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ORIGINAL PAPER

Converting natural vegetation to farmland alters functional structure of ground-dwelling beetles and spiders in a desert oasis

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Abstract A vast area of native shrub-dominated steppe at the margins of desert oases in arid regions of China had been reclaimed as farmland in the last century for grain production to feed growing human populations. This study evaluated the consequences of this land-use change on the activity density, taxa richness and composition of functional groups (herbivores, predators and detritivores) of ground-dwelling beetles and spiders, which include some important ecological groups of natural enemies of insect pests (e.g. predatory spiders and beetles), pollinators and decomposers (e.g. detritivorous beetles). Ground-dwelling beetles and spiders were collected using pitfall traps in native steppe habitats and adjacent irrigated farmland of different ages (cultivated either for 27 or at least for 90 years). It was found the conversion of native steppe to farmland, regardless of farmland age, led to a significant increase in activity density of predators, with a greater increase in 90-year-old farmland than in 27-year-old farmland, but did not affect their taxa richness. However, native steppe conversion to farmland, regardless of farmland age, led to significant declines in activity density and taxa richness of both detritivores and herbivores, with a much greater decrease of activity or richness in detritivores than in herbivores in both farmland types. We also observed taxa-specific responses to the land conversion within functional groups. The functional composition of the beetle and spider community shifted from a community dominated by detritivores in the native steppe sites to one dominated by predators in the irrigated farmland sites. Our results suggest that the different functional groups of ground-dwelling beetles and spiders responded in a different way to the land conversion. The remarkable increase in predators and the dramatic decline in detritivores by converting natural vegetation to agricultural land are expected to strongly affect the desert ecosystem services such as biological pest control, pollination and decomposition.

Keywords Agricultural expansion · Biological pest control · Detritivorous arthropods · Ecosystem services · Land-use change · Predatory arthropods

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Introduction

Ground-dwelling arthropods, which include keystone ecological groups of biological control agents (e.g. predatory spiders and insects) against insect pests (Shelton et al. 1983; Riechert and Lockley 1984; Marc and Canard 1997; Suenaga and Hamamura 2001), pollinators (Stanley and Stout 2013) and decomposers (e.g. detritivorous arthropods), have been shown to be important for the functioning of agricultural systems (Landis et al. 2000; Nyffeler and Sunderland 2003; Woltz et al. 2012; Stanley et al. 2013). The globe is undergoing a rapid loss of ground-dwelling arthropod diversity driven by climate change and anthropogenic activities (Wolters et al. 2000; Hoekstra et al. 2005; Gibbs et al. 2009; Kowal and Cartar 2012). Of these anthropogenic activities, human-induced changes in land use and cover are widely perceived to be a major threat to natural ecosystems and their native biodiversity (Downie et al. 1999; Perner and Malt 2003; Foley et al. 2005; Prieto-Benítez and Méndez 2011). Land use/cover changes can cause habitat alteration (Didham et al. 2007), including plant community composition, plant diversity and productivity, microclimatic conditions, soil properties and resource availability (Wagendorp et al. 2006; Garnier et al. 2007; Kueppers et al. 2008; Byrne et al. 2008; Jayawickreme et al. 2011; Laliberté and Tylianakis 2012; Zhao and Jackson 2013). These alterations can significantly affect the composition and diversity of functional groups in ground-dwelling arthropod communities and in turn alter the services of agroecosystems, such as biological pest control (Landis et al. 2000; Garratt et al. 2011), crop pollination (Wratten et al. 2012; Stanley et al. 2013) and decomposition (Liu et al. 2012). Thus, understanding the consequences of land-use changes on the functional composition and diversity of ground-dwelling arthropod assemblages is important to predict the land use-induced changes in ground-dwelling arthropod assemblages and develop appropriate management strategies for arthropod diversity conservation. However, this research has been conducted rarely so far in temperate desert ecosystems of China (Yin et al. 2010).

Desert ecosystems are widely distributed in inland arid lands in northwest China, which involve mainly three provinces of Xinjiang, Gansu and Inner Mongolia and occupy nearly one fifth of the country's land surface (Huang et al. 2013). This biome is characterised by sparse natural vegetation and severe water limitation (mean annual precipitation <200 mm and mean annual evapotranspiration >2,000 mm) and is recognized as one of the most vulnerable to environmental changes associated with climate and land use changes (Cheng et al. 1999). A feature of Chinese desert ecosystems is the occurrence of natural or artificial oases of differing sizes in the desert landscape. In general, a desert ecosystem consists of desert, oasis and transitional zone between oasis and desert, each with distinctive vegetation and soil characteristics (Cheng et al. 1999). Within oases, irrigated agriculture that relies primarily on snowmelt from distant high mountains is the primary type of land use (Wang et al. 2010). The desert outside oases is commonly occupied by dwarf shrub-dominated gravel-covered steppes (so-called 'Gobi steppes'; Liu et al. 2012). The transition zone is commonly occupied by tall shrub-dominated sandy steppes, which are an important ecological barrier for protecting inhabited oases (Su et al. 2007).

Over the last century, especially the recent 50 years, a vast area of natural sandy steppe at the margins of artificial oases has been reclaimed as farmland for grain production to feed rapidly growing human populations (Wang et al. 2010). Land conversions from structurally diverse but less productive natural steppe ecosystems to structurally simple but more productive agricultural systems will cause changes in abiotic and biotic conditions. These changes will further alter the functional composition and diversity of ground-dwelling beetles and spiders, which are dominant components of the ground-dwelling arthropod community in this desert ecosystem (Liu et al. 2012; Li et al. 2013a), ultimately affecting the ecosystem services and functions. However, little is known about the consequences of this land-use change for the composition, activity density and diversity of functional groups in ground-dwelling beetles and spiders, apart from a previous study addressing the effects of converting natural vegetation to farmland on the structure and composition of soil microarthropod communities (Li et al. 2013b).

The objectives of this study were to quantify (1) the effects of land conversion from native steppe to irrigated farmland of different ages on the functional composition and diversity of ground-dwelling beetles and spiders through habitat alteration and (2) the relative role of the measured environmental factors in shaping the patterns of ground-dwelling beetle and spider activity density and diversity. We hypothesized that the effects of converting natural vegetation to farmland on ground-dwelling beetles and spiders would differ across functional groups and between farmlands of different ages.

