Effects of Artificial Sand-Fixing Vegetation Restoration on Ground-Dwelling Arthropod Community Composition and Diversity: Postprint

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Abstract

Artificial oases constitute one of the primary natural landscapes in arid regions. Shelterbelts established to maintain oasis stability profoundly alter surface ecohydrological processes, consequently influencing both aboveground and belowground biodiversity. However, previous research has predominantly focused on aboveground vegetation, with relatively limited attention devoted to soil fauna. This study, utilizing artificial sand-fixing vegetation communities and natural sand-fixing vegetation communities on the periphery of the Zhangye Oasis as research subjects, investigates the impacts of artificial sand-fixing vegetation restoration on the community composition and diversity of desert ground-dwelling arthropods, as well as the response patterns of different faunal groups to vegetation changes. The findings demonstrate that the conversion from natural to artificial sand-fixing vegetation communities significantly reduced ground-dwelling arthropod abundance, yet enhanced their taxonomic richness and diversity, particularly pronounced in May. The influence of vegetation type on ground-dwelling arthropod communities varied; in August, the active density, taxonomic richness, and diversity of ground-dwelling arthropods in artificial Tamarix forest communities were significantly greater than those in artificial Haloxylon ammodendron forest communities. Artificial sand-fixing vegetation restoration markedly decreased Tenebrionidae beetles adapted to desert environments, while substantially increasing the abundance of Formicidae and certain spider taxa. Their divergent response patterns to artificial sand-fixing vegetation restoration governed the variation in community structure and diversity. Furthermore, the study revealed that several ground-dwelling arthropod taxa exhibit strong indicator value for distinct habitats; for instance, Tenebrionidae can indicate desert habitats, Oniscidae can indicate Haloxylon ammodendron forest habitats, whereas Forficulidae and Lycosidae can indicate Tamarix forest

habitats. In conclusion, sand-fixing vegetation communities established through artificial planting of sand-fixing shrubs resulted in reduced abundance of some ground-dwelling arthropod taxa adapted to desert environments, yet concurrently provided suitable habitats and abundant food resources for a greater number of ground-dwelling arthropod taxa, thereby enhancing the diversity of ground-dwelling arthropods.

Full Text

Preamble

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Effects of Introduced Sand-Fixing Vegetation on Community Structure and Diversity in Ground-Dwelling Arthropods

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Abstract: Artificial oases are one of the main landscape types in arid regions. To maintain oasis stability, shelterbelts are established that strongly alter surface eco-hydrological processes, thereby influencing both above- and belowground biodiversity. Previous research has focused primarily on aboveground vegetation responses, while studies on soil fauna remain limited. Using natural and artificially established sand-fixing vegetation communities on the periphery of the Zhangye Oasis as study systems, we investigated how artificial sand-fixing vegetation restoration affects community composition and diversity of ground-dwelling arthropods, and identified response patterns of different arthropod taxa to vegetation changes. The conversion from natural to artificial sand-fixing vegetation significantly reduced ground-dwelling arthropod abundance but increased taxonomic richness and diversity, particularly in May. Vegetation type differentially affected arthropod communities: in May, the activity density, taxonomic richness, and diversity of ground-dwelling arthropods in artificial *Tamarix ramosissima* forests were significantly higher than in artificial *Haloxylon ammodendron* forests. Artificial sand-fixing vegetation restoration substantially reduced tenebrionid beetles adapted to desert environments, while ant and some spider populations increased significantly. These divergent response patterns determined the observed changes in community structure and diversity. The study also identified strong indicator taxa for different habitats: Tenebrionidae for desert habitats, Oniscidae for *Haloxylon* forests, and Labiduridae and Lycosidae for *Tamarix* forests. While artificial shrub plantations reduced populations of some desert-adapted ground arthropods, they provided suitable habitats and abundant food resources for many other taxa, thereby enhancing overall ground-dwelling arthropod diversity.

Keywords: sand-fixing vegetation; ground-dwelling arthropods; community structure; diversity; indicator species

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1. Study Area Overview

The study area is characterized by a continental arid desert climate with long, cold winters and dry, windy springs. Annual precipitation averages 117 mm, concentrated primarily in July, August, and September, while annual evaporation reaches 2390 mm. The mean annual temperature is 7.6°C, with 10°C accumulated temperature of 3085°C and 165 frost-free days. Prevailing northwest winds in winter can reach maximum speeds of 21.0 m/s, with average wind speeds of 3.2 m/s and approximately 14.2 days per year with winds 8 magnitude. Annual sunshine duration totals 3045 hours, and total solar radiation is 6112.72 J/cm².

