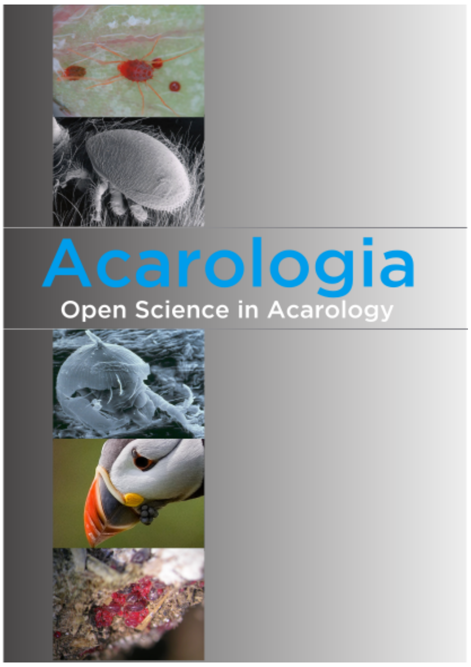
Changes in a soil microarthropod community in the vicinity of dominant tree species under trampling management at the Safari Zoological Center, Israel

Rentao Liu, Roy Meller, Yosef Steinberger


Acarologia
Open Science in Acarology

Acarologia

Open Science in Acarology

Changes in a soil microarthropod community in the vicinity of dominant tree species under trampling management at the Safari Zoological Center, Israel

Rentao Liu[a,b] , Roy Meller[b] , Yosef Steinberger[b]

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

[b] The Mina and Everard Goodman Faculty of Life Sciences, Bar-Ilan University, Ramat-Gan 5290002, Israel.

Original article

ABSTRACT

Tree-canopy and trampling management are reported to influence soil arthropod abundance and diversity. However, there is limited understanding of their interactive effects on a soil microarthropod community at the Safari Zoological Center, central Israel. This study assessed the spatial influence of three dominant tree species (*Cupressus sempervirens*, *Eucalyptus camaldulensis*, and *Tamarix aphylla*) under contrasting trampling and enclosure treatment on soil microarthropod abundance and diversity during a wet Mediterranean winter. There was a significant interactive effect of tree species and trampling management on soil moisture, organic matter, pH, and soil density, with an individual effect of tree species or trampling management on soil electrical conductivity and water-holding capacity. There was a significantly greater abundance of total microarthropods under enclosure than under trampling in open spaces and beneath the *E. camaldulensis* canopy, with the greatest abundance found in the open spaces under enclosure. However, there were no significant differences in the average abundance of total microarthropods between trampling and enclosure beneath either the *T. aphylla* or *C. sempervirens* canopy. The soil Acari diversity indices (i.e., taxon richness, Shannon index, and evenness index) were significantly greater under enclosure than under trampling in open spaces and beneath tree-canopy habitats, with the exception of taxon richness beneath the *C. sempervirens* canopy. We concluded that the trampling activities had a detrimental effect on soil microarthropod abundance and soil Acari diversity in some cases only. The distinctive canopy architecture of some tree species (i.e., *T. aphylla* and *C. sempervirens*) has ecophysiological attributes which could mediate the effect of trampling on soil microarthropods.

Keywords Safari park; soil microarthropods; Acari; trampling management; tree species; Israel

Introduction

Animal trampling and grazing has both direct and indirect effects on vegetation and soils, which alter the distribution of soil invertebrate communities (Denmead *et al.*, 2015). Bardgett *et al.* (2001) and Bugalho *et al.* (2011) reported that livestock trampling not only affected the physical habitats of soil organisms through compaction by the hooves, but also influenced biological processes that affect soil nutrients. Liu *et al.* (2017) indicated that perennial grazing had a large effect on soil fauna of the subalpine meadows in the Tibetan region. Bardgett and Wardle (2003)

Received 15 May 2018
Accepted 10 December 2018
Published 18 January 2019

Corresponding author
Yosef Steinberger:
Yosef.Steinberger@biu.ac.il

Academic editor
Roy, Lise

DOI
10.24349/acarologia/20194308

How to cite this article Liu R. *et al.* (2019), Changes in a soil microarthropod community in the vicinity of dominant tree species under trampling management at the Safari Zoological Center, Israel. **Acarologia 59(1): 33-45; DOI 10.24349/acarologia/20194308**

reported the effect of grazing practices on below-ground faunal communities. Holmquist *et al.* (2013) elucidated the potential negative effect of livestock trampling on arthropod assemblages. However, reduced trampling pressure could increase species richness and the abundance of phytophagous insects (Parfitta *et al.*, 2010; Bugalho *et al.*, 2011). The ungulate trampling management was found to have a significant effect on a soil biotic community (Galli *et al.*, 2015). Soil microarthropods are an important component of terrestrial ecosystems due to their role as regulators of key processes, such as plant litter decomposition and mineralization (Kampichler and Bruckner, 2009), soil formation (Persson, 1989), and nutrient cycling (Powers *et al.*, 1998). Understanding the abundance and diversity distribution of soil microarthropods as affected by trampling management could be beneficial for the design and management of intensive land-use systems (Barrios *et al.*, 2012).

Plant canopies as food resources and shelter refuges could play an important role in ungulates activities and trampling (Shinoda and Akasaka, 2017). Canopy habitats of different tree species could harbor distinctive variations of leaves and herbaceous vegetation, thus affecting the behavior of wandering herbivore animals (Blaum *et al.* 2009; Seeber *et al.*, 2008; 2009). In addition, tree canopy and crown structure could modify soil conditions beneath the canopy, including soil moisture, temperature, carbon substrate availability and nutrient regimes through shading, root turnover, and litter inputs (Kamau *et al.*, 2017). Tree stemflow could contribute nutrients to the soil at the base of trees through the washing of dust, insect remains, or bird droppings from the leaves and bark (Rhoades, 1997). Soil properties related to tree canopies, such as quantity and quality of resources as well as changes in soil chemistry beneath trees, play an important role not only in food selection of herbivores, but also in the distribution and composition of soil biota and related soil processes (Belsky and Blumenthal, 1997; Ayuke *et al.*, 2009; Pauli *et al.*, 2011; Mbau *et al.*, 2015).