Materials and methods

Study site

The study was conducted in a desert ecosystem located in the middle reaches of the Heihe River basin, Gansu Province, China (39°21′N, 100°07′E; 1,384 m a.s.l.). The arid continental climate of the study area is characterized by average annual temperature of 7.6 °C, varying from −10.7 °C in January to 23.8 °C in July, and average annual precipitation of 117 mm, over 70 % of which falling in June to September. Average annual potential evapotranspiration is 2,390 mm. The aridity index (precipitation/potential evapotranspiration) is 0.05. The average annual wind velocity is 3.3 m s^{-1}, and gales with wind velocities ≥17 m s^{-1} occur around 20 days per year during spring (March–May).

Study system

In the study region, an artificial oasis of approximately 6,000 km^2 in area for several 100 years old was chosen for the study. The study oasis consists of three separate artificial oases with areas ranging from 1,000 to 2,000 km^2 and distances between the three oases are 1–1.5 km. In each of the three oases, we chosen native sandy steppe and adjacent irrigated farmland of different cultivation ages (cultivated either for 27 or at least for 90 years, both of which were converted from native sandy steppes) as the study system. This system allowed us to quantify the effects of converting natural vegetation to farmland and farmland age on the functional composition and diversity of ground-dwelling beetles and spiders.

The native sandy steppes studied at the three oases 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 percentage cover of the shrub layer was 26.9 ± 3.9 % (mean ± SE) and that of the herbaceous layer was 9.6 ± 3.5 %. The aboveground herbaceous biomass (dry weight) was 13.7 ± 2.9 g m^{-2}. The 27-year-old farmlands studied at the three oases were reclaimed in 26–28 years (mean 27 years), whereas the 90-year-old farmlands studied at the three oases were reclaimed at least 90 years. Both farmland types practiced a crop rotation of maize and wheat and received similar irrigation and fertilization management practices over the last two decades. The annual mean irrigation was about 12,000 m^3 ha^{-1}, corresponding to 1,200 mm per year which is approximately tenfold of the natural precipitation in the study area. The annual mean chemical fertilizer input (complex fertilizer of NPK) was 1,500–1,800 kg ha^{-1}, and at the same time the farmyard manure was applied at a rate of 15,000–18,000 kg ha^{-1} at 2–3 year intervals. No pesticides were applied in both farmland types in the past. For the two farmland types, the annual mean output of aboveground crop biomass (dry weight; seeds plus crop straw) was 2–2.5 kg m^{-2} (for details see Li et al. 2013b).

Sampling design

In this study, we applied a nested sampling design (Fig. 1). In each oasis, three (30 m × 30 m) plots, at least 150 m apart, were established in each of the three habitats (native steppe, 27-year-old farmland and 90-year-old farmland). The distance was 400–800 m between the native steppes and the 27-year-old farmlands and 900–1,300 m between the native steppes and the 90-year-old farmlands. In each plot, five pitfall traps (10-cm diameter and 12-cm height) were placed for sampling ground-dwelling beetles and spiders. Each pitfall trap was made of two plastic cups, namely an outer permanent cup buried in the ground and a removable inner cup put in the outer permanent cup (Liu et al. 2012). Approximately 150–200 mL ethylene glycol was added to each trap as a killing agent and preservative. Trapping was conducted in three periods (6–20 May, 4–18 July and 8–22 September, respectively) of the growing season in 2010, resulting in a total of 405 traps (3 oases × 3 habitats per oasis × 3 plots per habitat × 5 pitfall traps per plot × 3 sampling periods). The traps were checked every 3 days during each sampling period. All caught beetles and spiders were preserved in 70 % ethyl alcohol prior to sorting and identification. All specimens were identified with a stereo microscope (40×) to the family level according to the taxonomic literature "The Classification of Insects in China" (Zheng and Gui 1999) and "The Spiders of China" (Song et al. 1999). Owing to the large number of juveniles that were trapped, it is difficult to identify these specimens to the genus or even species level.

To explore the relationship between environmental factors and ground-dwelling beetle and spider community composition, soil cores (5 cm diameter) were taken at a depth of 20 cm at five randomly chosen locations in each plot, and these five cores were pooled into one composite sample for analysing soil pH, bulk density (BD) and particle size distribution, as well as soil organic carbon (SOC) and total nitrogen (TN). Soil pH was determined in 1:2.5 (w/v) soil solutions. BD was measured using 100-cm^3 rings. Soil texture was determined using a Microtrac S3500 Particle Size Analyzer (Microtrac Inc., USA) by dividing the soil into three particle sizes: coarse sand (2–0.25 mm), fine sand (0.25–0.05 mm) and silt + clay (<0.05 mm), which were expressed as a percentage of soil weight. SOC was determined using an OI Analytical TOC analyzer. TN was measured using the Kjeldahl digestion method (DK Heating Digester, UDK140 Automatic Steam Distilling Unit, Titroline 96, Italy). Furthermore, time domain reflectometry (TRIME-FM, IMKO Micromodultechnik GmbH, Ettlingen, Germany) was used to measure soil moisture content (SMC) at a depth of 20 cm at five randomly chosen locations in each plot. Daily maximum ground temperatures (GT) at these locations were also measured at 14:00 with a geothermometer. The observations of SMC and GT lasted for three consecutive days in each of the three sampling periods, representing the growing season averages of SMC and GT (Liu et al. 2012). The main environmental variables of the three habitats studied can be found in Li et al. (2013b).

Data analysis

The present study aimed to assess the effects of native steppe conversion to farmland on the ground-dwelling