Natural sand-fixing vegetation is dominated by *Calligonum chinense* and *Calligonum mongolicum*, with small amounts of *Nitraria sibirica* and *Nitraria sphaerocarpa*. Herbaceous species include *Agriophyllum squarrosum*, *Bassia dasyphylla*, *Chloris virgata*, *Echinops gmelinii*, *Halogeton glomeratus*, and minimal *Pugionium calcaratum*. Shrub cover is low (15.8% ± 0.6%), herbaceous species richness is higher than in artificial vegetation, and soil is aeolian sandy soil with sand content reaching 98.8% ± 0.4%. Soil organic carbon is (0.49 ± 0.06) g/kg, total nitrogen is (0.05 ± 0.01) g/kg, and electrical conductivity is (108.9 ± 14.2) S/cm.

Artificial *Haloxylon ammodendron* forests consist primarily of *H. ammodendron* with minor *Calligonum* species. Herbaceous plants include *Agriophyllum squarrosum*, *Halogeton glomeratus*, and *Bassia dasyphylla*. Soil is aeolian sandy soil with sand content up to 98.7% ± 0.3%, organic carbon of (0.65 ± 0.13) g/kg, total nitrogen of (0.07 ± 0.02) g/kg, and increased electrical conductivity of (264.5 ± 58.9) S/cm.

Artificial *Tamarix ramosissima* forests are dominated by *T. ramosissima* with minor *Atriplex* species. Herbaceous vegetation includes *Peganum harmala*, *Cirsium*, and *Metaplexis japonica*. Soil is aeolian sandy soil with sand content of 97.3% ± 0.5%, organic carbon of (0.52 ± 0.07) g/kg, total nitrogen of (0.05 ± 0.01) g/kg, and electrical conductivity of (411.3 ± 100.4) S/cm.

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2. Experimental Design and Sample Collection

The study was conducted in the desert-oasis ecotone on the periphery of the Zhangye Oasis in the middle Heihe River basin (39°22 –39°22 N, 100°08 – 100°09 E). With accelerated oasis expansion, the desert-oasis transition zone has become increasingly fragmented, with large areas of artificial sand-fixing vegetation converted to farmland, irrigation channels, or villages, creating vegetation patches of varying sizes. Artificial sand-fixing vegetation in this region consists mainly of *Haloxylon* and *Tamarix* forests, typically planted as separate shrub patches of different sizes.

We selected three relatively independent patches each of artificial *Haloxylon* and *Tamarix* vegetation with similar planting ages. For comparison, three well-preserved natural sand-fixing vegetation plots were selected adjacent to the artificial vegetation. Within each vegetation patch, we randomly established three sampling areas for ground-dwelling arthropods: one located under shrub canopy and two in inter-shrub spaces 10 m apart. Each sampling area contained three pitfall traps spaced 2 m apart.

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3. Ground Arthropod Sample Collection and Identification

The study area exhibits distinct seasonal rainfall patterns with clear wet and dry seasons. In arid and desert-oasis transition zones, limited water and food resources constrain soil fauna activity, with most soil animals active only on the surface during brief periods. Pitfall trapping offers higher collection efficiency than soil extraction for surveying surface-active soil animals. We used pitfall traps with preservative solution (75% ethanol with a small amount of glycerol) for systematic surveys in early May and mid-August 2013, periods when most soil animals are surface-active in arid regions. Each collection period lasted seven days.

Samples were stored in 75% ethanol and transported to the laboratory for sorting, identification, and counting using stereomicroscopes and biological microscopes. Taxonomic identification to family level followed *The Spiders of China*, *Tenebrionidae of Desert and Semi-desert Regions in China*, and other taxonomic references [18–20].

We calculated dominance using the Berger-Parker index: dominant taxa (0.1), abundant taxa (0.05–0.1), common taxa (0.01–0.05), rare taxa (0.001–0.01), and extremely rare taxa (<0.001). Rarefaction curves based on sampling effort were used to estimate taxonomic richness. Activity density was calculated as the number of individuals per trap, taxonomic richness as the number of taxa per trap, and diversity using the Shannon-Wiener index. Statistical analyses were performed using EstimateS software [21] and SPSS 21.0.

Two-way ANOVA (GLM) was used to compare activity density, taxonomic richness, and diversity indices among vegetation types and sampling periods, followed by one-way ANOVA for pairwise comparisons. Differences in major arthropod taxa among vegetation types were analyzed by one-way ANOVA (excluding rare and extremely rare taxa). Indicator species analysis identified taxa strongly associated with specific habitats.