A zoological garden in a city is an important place for people of all ages to enjoy leisure time (Adams and Azubuike, 2014). The nature of such a site is that there are many ungulates fed by professional attendants (Blaszkiewitz, 2014). Our study area is the ”Safari”, the largest zoo in Israel; it simulates an African Savannah and is populated by more than five hundred ungulates (Meller, 2015). The ungulate activities, including wandering around the zoological garden, could cause soil compaction by trampling and affect plant growth by gnawing (Holtmeier, 2012; Meller, 2015). In order to alleviate the effects of ungulate activities on soil ecological process and grazing on trees, enclosures are fenced with barbed wire and/or steel pipe column around some trees. This trampling management, combined with plant species, could lead to variation of spatial patterns of resource distribution, affecting not only soil abiotic but also soil biotic activity distribution (Bugalho *et al.*, 2011; Pen-Mouratov *et al.*, 2016). In all, the heterogeneity of soil resources around a tree canopy, combined with trampling activities, was found to be a distinct area of favorable or unfavorable conditions, structuring the diversity distribution of soil arthropods (Korboulewsky *et al.*, 2016; Kamau *et al.*, 2017; Liu *et al.*, 2017).

Understanding soil biotic distribution beneath plant canopies under trampling management could enhance in-depth understanding of biodiversity conservation, land management, and rehabilitation measures in Safari Zoological garden ecosystems (de Gouvenain, 1996). Up to now, there were only a few reports regarding the effect of tree species under trampling management on soil free-living nematodes (Pen-Mouratov *et al.*, 2016) and soil microbiology (Meller, 2015). Little is known about the magnitude and pattern of both influences of tree species and grazing management on soil microarthropods in Safari Zoological Center habitats. The objectives of the present study were (1) to probe into the changes of physicochemical characteristics beneath plant canopy of dominant tree species under contrasting trampling and enclosure treatments; (2) to examine the effect of plant canopy on the abundance of soil microarthropods and soil Acari diversity under contrasting grazing treatments at the Safari Zoological Center, Israel; and (3) to assess the determinants of soil physicochemical characteristics on soil microarthropod abundance and Acari diversity. We hypothesized that (1) no grazing under enclosure could increase soil microarthropod and Acari diversity relative to grazing treatments; (2) the diversity of soil microarthropods under the tree canopy will be similar for three dominant tree species.

Materials and methods

Site description

The field experiment was set up at the Safari Zoological Center (E 34.82', N 32.04'; elevation 80 m above sea level) in Ramat-Gan, Israel (Fig. 1). The center was founded in 1974 in the format of an African safari, occupying 250 acres of nature in the heart of a densely populated urban area (http://www.safari.co.il/). The region has a typical Mediterranean climate, characterized by a short, cool, wet winter and a long, hot, dry summer, with a dry-out transition season in spring. The mean annual rainfall is 500 mm, and the mean annual temperature is 14 °C, with a maximum of 30 °C in summer and a minimum of 7 °C in winter (data from the Israel Meteorological Service). The soil types belong to the Grumsols and are dark, dull-colored clay soil according to the local Israeli classification system. The electrical conductivity is 0.73 mmho cm^{-1}, and the texture is sandy clay soil with 46.8%, 12.4%, and 40.7% of clay, silt, and sand, respectively. The $CaCO_3$ content is 88.7%, and according to SSA (Soil Science of America – standards), the calcium carbonate content is 234 m^2 g^{-1} (Dan and Koyumdjiski, 1979).

The Safari Zoological Center has the largest animal collection in the Middle East and is unique in the world because of the large herds of mixed species of African animals that roam the spacious African Park (for details, please go to http://www.safari.co.il/). The African Park and the zoo are home to 1,600 animals of different species, among them 68 species of mammals, 130 species of fowl, and 25 species of reptiles. Especially notable are its breeding herds of African and Asian elephants, the gorilla, chimpanzee, and orangutan families, the hippo herd, and the pride of lions. As in their natural habitats on the continent of Africa, the animals wander freely in large herds.

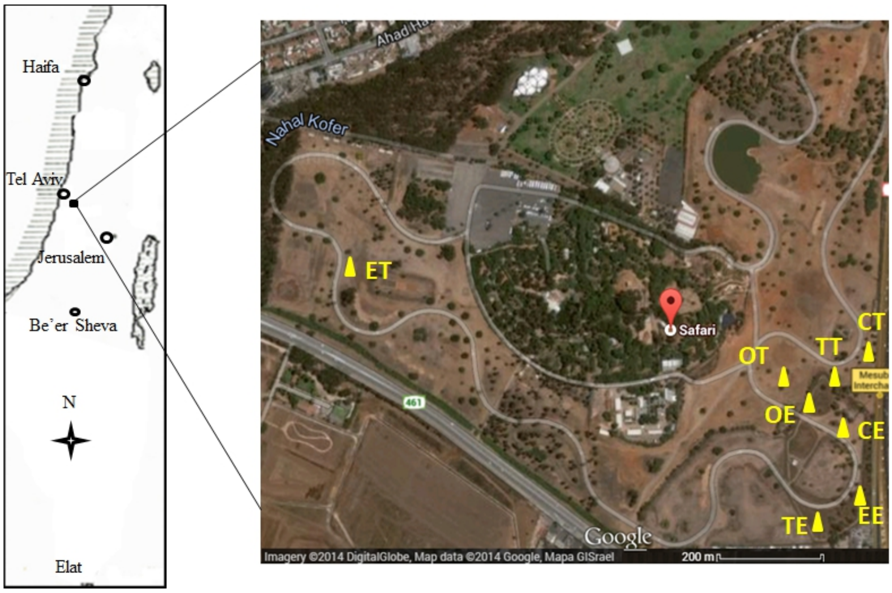


Figure 1 Location of study sites at the Safari Zoological Center, Israel. OE = open places under enclosure, OT = open places under trampling; EE = *E. camaldulensis* canopy habitat under enclosure, ET = *E. camaldulensis* canopy habitat under trampling, TE = *T. aphylla* canopy habitat under enclosure, TT = *T. aphylla* canopy habitat under trampling, CE = *C. sempervirens* canopy habitat under enclosure, CT = *C. sempervirens* canopy habitat under trampling.

Table 1 Sampling design (replication = 4) for sites at the Safari Zoological Center, Israel, December 2013. Herbaceous ground cover: +++ patchy; + a few plants, – no plants. OE = open places under enclosure conditions, OT = open places under trampling conditions; EE = *E. camaldulensis* canopy habitat under enclosure conditions, ET = *E. camaldulensis* canopy habitat under trampling conditions, TE = *T. aphylla* canopy habitat under enclosure conditions, TT = *T. aphylla* canopy habitat under trampling conditions, CE = *C. sempervirens* canopy habitat under enclosure conditions, CT = *C. sempervirens* canopy habitat under trampling conditions.