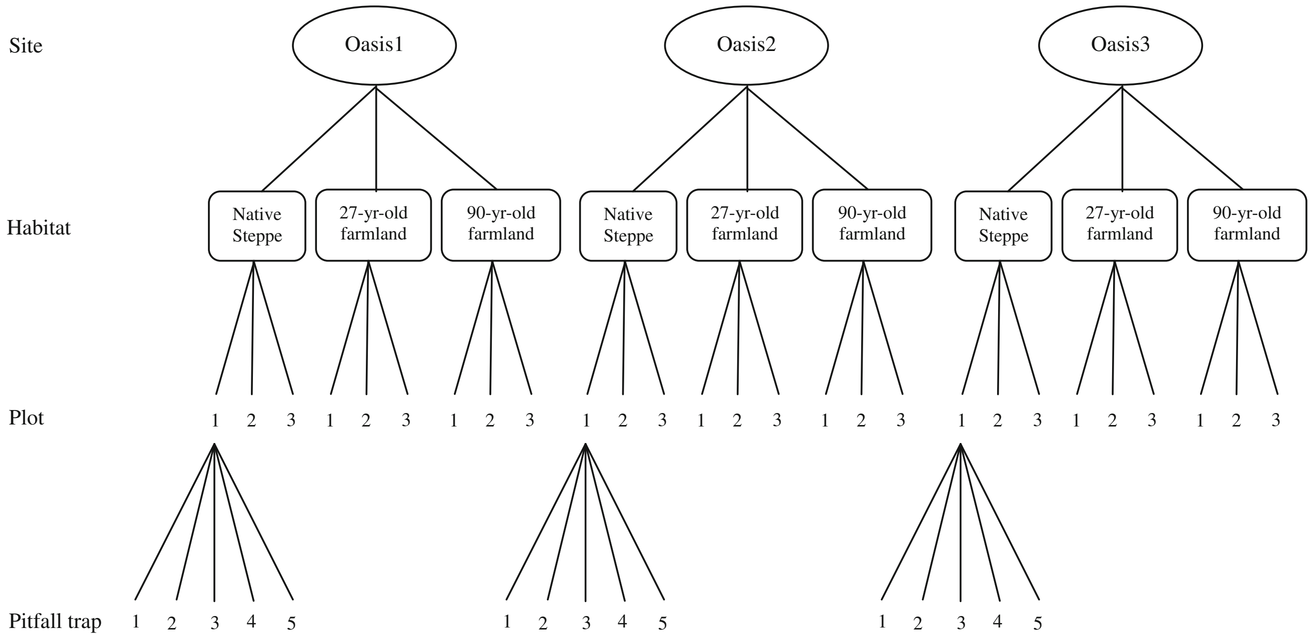

Fig. 1 A nested sampling design was applied in this study

beetle and spider community and, therefore, data from the three sampling periods were pooled for data analysis. Owing to the limitation of the taxonomic level (family), we grouped all collected beetles and spiders into three main functional groups, including herbivores, predators and detritivores, based on the literature (Hu 1984; Lawrence and Britton 1991; Song et al. 1999; Zheng and Gui 1999). It is valuable to analyse the effects of converting native steppe to farmland on the functional composition and diversity of the ground-dwelling beetle and spider community. Here, we used nested analysis of variance (ANOVAs) to determine the effects of the land conversion on the activity density (the number of individuals per trap averaged over the five pitfall traps within a plot), taxa richness (the number of families per plot) and relative abundance of the three functional groups. Nested ANOVAs were also performed to determine the effects of the land conversion on the activity density of the individual families within functional groups. When nested ANOVAs revealed a significant difference between the means, Tukey's honestly significant difference (HSD) tests were used for multiple comparisons among means. To avoid the risk of Type I error inflation, *P* values are corrected by the sequential Bonferroni method (Rice 1989). These analyses were performed using SPSS statistical package (SPSS, Chicago, IL, USA).

Differences in community composition (Bray–Curtis dissimilarity) of ground-dwelling beetles and spiders between habitats were assessed with the PERMANOVA+ package for PRIMER (Anderson et al. 2008). *P* values were obtained using pair-wise PERMANOVA tests (999 permutations). The data were log $(x + 1)$ transformed to down-weight the contributions of dominant taxa.

Redundancy analysis (RDA) on the family activity density data was chosen to determine the relative contribution of the measured environmental variables in explaining variability in the community composition. Environmental variables used included two microclimate related variables (GT and SMC) and seven soil property related variables (soil pH, BD, coarse sand content, fine sand content, silt plus clay content, SOC and TN).The data were first analysed by detrended correspondence analysis (DCA) suggesting that RDA is an appropriate approach (length of gradient <3). The relative contribution of each environmental variable to the explained variation in the data was determined by the inertia from the conditional effects, which show the amount of additional variation each variable contributes when it is added to the model (Lepš and Šmilauer 2003). Partial RDA and Monte Carlo permutations (999) were performed to determine the conditional effect of GT with the other variables as covariables, that of SMC with the other variables as covariables, that of soil pH with the other variables as covariables, that of BD with the other variables as covariables, that of coarse sand content with the other variables as covariables, that of fine sand content with the other variables as covariables, that of silt plus clay content with the other variables as covariables, that of SOC with the other variables as covariables, and that of TN with the other variables as covariables (Li et al. 2013a). Data on the activity density and

Table 1 Changes in the activity density (the number of individuals per trap) of the 20 families of ground-dwelling beetles and spiders in response to land conversion from native steppe to irrigated farmland of different ages (cultivated either for 27 or at least for 90 years) in a desert ecosystem of China

Functional group/family	Taxonomic group	Native steppe	27-year-old farmland	90-year-old farmland	$F_{2,\,26}$
Predators					
Araneidae	Spiders	0.2 ± 0.1^{a}	0.6 ± 0.3^{a}	1.1 ± 0.7^{a}	$1.49^{n.s.}$
Carabidae	Beetles	2.6 ± 0.6^{b}	2.1 ± 0.5^{b}	10.1 ± 2.6^{a}	7.04^{*}
Cicindelidae	Beetles	0.0 ± 0.0^{a}	1.0 ± 0.7^{a}	0.4 ± 0.3^{a}	$1.63^{n.s.}$
Coccinellidae	Beetles	0.0 ± 0.0^{b}	2.0 ± 0.9^{a}	2.0 ± 0.5^{a}	8.69^{*}
Gnaphosidae	Spiders	0.8 ± 0.2^{a}	0.1 ± 0.1^{c}	0.4 ± 0.1^{b}	7.18^{*}
Linyphiidae	Spiders	0.02 ± 0.02^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	$0.96^{n.s.}$
Lycosidae	Spiders	0.3 ± 0.1^{c}	1.6 ± 0.6^{b}	6.0 ± 1.3^{a}	14.07^{**}
Nesticidae	Spiders	0.0 ± 0.0^{a}	0.3 ± 0.2^{a}	0.3 ± 0.1^{a}	$1.71^{n.s.}$
Philodromidae	Spiders	0.2 ± 0.1^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	$1.60^{n.s.}$
Salticidae	Spiders	0.8 ± 0.3^{a}	0.0 ± 0.0^{b}	0.0 ± 0.0^{b}	23.69^{***}
Staphylinidae	Beetles	0.1 ± 0.1^{c}	1.2 ± 0.2^{a}	0.4 ± 0.1^{b}	25.46^{***}
Thomisidae	Spiders	0.0 ± 0.0^{a}	0.04 ± 0.04^{a}	0.0 ± 0.0^{a}	$1.01^{n.s.}$
Herbivores					
Curculionidae	Beetles	3.0 ± 0.6^{a}	0.0 ± 0.0^{b}	0.0 ± 0.0^{b}	19.57^{**}
Elateridae	Beetles	0.0 ± 0.0^{a}	0.04 ± 0.04^{a}	0.0 ± 0.0^{a}	$0.97^{n.s.}$
Melolonthidae	Beetles	0.3 ± 0.1^{a}	0.2 ± 0.2^{ab}	0.04 ± 0.04^{b}	14.74^{**}
Silvanidae	Beetles	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.2 ± 0.1^{a}	$2.25^{n.s.}$
Trogossitidae	Beetles	0.0 ± 0.0^{b}	0.6 ± 0.3^{a}	0.6 ± 0.2^{a}	5.75^{*}
Detritivores					
Geotrupidae	Beetles	0.02 ± 0.02^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	$1.00^{n.s.}$
Silphidae	Beetles	0.2 ± 0.1^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	$2.93^{n.s.}$
Tenebrionidae	Beetles	80.7 ± 8.8^{a}	0.0 ± 0.0^{b}	0.0 ± 0.0^{b}	957.79^{***}