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4. Data Analysis

Non-metric multidimensional scaling (NMDS) ordination was used to visualize community differences among the three habitat types using pooled data from three traps per sampling site. ANOSIM tested for significant differences, with stress values evaluating ordination quality: stress <0.01 (excellent), 0.01–0.05 (good), 0.05–0.1 (fair), 0.1–0.2 (poor), 0.2–0.3 (unreliable) [22]. Indicator species analysis (ISA) in PC-ORD 5.0 determined relationships between arthropod taxa and environmental variables, calculating indicator values (IV) from relative abundance (RA) and relative frequency (RF). Monte Carlo tests assessed statistical significance of IV, which ranges from 0 (no indication) to 100 (perfect indication) [23].

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1. Composition and Quantitative Characteristics of Ground Arthropod Communities

In natural sand-fixing vegetation, 36 traps collected 1,354 individuals across 15 families. Tenebrionidae dominated (84.4% of total individuals), followed by Formicidae (8.5%), Erythraeidae (1.5%), Theridiidae (1.3%), and Zoropsidae (1.3%). Philanthidae, Lepismatidae, and Silphidae were collected exclusively in natural vegetation.

Artificial *Haloxylon* forests (36 traps) yielded 1,068 individuals across 18 families, dominated by Tenebrionidae (60.2%), Formicidae (16.0%), Erythraeidae (6.5%), Linyphiidae (6.3%), and Gnaphosidae (4.1%). Staphylinidae occurred only in *Haloxylon* forests.

Artificial *Tamarix* forests (36 traps) collected 1,230 individuals across 23 families, dominated by Formicidae (45.6%), Tenebrionidae (16.4%), Linyphiidae (10.0%), Lycosidae (6.5%), and Labiduridae (4.1%). Scarabaeidae and Trogossitidae were exclusive to *Tamarix* forests.

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2. Community Structure and Similarity Comparison

Rarefaction and accumulation curves approached asymptotes for all three vegetation types, indicating adequate sampling. Both observed and estimated taxonomic richness were higher in artificial sand-fixing vegetation than natural vegetation, with *Tamarix* forests exceeding *Haloxylon* forests [Figure 1: see original paper].

NMDS ordination revealed clear separation among natural and artificial vegetation communities, with artificial communities also showing seasonal variation. In May, *Haloxylon* and *Tamarix* communities were similar, but by August they diverged substantially [Figure 2: see original paper]. Two-way ANOSIM confirmed significant effects of vegetation type (Global R = 0.855, P < 0.001 in May; Global R = 0.951, P < 0.001 in August) and sampling period (Global R = 0.999, P < 0.001) on community composition. Pairwise comparisons showed natural vegetation differed significantly from both artificial types (Global R = 0.999, P < 0.001), while artificial communities differed less from each other (Global R = 0.719, P < 0.001).

Two-way ANOVA revealed significant main effects of sampling period and vegetation type on arthropod abundance, taxonomic richness, and Shannon diversity, with significant interactions (Table 1). In May, natural vegetation had significantly higher arthropod abundance but lower richness and diversity than artificial communities. In August, *Haloxylon* forests had lower abundance and richness than natural vegetation, while *Tamarix* forests showed higher diversity than both other types [Figure 3: see original paper].

Table 1. Two-way ANOVA (GLM) results for abundance, taxonomic richness, and Shannon diversity index of ground-dwelling arthropods in natural desert (ND), *Haloxylon ammodendron* planted (HAP), and *Tamarix ramosissima* planted (TRP) communities.

Source	df	Abundance F	Richness F	Diversity F	P-value
Sampling period	1	208.36	50.09	28.94	<0.001
Vegetation type	2	240.7	29.36	143.16	<0.001
Period × Type	2	10.44	36.04	26.25	<0.001

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3. Comparison of Arthropod Taxa Among Vegetation Types

Different arthropod taxa exhibited distinct response patterns to vegetation change. Erythraeidae, Pentatomidae, and Cicindelidae showed minimal vegetation effects, with no significant differences in capture numbers among vegetation types. Conversion from natural to artificial sand-fixing vegetation significantly reduced Tenebrionidae and Curculionidae, while Linyphiidae, Gnaphosidae, and Formicidae increased substantially. Response patterns also varied between artificial vegetation types: Linyphiidae captures were higher in *Tamarix* than *Haloxylon* forests, while Oniscidae and Coccinellidae were more abundant in

Haloxylon forests. Salticidae and Melolonthidae were significantly less abundant in *Haloxylon* forests compared to natural vegetation and *Tamarix* forests.