Habitat	Code	Treatment	Tree height (m)	Tree canopy crown (m^2)	Herbaceous vegetation	Soil physical/biological top layer	Litter layer (cm)
Open spaces	OT	Trampling	-	-	No	No	No
	OE	Enclosure	-	-	+++	Physical top layer	No
E. camaldulensis	ET	Trampling	10-13	6×8	No	No	No
	EE	Enclosure			+	Biological top layer	2-3
T. aphylla	TT	Trampling	14-16	8×8	No	No	No
	TE	Enclosure			+++	Physical top layer	Few
C. sempervirens	CT	Trampling	14-16	7×9	No	No	No
	CE	Enclosure			+	Biological layer	1-2

The *Casuarina* sp., *Cupressus* sp., *Eucalyptus* sp., *Ficus* sp., and *Tamarix* sp. are among the most dominant trees, and are found in the area most frequently visited by the animals in the African Safari section. Trees, such as the *Cupressus sempervirens, Eucalyptus camaldulensis,* and *Tamarix aphylla*, provide shelter for many animals, especially the ungulates that inhabit the study area. Some of these trees are fenced and not available as shelter, which allows for comparative research on the impact of ungulate trampling.

Experimental setup

The paired habitats under contrasting trampling and enclosure managements beneath *E. camaldulensis*, *T. aphylla,* and *C. sempervirens* canopy as well as in adjacent open spaces (as control) were selected as sampling sites (Table 1; Fig. 1). Each paired habitat was represented by four replicate sites, with the total of 32 sampling sites obtained (i.e., 4 replicates × 4 pairs × 2 habitats per pair). The area of each paired sites ranged from 5×5 m^2 to 8×8 m^2. Each trampling habitats harbored more than six animals (*ca*. 1470-2356 kg per animal) per hectare during the period of over 30 years. Within each paired site, five sampling points were set up for soil sample collection.

Within each paired site, a soil composite sample from adjacent five soil cores at five sampling points was collected with an auger (diameter of 15 cm) at a depth of 0-10 cm after removing the upper litter layer. The collected soil samples were stored in sealed bags and kept in a cooler box during sample collection and transportation to the laboratory for soil arthropod extraction and soil physicochemical analysis. In addition, another intact soil core was collected for the determination of soil bulk density. The field study was conducted during the wet winter season in December of 2013, which enhanced biological activity in soil profiles.

Soil microarthropod collection and identification

The soil arthropods were extracted from the soil using 1/4 of the soil composite sample in a modified high-gradient Tullgren funnel (Crossley and Blair, 1991) for 72 h at room temperature, after which the substrate was reweighed to obtain dry weight. The extracted soil arthropods were preserved in 75% ethanol. Mites (Acari) and springtails (Collembola) were counted using a stereomicroscope (SMZ-168-B). The Acari were further identified to suborder and species levels using a compound microscope (BA410, Micro China Group Co. Ltd. Hainan) according to the keys provided in “A Manual of Acarology” (Krantz and Walter, 2009); a detailed list of taxa could be seen in the Supporting Information (Table S1). The springtails were regarded as one group due to the limited knowledge of Collembola identification.

Soil microarthropod abundance was expressed as the number of individuals per 10 grams dry weight of substrate. In addition, the soil Acari diversity indices, including taxonomic richness (number of taxa), Shannon index, Simpson index, and evenness index were calculated based on the abundance of Acari families.

Determination of soil physicochemical properties

The intact soil cores mentioned above were used for soil density (SD, g cm^{-3}) determined as the dry weight per unit volume. The soil composite samples obtained from the field (i.e., the remaining 3/4 of the soil composite sample) were sieved through a 2-mm sieve in order to remove plant parts and other debris. After this process, the following physicochemical parameters were determined: (a) soil moisture (SM, %) – oven-dried at 105 °C for 48 h for determination of soil gravimetric moisture content; (b) organic matter (OM, %) was determined by the $K_2Cr_2O_7$–H_2SO_4 oxidation method of Walkley and Black (Rowell, 1994); (c) soil pH (pH) was measured with a potentiometric glass electrode using a 1:2 soil:water ratio; (d) soil electrical conductivity (SEC, µ cm^{-1}) was determined in a 1:5 (v/v) soil water aqueous extract; and (e) soil water-holding capacity (WHC, %) was determined by the amount of water held between field capacity and wilting point.

Statistical analysis

All statistical analyses were carried out using version 15.0 of SPSS for Windows (SPSS Inc., Chicago, IL). We used the general linear model to test the interactive effects of tree species and trampling management on soil parameters, abundance of soil microarthropods, and the diversity indices of soil Acari community. Multiple comparisons with post-hoc Tukey HSD (honestly significant difference) were used to determine the differences between sites in terms of tree species and trampling management. Pearson correlation analysis was carried out to determine the strength of the relationship between abundance and diversity of microarthropods, and soil properties. Before applying parametric tests, we tested for normality and homogeneity of variances. Statistically significant differences were assigned to $p < 0.05$ for all tests.

Results

Environmental parameters

Soil electrical conductivity was consistently greater under trampling than under enclosure, regardless of habitats beneath tree canopy and in open spaces (Tables 2 and 3). Soil electrical conductivity was found to be markedly greater beneath tree canopy habitats in comparison with open spaces when under trampling, and markedly greater values were found beneath the *C. sempervirens* tree canopy habitats in comparison with the other habitats when under enclosure. In contrast, soil water-holding capacity was lower under trampling than under enclosure, regardless of tree species. The water-holding capacity was greater in the soils beneath *C. sempervirens* and *T. aphylla* canopy in comparison with the *E. camaldulensis* canopy and open spaces when under trampling.

The average soil moisture content in open places was significantly lower under trampling than under enclosure, while the habitats beneath the *E. camaldulensis* canopy followed a contrasting pattern, with greater values under trampling relative to enclosure (Tables 2 and 3). The amount of soil organic matter was lower under trampling than under enclosure in open spaces and beneath *C. sempervirens* canopy, in contrast to the pattern in both *E. camaldulensis* and *T. aphylla* canopy habitats. Soil pH was markedly lower under trampling than under enclosure in the *T. aphylla* canopy habitat, in contrast to the pattern in the *C. sempervirens* canopy habitat. Soil bulk density was markedly greater under trampling than under enclosure in open spaces, where it was found to be a considerably greater relative to tree-canopy habitats.