Means (±1 SE) with different letters in the same row are significantly different (*n.s.* not significant; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$ from nested ANOVAs followed by Tukey's HSD tests)

environmental variables were log $(x + 1)$ transformed prior to analysis. RDA was performed using CANOCO software for Windows 4.5 (Ter Braak and Šmilauer 2002).

Results

Response of community composition to land-use change

A total of 20 families of ground-dwelling beetles and spiders were collected by pitfall traps from the three habitats: 13 families in the native steppe, 12 families in the 27-year-old farmland and 11 families in the 90-year-old farmland (Table 1). The native steppe community consisted of beetles (99.3 %) and spiders (2.7 %), respectively, and the three most abundant families were Tenebrionidae, Curculionidae and Carabidae. The 27-year-old farmland community consisted of beetles (72.8 %) and spiders (27.2 %), respectively, and the three most abundant families were Carabidae, Coccinellidae and Lycosidae. The 90-year-old farmland community consisted of beetles (63.7 %) and spiders (36.3 %), respectively, and the three most abundant families were Carabidae, Lycosidae and Coccinellidae (Table 1).

PERMANOVA showed a significant effect of native steppe conversion to farmland on the community composition (Bray–Curtis dissimilarity) of ground-dwelling beetles and spiders ($F_{2,\,26} = 25.74$, $P < 0.001$). Pairwise comparisons showed significant differences in communities between the native steppe and the 27-year-old farmland ($t = 5.73$, $P < 0.002$) and between the native steppe and the 90-year-old farmland ($t = 7.26$, $P < 0.001$), while communities were mostly similar between the two farmland types ($t = 1.93$, $P = 0.131$).

Response of functional groups to land-use change

The activity density of the three functional groups was significantly affected by the conversion of native steppes to irrigated farmlands for predators ($F_{2,26} = 36.14, P < 0.001$), herbivores ($F_{2,\,26} = 6.88$, $P = 0.028$) and detritivores

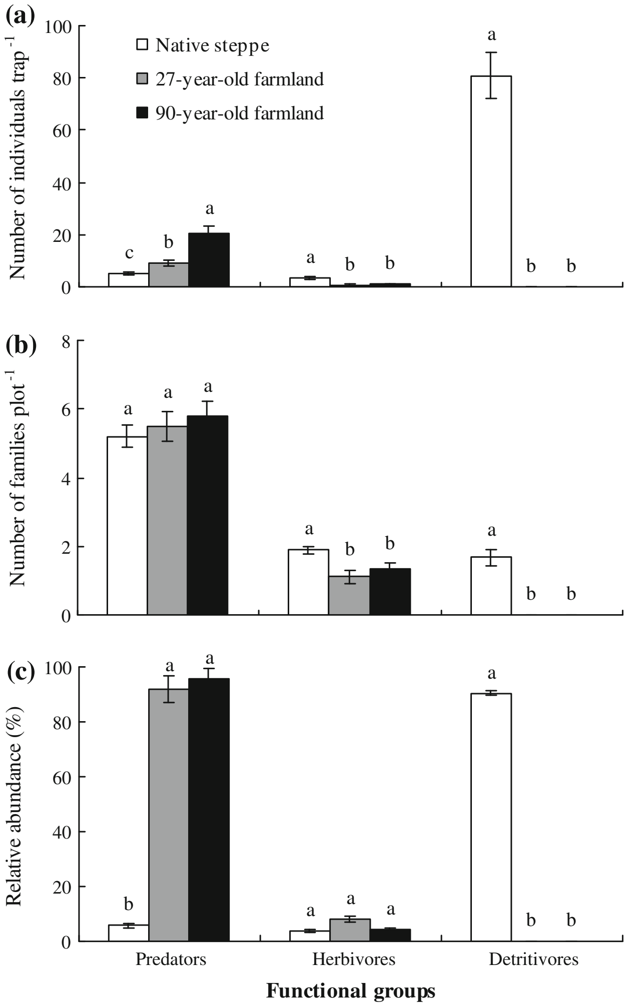

Fig. 2 The effects of native steppe conversion to irrigated farmland of different ages on the activity density, taxa richness and relative abundance of three functional groups (predators, herbivores and detritivores) of ground-dwelling beetles and spiders in a desert ecosystem of China. Means (±1 SE) with different letters within each functional group indicate significant differences among habitats ($P < 0.05$ from nested ANOVAs followed by Tukey's HSD tests)

($F_{2,26} = 942.43, P < 0.001$). Compared to the native steppe, total predator activity density increased, on average, by 75 % in the 27-year-old farmland and by 298 % in the 90-year-old farmland (Fig. 2a). However, the conversion of native steppe to either of the two farmland types significantly decreased the activity density of either herbivores or detritivores, with a greater decline in detritivores than in herbivores in both farmland types. The taxa richness of the three functional groups was differentially affected by the conversion of native steppes to irrigated farmlands for predators ($F_{2,\ 26} = 0.29$, $P = 0.757$), herbivores ($F_{2,\ 26} = 40.90$, $P < 0.001$) and detritivores ($F_{2,26} = 137.29, P < 0.001$). Overall, native steppe conversion to either of the two farmland types significantly decreased the taxa richness of herbivores and detritivores, but did not affect the predator taxa richness (Fig. 2b). Similarly, the relative abundance of the three functional groups was differentially affected by the conversion of native steppes to irrigated farmlands for predators ($F_{2,\ 26} = 191.69$, $P < 0.001$), herbivores ($F_{2,\ 26} = 0.34$, $P = 0.732$) and detritivores ($F_{2,26} = 294.81, P < 0.001$). Overall, native steppe conversion to either of the two farmland types significantly increased the relative abundance of predators, reduced the relative abundance of detritivores and had little impact on the relative abundance of herbivores (Fig. 2c).