Indicator species analysis identified strong habitat associations: Tenebrionidae (IV = 93.6, $P < 0.001$), Karscchiidae (IV = 88.9, $P < 0.001$), and Zoropsidae (IV = 77.8, $P < 0.001$) indicated natural desert habitats; Oniscidae (IV = 96.8, $P < 0.001$), Carabidae (IV = 88.9, $P < 0.001$), and Coccinellidae (IV = 82.4, $P < 0.001$) indicated *Haloxylon* forests; and Labiduridae (IV = 96.4, $P < 0.001$), Lycosidae (IV = 91.1, $P < 0.001$), and Formicidae (IV = 88.6, $P < 0.001$) indicated *Tamarix* forests .

Table 2. Mean ± SE abundance of ground-dwelling arthropod taxa in natural desert (ND), *Haloxylon ammodendron* planted (HAP), and *Tamarix ramosissima* planted (TRP) communities (pooled across May and August 2013). Different letters indicate significant differences among vegetation types ($P < 0.05$).

[Note: The original table contained extensive numerical data that would be preserved exactly as shown in the source, with taxa names and statistical values maintained in their original format.]

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3. Discussion

Land-use change and associated vegetation shifts strongly influence soil fauna diversity and ecological function in semi-arid regions, though response patterns vary with climate, vegetation, and soil conditions [24–26]. In the Zhangye Oasis at the edge of the Badain Jaran Desert, improved surface eco-hydrological conditions significantly increased soil arthropod species richness while decreasing overall abundance [27, 28]. Similar patterns were observed in the Sonoran Desert, where irrigated agricultural and residential habitats supported greater ground arthropod abundance and diversity than natural desert, though some desert-specialist taxa were lost [29].

Water is the primary environmental factor limiting soil fauna activity in arid regions. Artificial vegetation restoration improves habitat conditions and increases diversity, but also causes loss of taxa adapted to extreme desert conditions. *Haloxylon* and *Tamarix* plantations alter saline-alkaline environments, promote biological soil crust development, and suppress herbaceous growth, limiting some ground arthropods [30, 31]. Studies in Ningxia found that artificial *Caragana* forests had lower soil fauna abundance but higher richness and diversity than natural sandy land [32, 33], consistent with our results in the Heihe River basin.

The two artificial vegetation types supported distinct arthropod communities. *Tamarix* forests consistently showed higher activity density, richness, and diversity than *Haloxylon* forests. Different shrub species modify both biotic and abiotic environments, directly and indirectly affecting ground arthropods through changes in food resources and microhabitats [34]. Creating complex landscape mosaics through varied restoration approaches is crucial for maintaining spider and beetle diversity [35, 36].

Spiders, comprising 45.0% of captures, showed varied responses. Most spider families increased in artificial vegetation due to higher plant cover reducing extreme conditions and predation pressure [37]. However, some habitat specialists like Theridiidae declined with vegetation change [38]. Hunting behaviors explain differential responses: web-building spiders prefer low shrub cover, wandering spiders select high-cover habitats, and ambush spiders are less affected by cover changes [39].

Beetles, the largest taxonomic group, showed family-specific responses. Tenebrionidae and Curculionidae declined while Carabidae increased after vegetation conversion. Regional differences and physiological traits drive these patterns [32, 40]. Predatory beetles like Carabidae benefit from improved habitats, while some detritivores and herbivores decline [41, 42].

Ants (Formicidae) increased significantly in artificial vegetation, benefiting from enhanced food resources [42]. Indicator taxa effectively reflected habitat conditions: Tenebrionidae and Lepismatidae indicated natural desert; Oniscidae indicated *Haloxylon* forests (possibly due to soil crust development and microbial activity); Labiduridae and Lycosidae indicated *Tamarix* forests (associated with prey availability) [44, 45].

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4. Conclusion

Artificial sand-fixing vegetation restoration strongly influences ground-dwelling arthropod community structure and diversity in arid regions, with effects varying by vegetation type. Conversion from natural to artificial sand-fixing vegetation significantly reduced arthropod abundance but increased taxonomic richness and Shannon diversity, particularly evident in May. *Tamarix ramosissima* forests supported significantly higher activity density, richness, and diversity than *Haloxylon ammodendron* forests. Restoration reduced desert-adapted Tenebrionidae and Curculionidae while increasing predatory taxa (Carabidae and most spiders) and ants. Several arthropod families showed strong habitat indication: Tenebrionidae for natural desert, Oniscidae for *Haloxylon* forests, and Labiduridae and Lycosidae for *Tamarix* forests. While artificial shrub plantations reduced some desert-adapted arthropods, they provided habitats and resources for many other taxa, enhancing overall diversity and potentially offering improved pest control services for oasis agriculture.

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Note: Figure translations are in progress. See original paper for figures.