Table 2 Mean values (± SD) of soil physical and chemical parameters at different treatment sites at the Safari Zoological Center, Israel, December 2013. SM = soil moisture, OM = organic matter, pH = soil pH, SEC = soil electrical conductivity, SD = soil density, WHC = water-holding capacity. OE = open places under enclosure conditions, OT = open places under trampling conditions; EE = *E. camaldulensis* canopy habitat under enclosure conditions, ET = *E. camaldulensis* canopy habitat under trampling conditions, TE = *T. aphylla* canopy habitat under enclosure conditions, TT = *T. aphylla* canopy habitat under trampling conditions, CE = *C. sempervirens* canopy habitat under enclosure conditions, CT = *C. sempervirens* canopy habitat under trampling conditions. Different letters in the same column represent significant difference at $p<0.05$.

	SM (%)	OM (%)	pH	SEC (μ cm^{-1})	SD (g cm^{-3})	WHC (%)
OE	25.6±3.4a	1.1±0.2b	7.5±0.2b	87.6±17.5d	1.1±0.0b	53.6±0.9ab
OT	7.8±1.7c	0.2±0.0e	7.6±0.0b	150.3±51.3c	1.6±0.0a	25.6±1.0c
EE	16.6±1.6b	1.3±0.2b	7.6±0.0b	130.2±9.4cd	1.0±0.1c	52.6±11.1ab
ET	23.2±3.8a	2.0±0.3a	7.6±0.0b	255.3±39.6ab	1.1±0.0bc	31.9±3.5c
TE	21.9±4.4ab	0.4±0.1d	7.9±0.0a	152.0±17.8c	1.0±0.1c	52.1±14.6ab
TT	14.1±5.2b	1.1±0.1b	7.6±0.1b	254.1±48.0ab	1.0±0.1c	43.3±6.2b
CE	26.9±3.4a	0.8±0.3c	7.6±0.1b	209.9±22.5b	1.0±0.1c	56.3±5.8a
CT	22.0±6.0ab	0.5±0.2d	7.8±0.1a	275.9±21.9a	1.0±0.0c	43.0±3.9b

Soil microarthropod abundance

There was a greater abundance of total microarthropods under enclosure than under trampling both in open spaces and beneath the *E. camaldulensis* canopy (Fig. 2; Table 3). The open spaces under enclosure had greater abundance of total microarthropods than all other habitats, regardless of tree species. The average abundance of soil Acari and Collembola followed a distribution pattern similar to that of total abundance (Fig. 2; Table 3). However, there were no significant differences in the average abundance of total microarthropods, soil Acari and Collembola between trampling and enclosure beneath either *T. aphylla* or *C. sempervirens* canopy. There was little effect of tree species, trampling management, or their interaction on the average abundance distribution of 'other soil arthropods' since only a few individuals were found in the soils.

Taxon richness and diversity indices of the soil Acari community

The taxon richness, Shannon index, and evenness index of the soil Acari community were greater under enclosure than under trampling in the open spaces and beneath the tree canopy habitats, with the exception of taxon richness beneath the *C. sempervirens* canopy (Fig. 3; Table 3). The *T. aphylla* canopy habitat under enclosure had the greatest taxon richness and Shannon index of the soil Acari community relative to all other habitats. The *T. aphylla* canopy habitats under trampling had greater evenness index in comparison with all the other habitats. Simpson index was significantly greater under enclosure conditions than under trampling in open spaces and beneath the *C. sempervirens* canopy. However, there were no significant differences in taxon richness between trampling and enclosure under the *C. sempervirens* canopy (Fig. 3). There were no significant differences in taxon richness and Shannon index between the open spaces and beneath *E. camaldulensis* and *T. aphylla* canopy, and no significant differences in the evenness index were found between all the eight habitats when under enclosure. There were no significant differences in the Simpson index between enclosure and trampling treatment beneath both *T. aphylla* and *E. camaldulensis* canopies.

The relationship between community indices and soil factors

The abundance of total microarthropods was negatively correlated with soil pH and electrical conductivity while it was positively correlated with soil water-holding capacity. Abundance of soil Acari was positively correlated with soil moisture and water-holding capacity, and

Table 3 Effects of sampling habitat ("Habitat"), trampling management ("Trampling"), and their interaction on soil parameters, abundance of soil microarthropods, and diversity indices of soil Acari at the Safari Zoological Center, Israel, December 2013 (General linear model, α = 0.05). *p<0.05, **p<0.01, ***p<0.001.

Microarthropods	d_f	F	Soil parameters	d_f	F
Total microarthropod abundance			**Soil moisture**		
Model	8	15.85***	Model	8	109.38***
Trampling	1	39.13***	Trampling	1	18.46***
Habitat	3	1.65	Habitat	3	5.90**
Trampling * Habitat	3	4.89**	Trampling * Habitat	3	12.84***
Collembola abundance			**Organic matter**		
Model	8	4.90**	Model	8	116.32***
Trampling	1	11.18**	Trampling	1	0.05
Habitat	3	2.29	Habitat	3	48.99***
Trampling * Habitat	3	2.56	Trampling * Habitat	3	32.99***
Other arthropod abundance			**Soil pH**		
Model	8	1	Model	8	35120.21***
Trampling	1	1.8	Trampling	1	0.5
Habitat	3	0.73	Habitat	3	4.69*
Trampling * Habitat	3	0.73	Trampling * Habitat	3	13.93***
Soil Acari abundance			**Electrical conductivity**		
Model	8	18.85***	Model	8	156.31***
Trampling	1	43.09***	Trampling	1	61.80***
Habitat	3	0.88	Habitat	3	20.89***
Trampling * Habitat	3	3.60*	Trampling * Habitat	3	1.76
Taxon richness of soil Acari			**Soil density**		
Model	8	16.11***	Model	8	1769.86***
Trampling	1	34.68***	Trampling	1	57.12***
Habitat	3	3.17*	Habitat	3	82.99***
Trampling * Habitat	3	1.23	Trampling * Habitat	3	36.99***
Shannon index of soil Acari			**Water-holding capacity**		
Model	8	18.88***	Model	8	155.49***
Trampling	1	51.07***	Trampling	1	45.98***
Habitat	3	4.03*	Habitat	3	3.22*
Trampling * Habitat	3	0.78	Trampling * Habitat	3	2.6
Simpson index of soil Acari					
Model	8	13.42***			
Trampling	1	0			
Habitat	3	7.47**			
Trampling * Habitat	3	5.22**			
Evenness index of soil Acari					
Model	8	42.11***			
Trampling	1	120.61***			
Habitat	3	3.68*			
Trampling * Habitat	3	1.82			