Response of individual taxa to land-use change

The different families of ground-dwelling beetles and spiders within functional groups responded differently to the land conversion. Four distinctive response groups were identified from the response of the five families of the herbivore assemblage to the conversion of native steppe to farmland. As compared with the native steppe, two families (Elateridae and Silvanidae) showed little change of activity density in both the young and old farmlands, while one family (Melolonthidae) showed a significant increase in activity density only in the 90-year-old farmland as well as one family (Curculionidae) showed a significant decline in activity density and one family (Trogossitidae) showed a significant increase in activity density in both farmland types (Table 1). Likewise, four contrasting response groups were identified from the response of the 12 families of the predatory assemblage. Compared to the native steppe, two families (Salticidae and Gnaphosidae) showed a consistent decline in activity density and three families (Coccinellidae, Lycosidae and Staphylinidae) showed a consistent increase in activity density in both farmland types, while one family (Carabidae) showed a significant increase in activity density in the 90-year-old farmland and the remaining six families showed no change in activity density in both farmland types (Table 1). Moreover, two contrasting response groups were identified from the response of the three families of the detritivore assemblage. One family (Tenebrionidae) showed a decline in activity density and two families (Geotrupidae and Silphidae) showed little change in activity density in both farmland types relative to the native steppe (Table 1).

Environmental factors related to changes in community composition

RDA showed that the first two axes explained 80.3 % of the variation in the community composition (71.4 % by Axis 1 and 6.2 % by Axis 2; Fig. 3). The first axis (Monte Carlo permutation test: $F = 42.40$, $P < 0.001$) showed a clear environmental gradient of increasing GT (correlation

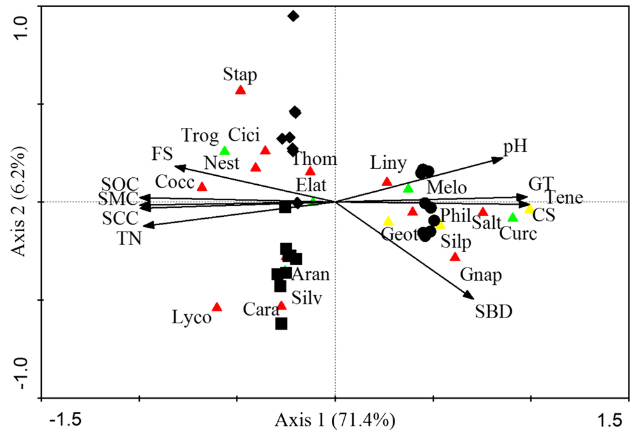

Fig. 3 Biplot of the first two RDA axes for showing the association of ground-dwelling beetle and spider community composition with environmental variables. *Circle* native steppe, *square* 27-year-old irrigated farmland and *triangle* 90-year-old irrigated farmland. Ground-dwelling beetles and spiders are represented by *triangles* (predators in *red*, herbivores in *green* and detritivores in *yellow*). The families are labeled by the first *four letters* of the family name: Tenebrionidae (Tene), Cicindelidae (Cici), Carabidae (Cara), Staphylinidae (Stap), Curculionidae (Curc), Melolonthidae (Melo), Geotrupidae (Geot), Elateridae (Elat), Silphidae (Silp), Coccinellidae (Cocc), Trogossitidae (Trog), Silvanidae (Silv), Gnaphosidae (Gnap), Lycosidae (Lyco), Salticidae (Salt), Linyphiidae (Liny), Nesticidae (Nest), Araneidae (Aran), Philodromidae (Phil) and Thomisidae (Thom). Environmental variables (*GT* ground temperature, *SMC* soil moisture content, *pH* soil pH, *SBD* soil bulk density, *CS* coarse sand content, *FS* fine sand content, *SCC* silt plus clay content, *SOC* soil organic carbon, *TN* total nitrogen) were represented as *arrows* and the strength of their impact was directly proportional to the length of the *arrow lines*. (Color figure online)

coefficient, $r = 0.973$, $n = 27$, $P < 0.001$), pH ($r = 0.848$, $n = 27$, $P < 0.001$), SBD ($r = 0.701$, $n = 27$, $P < 0.001$) and CSC ($r = 0.984$, $n = 27$, $P < 0.001$) and decreasing SMC ($r = -0.990$, $n = 27$, $P < 0.001$), SOC ($r = -0.991$, $n = 27$, $P < 0.001$), TN ($r = -0.971$, $n = 27$, $P < 0.001$), FSC ($r = -0.812$, $n = 27$, $P < 0.001$) and SCC ($r = -0.988$, $n = 27$, $P < 0.001$), which separated the ground-dwelling beetle and spider community between the native steppe sites with higher GT, pH, SBD and CSC and the irrigated farmland sites with higher SMC, SOC, TN, FSC and SCC (Fig. 3). Although all examined nine environmental variables explained 83.7 % of the variation in the community composition, pRDA showed that of these nine variables, only the conditional effects of SMC and SBD were significant in the Monte Carlo permutation test ($F = 61.03$, $P < 0.001$ in SMC and $F = 3.70$, $P = 0.002$ in SBD). Of the total 83.7 % variation explained by the RDA, 70.8 % was caused by SMC, 3.9 % by SBD and the rest (9.0 %) by variables that were not significant in the Monte Carlo permutation test (Table 2). The RDA graph also showed that one spider family (Salticidae) and two beetle families (Tenebrionidae and Curculionidae) were characteristic of the native steppe sites, whereas one spider family (Lycosidae) and two beetle families (Coccinellidae and Staphylinidae) were characteristic of the irrigated farmland sites (Fig. 3).

