regardless of tree species had a consistent positive effect on the activity of spiders and a consistent negative effect on the activity of predatory, herbivorous, and detritivorous beetle assemblages. The increase in spider activity density was largely due to increased activity density of lycosid spiders in the poplar plantation and increased activity density of linyphiid and nesticid spiders in the pine plantation. In our study system, lycosids can be used as a

bioindicator for the positive effects of grassland conversion to broad-leaved poplar plantations, whereas linyphiids and nesticids can be used as bioindicators for the positive effects of grassland conversion to needle-leaved pine plantations.

Such trophic group and taxa specific responses to changes in land use indicate that historical land conversion-driven environmental changes may have distinctive effects on different trophic groups or taxa due to complex underlying mechanisms. Taxa or species specific responses to changes in land use or climate have been reported by previous studies involving ground arthropod communities (With and Pavuk 2012; Liu et al. 2014) and butterfly communities (Pöyry et al. 2009; Negro et al. 2010). More importantly, our results may also provide evidence for the maintenance of the diversity and stability in the investigated ground arthropod community through trophic group or taxa specific adaptive strategies to habitat change.

In this study, we also observed a land use-driven shift in the trophic structure of the ground arthropod community with detritivorous beetles (relative abundance of 90 %) dominating in the native grassland, both detritivorous beetles (relative abundance of 65 %) and spiders (relative abundance of 26 %) dominating in the shrub plantation, spiders dominating in both poplar (relative abundance of 79 %) and pine (relative abundance of 84 %) plantations. This variation largely reflects the differences between habitats in the availability and diversity of food resources (Wardhaugh et al. 2012) as well as in environmental conditions (Stapp 1997; Ruggiero et al. 2009; Koivula 2011). For example, the observed spider-dominated trophic structure in ground arthropod communities of both forest plantations may suggest more favorable habitat conditions for the establishment of spider assemblages because of two main reasons. First, relative to native grassland, established forest plantations have greater availability of food resources, such as soil collembolans and mites, which have been identified as important food sources of certain spiders (Kajak 1995; Rusek 1998; Sereda et al. 2012). Our previous investigations showed that abundance and richness of soil mites and collembolans in forest plantation soils are significantly higher than in native grassland soils (FR Li unpublished data). Second, relative to native grassland, established forest plantations have a more favorable microclimate (e.g., greater water availability and cooler microclimate during the summer season) for the establishment of spider assemblages. Indeed, a favorable microhabitat in these forest plantation systems with a relatively mild and stable microclimate, higher resource availability, and structurally more complex vegetation has been hypothesized to support a greater abundance of ground spider assemblages (Hatley and MacMahon 1980; Pearce et al. 2004; Cobbold and MacMahon 2012).

Nevertheless, the observed detritivore-dominated trophic structure in the native grassland community may suggest more favorable habitat conditions for the establishment of detritivorous beetle assemblages. This could be associated with the environmental conditions within this habitat that are characterized by a low VC, a higher shrub species diversity, a higher GT, a higher pH, and lower soil moisture availability (Table 1). In our study, the detritivorous beetle assemblage was dominated by tenebrionid beetles that are known to be xerophilic and characteristic of desert sites with a higher GT, a higher pH value, coarse-textured soils, and a higher shrub species diversity (Li et al. 2013). A previous study in this desert ecosystem demonstrated that different tenebrionid beetle species tended to use different shrub species as food sources, which emphasizes the importance of shrub species diversity for maintaining a diverse tenebrionid beetle assemblage (Li et al. 2013). Interestingly, we found that detritivores and spiders co-dominated the trophic structure in the shrub plantation community, which is remarkably different from the trophic structure in the native grassland community and in both forest plantation communities. This pattern probably arose due to particular biotic (higher shrub cover and height but lower shrub species diversity) and abiotic (higher GT and lower soil water availability) conditions within this habitat (Table 1). These particular biotic and abiotic conditions are likely to have profound impacts on the choice of habitat type for ground arthropod communities (Slobodchikoff 1983; Parmenter et al. 1989; Stapp 1997; Pearce et al. 2004; Schweiger et al. 2005; Ziesche and Roth 2008; Woodcock et al. 2010; Koivula 2011).

## Conclusions

Our study demonstrated that conversion from native grassland to cultivated plantations can significantly affect the structure and diversity of ground arthropod communities by altering the environmental conditions of their habitats. However, the magnitude and direction of these land use change effects differed between the trophic groups and their performance parameters. Overall, converting native grassland to a non-irrigated rainfed shrub plantation could have the negative consequences of reducing the activity density of predatory, herbivorous, and detritivorous beetle assemblages, but it might not affect their taxa richness. In contrast, converting native grassland into irrigated forest plantations regardless of tree species could have the positive consequences of increasing the activity density of spider assemblages and the negative consequences of reducing the activity density of predatory, herbivorous, and detritivorous beetle assemblages. We also show that conversion of native grassland to either of the two forest plantations could

enhance predatory beetle taxa richness, reduce the taxa richness of both herbivorous and detritivorous beetle assemblages, and does not affect spider taxa richness. Taken together, these findings have important implications for the development of innovative management strategies for conserving native arthropod diversity and increasing the ecological functions of desert ecosystems. In this study, we only addressed the effects of land use change on the performance of four trophic groups and 23 families of ground arthropods. Further research is necessary to investigate individual species from different trophic groups to better understand the generality of our findings.

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