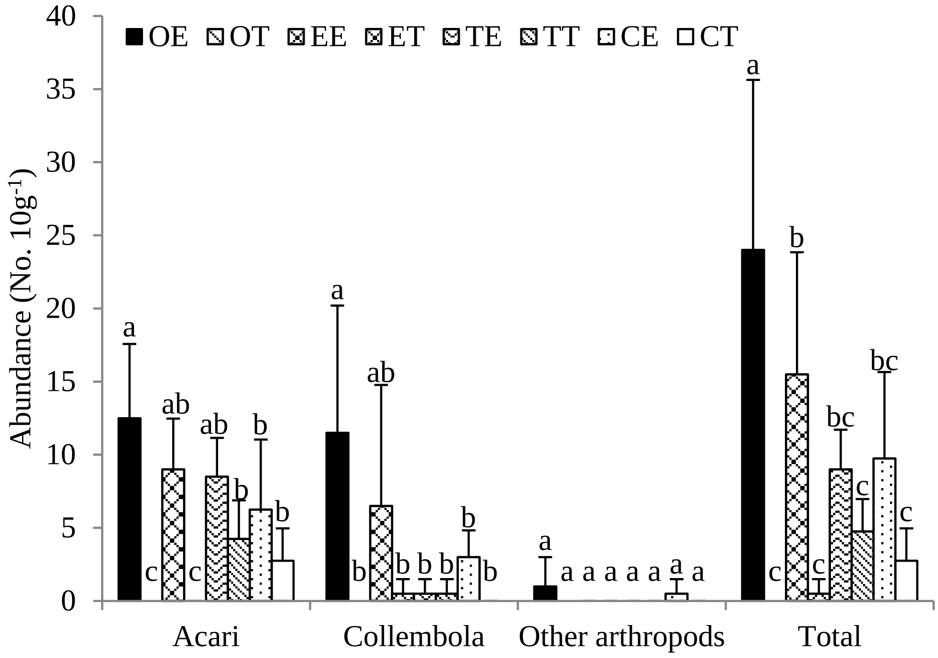


Figure 2 The abundance (individuals per 10 g dry soil substrate; mean ± SD) of soil microarthropod taxa extracted from core samples at different treatment sites at the Safari Zoological Center, Israel, December 2013. OE = open places under enclosure, OT = open places under trampling; EE = *E. camaldulensis* canopy habitat under enclosure, ET = *E. camaldulensis* canopy habitat under trampling, TE = *T. aphylla* canopy habitat under enclosure, TT = *T. aphylla* canopy habitat under trampling, CE = *C. sempervirens* canopy habitat under enclosure, CT = *C. sempervirens* canopy habitat under trampling. Different letters within the same group represent significance at $p<0.05$.

negatively correlated with soil bulk density (Table 4). The Collembola abundance was negatively correlated with soil pH and electrical conductivity. The taxon richness, Shannon index, and evenness index of the soil Acari community were negatively correlated with soil electrical conductivity, while positively correlated with soil water-holding capacity (Table 4). The evenness index was positively correlated with soil moisture while negatively correlated with soil density. The Simpson index was negatively correlated with soil density.

Table 4 Correlation coefficients (Pearson correlation, *r*) between the abundance of microarthropods, diversity indices of soil Acari, and soil parameters at the Safari Zoological Center, Israel, December 2013. SM = soil moisture, OM = organic matter, pH = soil pH, SEC = soil electrical conductivity, SD = soil density, WHC = water-holding capacity. $*p<0.05$, $**p<0.01$, $***p<0.001$.

Index		SM	OM	pH	SEC	SD	WHC
Abundance	Acari	0.349*	0.068	-0.198	-0.506**	-0.299	0.571***
	Collembola	0.153	0.210	-0.486**	-0.506**	-0.107	0.207
	Other soil arthropods	0.202	0.098	-0.294	-0.209	-0.065	0.245
	Total microarthropod	0.292	0.158	-0.403*	-0.574***	-0.233	0.445*
Diversity indices of Acari	Taxon richness	0.253	0.023	-0.098	-0.392*	-0.316	0.561***
	Shannon index	0.285	0.032	-0.120	-0.455**	-0.293	0.585***
	Simpson index	-0.006	-0.175	0.165	0.240	-0.475**	0.336
	Evenness index	0.387*	0.009	-0.203	-0.466**	-0.411*	0.739***

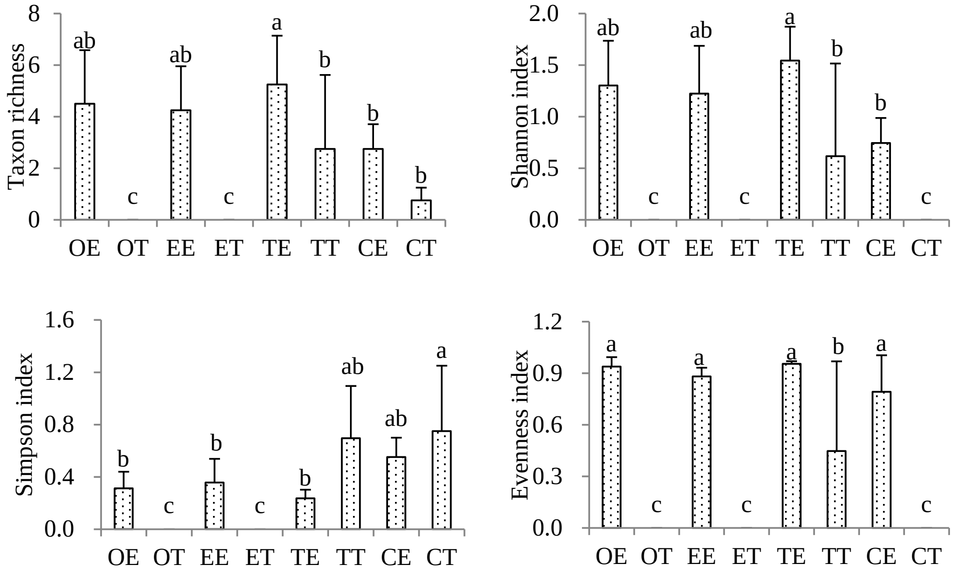


Figure 3 The taxon richness, Shannon index, Simpson index, and Evenness index (mean ± SD) of soil Acari at different treatment sites at the Safari Zoological Center, Israel, December 2013. OE = open places under enclosure, OT = open places under trampling; EE = *E. camaldulensis* canopy habitat under enclosure, ET = *E. camaldulensis* canopy habitat under trampling, TE = *T. aphylla* canopy habitat under enclosure, TT = *T. aphylla* canopy habitat under trampling, CE = *C. sempervirens* canopy habitat under enclosure, CT = *C. sempervirens* canopy habitat under trampling. Different letters represent significance at $p<0.05$.