Table 2 Redundancy analysis for quantifying the conditional effects of the environmental factors on the ground-dwelling beetle and spider community composition

Factors	Inertia conditional effects	*F*-value	*P* value	MCR (%)
Ground temperature	0.015	1.42	0.196	1.5
Soil moisture content	0.709	61.03	0.001	70.8
Soil BD	0.039	3.69	0.002	3.9
Soil pH	0.01	1.01	0.393	1.0
Soil organic carbon	0.014	1.35	0.249	1.4
Total nitrogen	0.017	1.75	0.113	1.7
Coarse sand (2–0.25 mm)	0.011	1.10	0.343	1.1
Fine sand (0.25–0.05 mm)	0.011	1.15	0.340	1.1
Silt plus clay (<0.05 mm)	0.012	1.24	0.302	1.2
Total	0.838	9.71	0.001	83.7

The inertia from the conditional effects is used to calculate the multivariate correlation ratio (MCR), which represents the proportion of variation explained by the individual environmental factors. The sum of all eigenvalues = 1.001

Discussion

In this paper, we investigated the effects of land-use changes through conversion from natural vegetation to agricultural land on the functional structure and diversity of ground-dwelling beetle and spider assemblages in China's desert ecosystem. Our results demonstrate that land conversion from native desert steppe to intensively managed farmland can significantly alter the functional composition and diversity of the ground-dwelling beetle and spider community through altered local environmental conditions, including GT, soil moisture availability and soil properties (Li et al. 2013b). Several studies have demonstrated that land conversions from croplands or grasslands to needleleaf or deciduous broadleaf forests can significantly alter biophysical properties, including albedo, surface roughness, sensible and latent heat fluxes and canopy conductance (Zhao and Jackson 2013) and such changes can further induce changes in surface temperature, evapotranspiration and soil moisture availability (Kueppers et al. 2008; Jayawickreme et al. 2011). The multivariate (RDA) analysis used here revealed that changes in the community structure of ground-dwelling beetles and spiders were largely mediated by changes in environmental conditions, as a major portion (83.7 %) of the variation in the community composition was related to the changes in the measured environmental variables, including GT, SMC, soil pH, BD, coarse sand content, fine sand content, silt plus clay content, SOC and TN. This result is consistent with the findings of previous studies in arid and semiarid ecosystems, suggesting that human-induced changes in microclimatic conditions and soil properties interact to have strong impacts on the distribution and structure of ground-dwelling beetle communities (Slobodchikoff 1983; Stapp 1997; Antvogel and Bonn 2001; Pétillon et al. 2008; Ruggiero et al. 2009; Woodcock et al. 2010; Yang et al. 2011). However, the results from pRDA analysis further revealed that SMC is the most important factor determining the ground-dwelling beetle and spider community composition as it contributed to the major part of the total variation explained by the RDA. A study of the response of ground-dwelling spiders and beetles to the conversion of arable land to grassland in a semiarid region also found that ground-dwelling spider and beetle assemblages respond strongly to changes in soil moisture conditions (Perner and Malt 2003). Therefore, the effect of land conversion on the ground-dwelling beetle and spider community is strongly mediated by the effect of land conversion on soil moisture availability resulting from the change of aboveground vegetation type and biophysical properties (Zhao and Jackson 2013). Previous studies have suggested that water availability is the most frequent limiting factor of the ecological processes in arid and semiarid ecosystems (Noy-Meir 1973; Austin et al. 2004).

The hypothesis of this study was that the effects of native steppe conversion to farmland on ground-dwelling beetles and spiders would differ across functional groups. Our results support this hypothesis. It was found that even though the taxa richness of predators was only slightly higher in the irrigated farmland sites, regardless of farmland age, than in the native steppe sites, the irrigated farmland sites had significantly higher activity density and relative abundance (dominance) of predators relative to the native steppe sites. These data suggest that converting native steppes to farmlands produce a greater frequency of activity or colonization for ground-dwelling predatory arthropods in the farmland habitats. In our study, the increase in predatory activity density in the 27-year-old farmland was mainly ascribed to the enhanced activity of three dominant taxa, including predatory lycosid spiders, coccinellid beetles and staphylinids beetles, whereas the increase in predatory activity density in the 90-year-old farmland was primarily due to the enhanced activity of predatory lycosids, carabid beetles, coccinellids and staphylinids. Because most species from these four taxa are important natural enemies of insect pests (Vlijm and Kessler-Geschiere 1967; Suenaga and Hamamura 2001; Gavish-Regev et al. 2008; Hatteland et al. 2011), the remarkable increase in their activity density is likely to improve the pest control function of agricultural system. In addition, the increase in predators in the irrigated farmland sites could not be ascribed to increase in either herbivores or detritivores as potential prey because both groups were found to have significantly lower activity density in the irrigated farmland sites than in the native steppe sites. Therefore, some other causes may be responsible for the increased activity density of predators in these irrigated farmland sites. It is reasonable to predict that the higher activity density of ground-dwelling predators in the farmland habitats may partly be explained by the higher density of soil microarthropods in these farmland habitats because there were significantly higher density and species richness of soil microarthropods (mites, springtails and other microarthropods) in the irrigated farmland sites relative to the native steppe sites (Li et al. 2013b).

Unlike predators, herbivores and detritivores showed a consistent negative response to the conversion of native steppe to farmland as both groups had significantly lower activity density, taxa richness and relative abundance (except herbivores) in the irrigated farmland sites than in the native steppe sites. These data suggest that converting native steppes to farmlands had negative consequences of decreasing the frequency of activity and diversity of herbivores and detritivores in the farmland habitats. In our study, the decrease in herbivore activity density in the irrigated farmland sites was mainly caused by the decreased activity density of herbivorous curculionid beetles. Because many species from this beetle family are important agricultural pests (Zheng and Gui 1999), the remarkable decline in curculionid beetle activity density caused by the conversion of native steppe to farmland could be important for effectively reducing pest pressure on crops in our system. Furthermore, the observed dramatic decrease in activity density of detritivorous beetles in the irrigated farmland sites was mainly caused by the decreased activity density of detritivorous tenebrionid beetles. The tenebrionid assemblage has been known to be xerophilic and characteristic of desert steppe sites with low SMC and higher GT, coarse sand content and shrub species diversity (Ren and Yu 1999; Liu et al. 2012). Therefore, the dramatic decline in tenebrionid beetle activity density in the irrigated farmland habitats could be explained by the reduced resource diversity and altered abiotic conditions such as GT, soil moisture and soil texture. A recent study in the desert ecosystem has demonstrated that a high diversity of shrub species is important for the maintenance of a diverse tenebrionid beetle assemblage because different tenebrionid beetle species preferred different shrub species as food sources (Liu et al. 2012). Because the tenebrionid assemblage is a dominant component of the detrital food web in the desert ecosystem (Ren and Yu 1999), the dramatic decline in activity density and diversity of this functional group caused by the conversion of native steppe to farmland is most likely to adversely affect the decomposition function and persistence of the desert ecosystem (Ren and Yu 1999; Moore et al. 2004).