Discussion

The pattern of soil moisture content, organic matter, and water-holding capacity in the open spaces differed between trampling and enclosure conditions from that of soil electrical conductivity and soil density, which was in accordance with the results of Liu *et al.* (2013) and Su *et al.* (2005). The greater soil electrical conductivity under trampling in comparison with enclosure conditions was attributed to animal excreta with high salinity content mixed with the soils as a result of animal trampling activities (Steffens *et al.*, 2008). In our study, the pattern of soil density differed between trampling and enclosure conditions under three tree canopies in contrast to the pattern at the open spaces, suggesting that the soil habitats under the canopies of trees with developed root systems could mediate the effect of trampling management on soil density (Steffens *et al.*, 2008). The pattern of soil electrical conductivity between trampling and enclosure conditions was similar beneath each canopy habitat to that in the open spaces, in contrast to the results obtained from grassland ecosystems showing no marked effect of trampling management on soil electrical conductivity (Liu *et al.*, 2012).

The lower soil-moisture content observed under enclosure conditions in comparison with trampling conditions beneath the *E. camaldulensis* canopy was in contrast to the finding of Belsky and Blumenthal (1997). This result could be explained by the presence of a litter layer that covered the soil surface and controlled the amount of rainfall entering the belowground soils (Lull, 1959). However, no significant differences in soil moisture content between trampling and enclosure conditions beneath either *T. aphylla* or *C. sempervirens* canopy were attributed to their canopy crown structure, with needle leaves accumulated on the soil surface, as reported by Saetre and Baath (2000). The greater amount of organic matter accumulated beneath the *E. camaldulensis* and *T. aphylla* canopy under trampling could be explained by the presence of many feces as a result of ungulate trampling activities (Su *et al.*, 2005). A similar pattern of soil water-holding capacity between trampling and enclosure beneath each canopy habitat relative to open spaces, confirmed a greater soil water-holding capacity under multi-paddock trampling conditions in comparison with ungrazed soil areas, as shown by Teague *et al.* (2011). However, no significant differences were found in soil pH between trampling and enclosure conditions in the open spaces, thus confirming the findings of Steffens *et al.* (2008) who reported no effect of trampling management on soil pH.

Regarding total microarthropod distribution under trampling and enclosure conditions, a similar pattern was found between the open spaces and the *E. camaldulensis* canopy habitats, suggesting the effect of trampling disturbances on plant-associated animal communities, and thus on soil milieu inhabitants (e.g., invertebrates), as reported by Bardgett *et al.* (2001), Grayston *et al.* (2001), and Parfitta *et al.* (2010). It was reported that trampling activities could negatively affect soil arthropods, and sufficiently heavy trampling pressure was found to produce detrimental effects on arthropod assemblages (Liu *et al.*, 2013; Gonzalez-Megias *et al.*, 2004; Lindsay and Cunningham, 2009). However, the pattern of total microarthropod abundance under trampling and enclosure conditions beneath *C. sempervirens* and *T. aphylla* canopies was different from the *E. camaldulensis* canopy habitats. This finding was attributed to tree-canopy architecture, the accumulation of organic matter, and soil moisture-content distribution within the canopy systems (Winchester and Behan-Pelletier, 2003). Similarly, the abundance distribution of soil Acari and Collembola was greater under enclosure than under trampling in the open spaces and beneath the *E. camaldulensis* canopy, indicating a detrimental effect of trampling on soil microarthropods, including both Acari and Collembola (Parfitta *et al.*, 2010).

Comparably, no significant differences in total soil microarthropod abundance between trampling and enclosure were found in the vicinity of *C. sempervirens* or *T. aphylla* canopy habitats, which could be explained by the fact that almost no litter layer covered the soil surface that affected soil moisture content. Similar distribution of soil moisture content under trampling and enclosure conditions beneath both *T. aphylla* and *C. sempervirens* canopy habitats confirmed this point. It was reported that water availability played implications on soil animal-community composition and functioning (Sylvain *et al.*, 2014). All these findings indicated a homogeneous distribution of soil microarthropods under both trampling and enclosure conditions beneath both such canopy habitats (i.e., *T. aphylla* and *C. sempervirens*). Also, no significant differences in abundance distribution of soil Acari and Collembola between trampling and enclosure beneath *C. sempervirens* and *T. aphylla* habitats canopy, suggested a homogeneous distribution of soil microarthropod abundance regardless of trampling treatment. This finding was similar to the results of Winchester *et al.* (1999) and Lindo and Winchester (2006). They reported that the feeding habits and niche specialization of soil Acari and Collembola due to morphological and physiological modifications resulted in the differences in abundance differences between canopy habitats in terms of tree species under trampling management.

Tree canopies were reported to modify soil moisture, temperature, carbon substrate availability, and nutrient regimes through shading, root turnover, and litter inputs (Kamau *et al.*, 2017), which could, therefore, affect the distribution of soil arthropods as indicated by Pauli *et al.* (2011) and as found in our study. Plant stemflow and changes in soil chemistry beneath tree canopies could potentially affect the occurrence and distribution of soil invertebrates, as indicated by Rhoades (1997), Ayuke *et al.* (2009), Pauli *et al.* (2011), and Mbau *et al.* (2015). The present study could be considered as a first step in probing into the tree canopy and herbivore trampling effects on the spatial distribution of soil microarthropods, since there is little information available on soil arthropods under trampling management in zoological ecosystems. As such, it is necessary to develop an in-depth research that addresses spatial patterns of soil microarthropod communities as affected by tree attributes under contrasting trampling management conditions (Kamau *et al.*, 2017).

There was also a detrimental effect of trampling on the taxon richness, Shannon index, evenness index, and Simpson index of soil Acari communities in open spaces, which was in agreement with Galli *et al.* (2015). This pattern was also true for the Shannon index and evenness index of soil Acari communities in all the habitats beneath the tree canopies, and for the taxon richness and Simpson index of soil Acari communities beneath the *E. camaldulensis* and *T. aphylla* canopy habitats. Pearson analysis indicated a negative correlation of taxon richness, Shannon index, and evenness index with soil electrical conductivity, while it indicated a positive correlation of these three diversity indices with soil water-holding capacity. It was found that there was a positive correlation of the evenness index with soil moisture. The considerably lower values of taxon richness and Shannon diversity index as a result of trampling disturbance thereby created a series of negative feedbacks in the soil degradation processes that continued to degrade the system (Bugalho *et al.*, 2011; Galli *et al.*, 2015). However, no significant differences in the taxon richness and Simpson index of soil Acari communities between trampling and enclosure conditions beneath the *C. sempervirens* canopy were found. This could be explained by the availability of suitable habitats and food resources. Anderson (1977) reported that most of the soil arthropod distribution was on the basis of microhabitat associations and feeding preferences. The decreased habitat heterogeneity beneath the *C. sempervirens* canopy could be a determining factor in shaping the oribatid mite communities of the Mediterranean Safari Zoological Center (Lindo and Winchester, 2006).