Conclusions and implications for management

Overall, our study provides several insights into the consequences of converting natural vegetation to intensively managed farmland on the activity density, taxa richness and composition of main functional groups of ground-dwelling beetles and spiders through altered microclimate, soil properties and resource diversity. The first insight is that land conversion from natural vegetation to irrigated farmland has led to a significant increase in either activity density or relative abundance of predators through increased activity density of predatory lycosids, carabids, coccinellids and staphylinids. The remarkable increase in these predatory taxa in the irrigated farmland habitats is expected to positively affect the function of biological control of insect pests in agricultural landscape. The second insight is that land conversion from natural vegetation to irrigated farmland has led to dramatic declines of activity density, taxa richness and relative abundance of detritivores through reduced activity density of detritivorous tenebrionid beetles. The remarkable decrease in detritivores is expected to have an adverse impact on the decomposition function of the desert ecosystem. The third insight is that land conversion from natural vegetation to irrigated farmland has also led to significant declines of activity density and taxa richness of herbivores through reduced activity density of herbivorous curculionid beetles that are known important insect pests. The remarkable decrease in these insect pests is expected to reduce pest pressures on crops in our system. Taken together, these findings highlight the importance of detailed knowledge of understanding how conversions from native steppes to farmlands affect the functional structure and diversity of ground-dwelling beetle and spider communities in order to balance agricultural production, ground arthropod conservation and ecosystem services (e.g. biological pest control and decomposition). Such knowledge can help land managers develop a more effective land use planning in this desert ecosystem. Furthermore, our results could also provide practical guidance for land management in other arid regions of the world.

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References

Anderson MJ, Gorley RN, Clarke KR (2008) PERMANOVA+ for PRIMER: guide to software and statistical methods. PRIMER-E Ltd, Plymouth

Antvogel H, Bonn A (2001) Environmental parameters and microspatial distribution of insects: a case study of carabids in an alluvial forest. Ecography 24:470–482

Austin AT, Yahdjian L, Stark JM, Belnap J, Porporato A, Norton U, Ravetta DA, Schaeffer SM (2004) Water pulses and biogeochemical cycles in arid and semiarid ecosystems. Oecologia 141:221–235

Byrne LB, Bruns MA, Kim KC (2008) Ecosystem properties of urban land covers at the aboveground–belowground interface. Ecosystems 11:1065–1077

Cheng GD, Xiao DN, Wang GX (1999) On the characteristics and building of landscape ecology in arid area. Adv Geosci 14:11–15 (in Chinese with English abstract)

Didham RK, Tylianakis JM, Gemmell NJ, Rand TA, Ewers RM (2007) Interactive effects of habitat modification and species invasion on native species decline. Trends Ecol Evol 22:489–496

Downie IS, Wilson WL, Abernethy VJ (1999) The impact of different agricultural land-uses on epigeal spider diversity in Scotland. J Insect Conserv 3:273–286

Foley JA, DeFries R, Asner GP, Barford C, Bonan G, Carpenter SR, Chapin FS, Coe MT, Daily GC, Gibbs HK, Helkowski JH, Holloway T, Howard EA, Kucharik CJ, Monfreda C, Patz JA, Prentice IC, Ramankutty N, Snyder PK (2005) Global consequences of land use. Science 309:570–574

Garnier E, Lavorel S, Ansquer P, Castro H, Cruz P, Dolezal J, Eriksson O, Fortunel C, Freitas H, Golodets C, Grigulis K, Jouany C, Kazakou E, Kigel J, Kleyer M, Lehsten V, Leps J, Meier T, Pakeman R, Papadimitriou M, Papanastasis VP, Quested H, Quetier F, Robson M, Roumet C, Rusch G, Skarpe C, Sternberg M, Theau JP, Thebault A, Vile D, Zarovali MP (2007) Assessing the effects of land-use change on plant traits, communities and ecosystem functioning in grasslands: a standardized methodology and lessons from an application to 11 European sites. Ann Bot 99:967–985

Garratt MPD, Wright DJ, Leather SR (2011) The effects of farming system and fertilizers on pests and natural enemies: a synthesis of current research. Agric Ecosyst Environ 141:261–270

Gavish-Regev E, Lubin Y, Coll M (2008) Migration patterns and functional groups of spiders in a desert agroecosystem. Environ Entomol 33:202–212

Gibbs KE, Mackey RL, Currie DJ (2009) Human land use, agriculture, pesticides and losses of imperiled species. Divers Distrib 15:242–253

Hatteland BA, Symondson WOC, King RA, Skage M, Schander C, Solhoy T (2011) Molecular analysis of predation by carabid beetles (Carabidae) on the invasive Iberian slug *Arion lusitanicus*. Bull Entomol Res 101:675–686

Hoekstra JM, Boucher TM, Ricketts TH, Roberts C (2005) Confronting a biome crisis: global disparities of habitat loss and protection. Ecol Lett 8:23–29

Hu JL (1984) The Chinese spiders collected from the fields and forests. Tianjin Science & Technology Press, Tianjin (in Chinese)

Huang R, Xu LG, Liu JM (2013) Research on spatio–temporal change of temperature in the northwest Arid Area. Acta Ecol Sin 33:4078–4089 (In Chinese with English abstract)

Jayawickreme DH, Santoni CS, Kim JH, Jobbagy EG, Jackson RB (2011) Changes in hydrology and salinity accompanying a century of agricultural conversion in Argentina. Ecol Appl 21:2367–2379

Kowal VA, Cartar RV (2012) Edge effects of three anthropogenic disturbances on spider communities in Alberta's boreal forest. J Insect Conserv 16:613–627

Kueppers LM, Snyder MA, Sloan LC, Cayan D, Jin J, Kanamaru H, Kanamitsu M, Miller NL, Tyree M, Due H, Weare B (2008) Seasonal temperature responses to land use change in the western United States. Glob Planet Change 60:250–264

Laliberté E, Tylianakis JM (2012) Cascading effects of long-term land-use changes on plant traits and ecosystem functioning. Ecology 93:145–155

Landis DA, Wratten SD, Gurr GM (2000) Habitat management to conserve natural enemies of arthropod pests in agriculture. Ann Rev Entomol 45:175–201

Lawrence JF, Britton EB (1991) Coleoptera. In: CSIRO (ed) The insects of Australia: a textbook for students and research workers, 2nd edn. Melbourne University Press, Melbourne, pp 543–683

Lepš J, Šmilauer P (2003) Multivariate analysis of ecological data using CANOCO. Cambridge University Press, Cambridge

Li FR, Liu JL, Liu CA, Liu QJ, Niu RX (2013a) Shrubs and species identity effects on the distribution and diversity of ground-dwelling arthropods in a Gobi desert. J Insect Conserv 17:319–331