Conclusions

It was found that there was an interactive effect of tree canopy habitats and trampling management on soil moisture, organic matter, pH, and soil density. There was a marked effect of a single factor (i.e., tree species or trampling management) on soil electrical conductivity and on soil water-holding capacity. Likewise, there was an interactive effect of tree species and trampling management on the abundance of total soil microarthropods, including soil Acari and Collembola. There was a detrimental effect of trampling on the abundance of soil microarthropods and on the diversity of soil Acari in some cases only. The ecophysiological attributes of the *C. sempervirens* canopy could mediate the negative effect of trampling and benefit soil microarthropods. Therefore, adequate protection and management of the Safari Zoological Garden soils should be carried out to curb the unsustainable trampling activities, thereby allowing the arthropods to occupy their niche in the zoological ecosystem.

Acknowledgements

We thank the anonymous reviewers for their valuable comments. We thank Dr. Haggai Wasserstrom for his help with the identification of soil microarthropod samples and thank Dr. Chen Sherman and Dr. Stanislav Pen-Mouratov for scientific assistance in the field and lab. Special thanks to Ms. Sharon Victor for her useful comments. This paper was financially supported by CSC/BIU Joint Scholarships of The KORT 25 Postdoc Program, National Natural Science Foundation (41661054; 41867005), Ningxia Higher Education Foundation (NGY2018007), Specialized Foundation for Innovative Platform of Fundamental Condition Construction in Ningxia Science and Technology (2018DPC05021), Ningxia Natural Science Foundation (2018AAC02004), and Project of First-Class Discipline Construction (Ecology) for Ningxia Higher Education (NXYLXK2017B06) to Rentao Liu.

References

Adams A., Azubuike A. 2014. Impacts of zoological garden in schools (a case study of zoological garden, Kano State Nigeria). Open J. Ecol., 4: 612-618. doi:10.4236/oje.2014.410051

Anderson J.M. 1977. The organization of soil animal communities. Ecol. Bull., 25: 15-23.

Ayuke F.O., Karanja N.K., Muya E.M., Musombi B.K., Mungatu J., Nyamasyo G.H.N. 2009. Macrofauna diversity and abundance across different land use systems in Embu, Kenya. Trop. Subtrop. Agroecosyst., 11/2: 371-384.

Bardgett R.D., Jones A.C., Jones D.L., Kemmitt S.J., Cook R., Hobbs P.J. 2001. Soil microbial community patterns related to the history and intensity of grazing in sub-montane ecosystems. Soil Biol. Biochem., 33: 1653-1664. doi:10.1016/S0038-0717(01)00086-4

Bardgett R.D., Wardle D.A. 2003. Herbivore-mediated linkages between aboveground and belowground communities. Ecology, 84: 2258-2268. doi:10.1890/02-0274

Barrios E., Sileshi G.W., Shepherd K., Sinclair F. 2012. Agroforestry and soil health: linking trees, soil biota and ecosystem services. In: Wall D.H., Bardgett R.D., Behan-Pelletier V., J.E. H., Jones H., Ritz K., Six J., Strong D.R., van der Putten W.H. (Eds). Soil ecology and ecosystem services. Oxford: Oxford University Press. pp. 315-330. doi:10.1093/acprof:oso/9780199575923.003.0028

Belsky A.J., Blumenthal D.M. 1997. Effects of livestock grazing on stand dynamics and soils in upland forests of the interior West. Conserv. Biol., 11: 315-327. doi:10.1046/j.1523-1739.1997.95405.x

Blaszkiewitz B. 2014. Biodiversity and zoological gardens. Der Zool. Garten, 83: 33-41. doi:10.1016/j.zoolgart.2014.07.003

Blaum N., Seymour C., Rossmanith E., Schwager M., Jeltsch F. 2009. Changes in arthropod diversity along a land use driven gradient of shrub cover in savanna rangelands: identification of suitable indicators. Biodivers. Conserv., 18: 1187-1199. doi:10.1007/s10531-008-9498-x

Bugalho M.N., Lecomte X., Goncalves M., Caldeira M.C., Branco M. 2011. Establishing grazing and grazing-excluded patches increases plant and invertebrate diversity in a Mediterranean oak woodland. Forest Ecol. Manage., 261: 2133-2139. doi:10.1016/j.foreco.2011.03.009

Crossley D.A., Blair J.M. 1991. A high-efficiency, low-technology Tullgren-type extractor for soil microarthropods. Agric. Ecosyst. Environ. 34:187-192. doi:10.1016/0167-8809(91)90104-6

Dan J., Koyumdjiski H. 1979. The classification of Israel soils by the committee on soil classification in Israel. Special publication no. 137. Bet Dagan, Israel: Division of Scientific Publications, The Volcani Center.

de Gouvenain R.C. 1996. Indirect impacts of soil trampling on tree growth and plant succession in the North Cascade Mountains of Washington. Biol. Conserv., 75: 279-287. doi:10.1016/0006-3207(95)00036-4

Denmead L.H., Barker G.M., Standish R.J., Didham R.K. 2015. Experimental evidence that even minor livestock trampling has severe effects on land snail communities in forest remnants. J. Applied. Ecol., 52: 161-170. doi:10.1111/1365-2664.12370

Galli L., Bonacchi A., Capurro M., Conti I., Crovetto F., Ferrari C., Mentqa C., Conti F.D. 2015. Assessment of the impact of trampling on soil Arthropoda in a Mediterranean habitat. Acta Soc. Zool. Bohemicae, 79: 193-198.