Li FR, Feng Q, Liu JL, Sun TS, Ren W, Guan ZH (2013b) Effects of the conversion of native vegetation to farmlands on soil microarthropod biodiversity and ecosystem functioning in a desert oasis. Ecosystems 16:1364–1377

Liu JL, Li FR, Liu CA, Liu QJ, Niu RX (2012) Influences of shrub vegetation on distribution and diversity of a ground beetle community in a Gobi desert ecosystem. Biodivers Conserv 21:2601–2619

Marc P, Canard A (1997) Maintaining spider biodiversity in agroecosystems as a tool in pest control. Agric Ecosyst Environ 62:229–235

Moore JC, Berlow EL, Coleman DC, de Ruiter PC, Dong Q, Hastings A, Johnson NC, McCann KS, Melville K, Morin PJ, Nadelhoffer K, Rosemond AD, Post DM, Sabo JL, Scow KM, Vanni MJ, Wall DH (2004) Detritus, trophic dynamics and biodiversity. Ecol Lett 7:584–600

Noy-Meir I (1973) Desert ecosystems: environment and producers. Annu Rev Ecol Syst 4:25–52

Nyffeler M, Sunderland KD (2003) Composition, abundance and pest control potential of spider communities in agroecosystems: a comparison of European and US studies. Agric Ecosyst Environ 95:579–612

Perner J, Malt S (2003) Assessment of changing agricultural land use: responses of vegetation, ground-dwelling spiders and beetles to the conversion of arable land into grassland. Agric Ecosyst Environ 98:169–181

Pétillon J, Georges A, Canard A, Lefeuvre JC, Bakker JP, Ysnel F (2008) Influence of abiotic factors on spider and ground beetle communities in different salt-marsh systems. Basic Appl Ecol 9:743–751

Prieto-Benítez S, Méndez M (2011) Effects of land management on the abundance and richness of spiders (Araneae): a meta-analysis. Biol Conserv 144:683–691

Ren GD, Yu YZ (1999) The darking beetles from deserts and semideserts of China (Coleoptera: Tenebrionidae). Hebei University Publishing House, Baoding (in Chinese)

Rice WR (1989) Analyzing tables of statistical tests. Evolution 43:223–225

Riechert SE, Lockley T (1984) Spiders as biological control agents. Ann Rev Entomol 29:299–320

Ruggiero A, Sackmann P, Farji-Brener AG, Kun M (2009) Beetle abundance–environment relationships at the subantarctic–patagonian transition zone. Insect Conserv Divers 2:81–92

Shelton AM, Andaloro JT, Hoy CW (1983) Survey of ground-dwelling predaceous and parasitic arthropods in cabbage fields in upstate New York. Environ Entomol 12:1026–1030

Slobodchikoff CN (1983) Water balance and temperature preferences and their role in regulatory activity of tenebrionid beetles. Oikos 40:113–119

Song DX, Zhu MS, Chen J (1999) The spiders of China. Hebei Science and Technology Publishing House, Baoding (in Chinese)

Stanley DA, Stout JC (2013) Quantifying the impacts of bioenergy crops on pollinating insect abundance and diversity: a field-scale evaluation reveals taxon-specific responses. J Appl Ecol 50:335–344

Stanley DA, Gunning D, Stout JC (2013) Pollinators and pollination of oilseed rape crops (*Brassica napus* L.) in Ireland: ecological and economic incentives for pollinator conservation. J Insect Conserv. doi:10.1007/s10841-013-9599-z

Stapp P (1997) Microhabitat use and community structure of darkling beetles (Coleoptera: Tenebrionidae) in shortgrass prairie: effects of season, shrub cover and soil type. Am Nat 137:298–311

Su YZ, Zhao WZ, Su PX, Zhang ZH, Chang XX (2007) Ecological effects of desertification control and desertified land reclamation in oasis-desert ecotone in an arid region: a case study in Hexi Corridor, Northwest China. Ecol Eng 29:117–124

Suenaga H, Hamamura T (2001) Occurrence of carabid beetles (Coleoptera: Carabidae) in cabbage fields and their possible impact on lepidopteran pests. Appl Entomol Zool 36:151–160

Ter Braak CJF, Šmilauer P (2002) CANOCO reference manual and CanoDraw for windows user's guide: software for canonical community ordination (Version 4.5). Microcomputer Power, Ithaca

Vlijm L, Kessler-Geschiere AM (1967) The phenology and habitat of *Pardosa monticola*, *P. nigriceps* and *P. pullata* (Araneae, Lycosidae). J Anim Ecol 36:31–56

Wagendorp T, Gulinck H, Coppin P, Muys B (2006) Land use impact evaluation in life cycle assessment based on ecosystem thermodynamics. Energy 31:112–125

Wang Q, Li FR, Zhao L, Zhang EH, Shi SL, Zhao WZ, Song WX, Vance MM (2010) Effects of irrigation and nitrogen application rates on nitrate nitrogen distribution and fertilizer nitrogen loss, wheat yield and nitrogen uptake on a recently reclaimed sandy farmland. Plant Soil 337:325–339

Wolters V, Silver WL, Bignell DE (2000) Effects of global changes on above- and belowground biodiversity in terrestrial ecosystems: implications for ecosystem functioning. Bioscience 50:1089–1098

Woltz JM, Isaacs R, Landis DA (2012) Landscape structure and habitat management differentially influence insect natural enemies in an agricultural landscape. Agric Ecosyst Environ 152:40–49

Woodcock BA, Redhead J, Vanbergen AJ, Hulmes L, Hulmes S, Peyton J, Nowakowski M, Pywell RF, Heard MS (2010) Impact of habitat type and landscape structure on biomass, species richness and functional diversity of ground beetles. Agric Ecosyst Environ 139:181–186

Wratten SD, Gillespie M, Decourtye A, Mader E, Desneux N (2012) Pollinator habitat enhancement: benefits to other ecosystem services. Agric Ecosyst Environ 159:112–122

Yang GJ, He Q, Wang XP (2011) Darkling beetle community structure and its relations with environmental factors in Sidunzi of Yanchi, Ningxia, China. Chin J Appl Ecol 21:2374–2382 (in Chinese with English abstract)

Yin XQ, Song B, Wu DH (2010) A review on the eco-geography of soil fauna in China. Acta Geogr Sci 20:333–346

Zhao K, Jackson RB (2013) Biophysical forcings of land-use changes from potential forestry activities in North America. Ecol Monogr. doi:10.1890/12-1705.1

Zheng LY, Gui H (1999) Classification of insects in China. Nanjing Normal University Publishing House, Nanjing (in Chinese)