Gonzalez-Megias A., Gomez J.M., Sanchez-Pinero F. 2004. Effects of ungulates on epigeal arthropods in Sierra Nevada National Park (southeast Spain). Biodivers. Conserv., 13: 733-752. doi:10.1023/B:BIOC.0000011723.82351.82

Grayston S.J., Griffith G.S., Mawdsley J.L., Campbell C.D., Bardgett R.D. 2001. Accounting for variability in soil microbial communities of temperate upland grassland ecosystems. Soil Biol. Biochem., 33: 533-551. doi:10.1016/S0038-0717(00)00194-2

Holmquist J.G., Schmidt-Gengenbach J., Haultain S.A. 2013. Effects of a long-term disturbance on arthropods and vegetation in subalpine wetlands: Manifestations of pack stock grazing in early versus mid-season. PLOS ONE, 8: ARTN e54109. doi:10.1371/journal.pone.0054109

Holtmeier F.K. 2012. Impact of wild herbivorous mammals and birds on the altitudinal and northern treeline ecotones. Landscape Online, 30: 1-28. doi:10.3097/LO.201230

Kamau S., Barrios E., Karanja N.K., Ayuke F.O., Lehmann J. 2017. Soil macrofauna abundance under dominant tree species increases along a soil degradation gradient. Soil Biol. Biochem., 112: 35-46. doi:10.1016/j.soilbio.2017.04.016

Kampichler C., Bruckner A. 2009. The role of microarthropods in terrestrial decomposition: a meta-analysis of 40 years of litterbag studies. Biol. Rev., 84: 375-389. doi:10.1111/j.1469-185X.2009.00078.x

Korboulewsky N., Perez G., Chauvat M. 2016. How tree diversity affects soil fauna diversity: A review. Soil Biol. Biochem., 94: 94-106. doi:10.1016/j.soilbio.2015.11.024

Krantz G.W., Walter D.E. 2009. A manual of acarology, 3rd edition. Lubbock, TX: Texas Tech University Press.

Lindo Z., Winchester N.N. 2006. A comparison of microarthropod assemblages with emphasis on oribatid mites in canopy suspended soils and forest floors associated with ancient western redcedar trees. Pedobiologia, 50: 31-41. doi:10.1016/j.pedobi.2005.09.002

Lindsay E.A., Cunningham S.A. 2009. Livestock grazing exclusion and microhabitat variation affect invertebrates and litter decomposition rates in woodland remnants. Forest Ecol. Manage. 258: 178-187. doi:10.1016/j.foreco.2009.04.005

Liu J.L., Li F.R., Liu C.A., Liu Q.J. 2012. Influences of shrub vegetation on distribution and diversity of a ground beetle community in a Gobi desert ecosystem. Biodivers. Conserv., 21: 2601-2619. doi:10.1007/s10531-012-0320-4

Liu R.T., Zhao H.L., Zhao X.Y., Zhu F. 2013. Effects of cultivation and grazing exclusion on the soil macro-faunal community of semiarid sandy grasslands in northern China. Arid Land Res. Manage. 27: 377-393. doi:10.1080/15324982.2013.787470

Liu S.J., Yang X.D., Ives A.R., Feng Z.L., Sha L.Q. 2017. Effects of seasonal and perennial grazing on soil fauna community and microbial biomass carbon in the subalpine meadows of Yunnan, Southwest China. Pedosphere, 27: 371-379. doi:10.1016/S1002-0160(17)60325-4

Lull H.W. 1959. Soil compaction on forests and rangelands. Miscellaneous publication. Washington, D.C.: U.S. Department of Agriculture.

Mbau S.K., Karanja N., Ayuke F. 2015. Short-term influence of compost application on maize yield, soil macrofauna diversity and abundance in nutrient deficient soils of Kakamega County, Kenya. Plant Soil, 387: 379-394. doi:10.1007/s11104-014-2305-4

Meller R. 2015. Ungulates and trees effects on a soil microbial community and its functional diversity [MSc Thesis]. Ramat-Gan: Bar-Ilan University.

Parfitta R.L., Yeates G.W., Ross D.J., Schon N.L., Mackay A.D., Wardle D.A. 2010. Effect of fertilizer, herbicide and grazing management of pastures on plant and soil communities. Appl. Soil Ecol., 45: 175-186. doi:10.1016/j.apsoil.2010.03.010

Pauli N., Barrios E., Conacher A.J., Oberthur T. 2011. Soil macrofauna in agricultural landscapes dominated by the Quesungual Slash-and-Mulch Agroforestry System, western Honduras. Appl. Soil Ecol., 47: 119-132. doi:10.1016/j.apsoil.2010.11.005

Pen-Mouratov S., Meller R., Liu R.T., Steinberger Y. 2016. Animal trampling effects on soil free-living nematodes in a man-made safari-zoo habitat. In. The 32nd European Society of Nematologists (ESN) Symposium 28 August-1 September 2016; Braga, Portugal.

Persson T. 1989. Role of soil animals in C and N mineralization. Plant Soil, 115: 241-245. doi:10.1007/BF02202592

Powers S.E., Nambi I.M., Curry G.W. 1998. Non-aqueous phase liquid dissolution in heterogeneous systems: Mechanisms and a local equilibrium modeling approach. Water Resour. Res., 34: 3293-3302. doi:10.1029/98WR02471

Rhoades C. 1997. Single-tree influences on soil properties in agroforestry: lessons from natural forest and savanna ecosystems. Agroforest. Syst., 35: 71-94. doi:10.1007/BF02345330

Rowell D.L. 1994. Soil science: Methods and applications. London: Longman Group UK Ltd.

Saetre P., Baath E. 2000. Spatial variation and patterns of soil microbial community structure in a mixed spruce-birch stand. Soil Biol. Biochem., 32: 909-917. doi:10.1016/S0038-0717(99)00215-1

Seeber J., Langel R., Meyer E., Traugott M. 2009. Dwarf shrub litter as a food source for macro-decomposers in alpine pastureland. Appl. Soil Ecol., 41: 178-184. doi:10.1016/j.apsoil.2008.10.006

Seeber J., Seeber G.U.H., Langel R., Scheu S., Meyer E. 2008. The effect of macro-invertebrates and plant litter of different quality on the release of N from litter to plant on alpine pastureland. Biol. Fertil. Soils, 44: 783-790. doi:10.1007/s00374-008-0282-6

Shinoda Y., Akasaka M. 2017. Incorporating habitats of plants and ungulates contributes to prioritize targets for conserving regional plant diversity. Ecosphere, 8: e01713. doi:10.1002/ecs2.1713

Steffens M., Kolbl A., Totsche K.U., Kogel-Knabner I. 2008. Grazing effects on soil chemical and physical properties in a semiarid steppe of Inner Mongolia (PR China). Geoderma, 143: 63-72. doi:10.1016/j.geoderma.2007.09.004

Su Y.Z., Li Y.L., Cui H.Y., Zhao W.Z. 2005. Influences of continuous grazing and livestock exclusion on soil properties in a degraded sandy grassland, Inner Mongolia, northern China. Catena, 59: 267-278. doi:10.1016/j.catena.2004.09.001

Sylvain Z.A., Wall D.H., Cherwin K.L., Peters D.P.C., Reichmann L.G., Sala O.E. 2014. Soil animal responses to moisture availability are largely scale, not ecosystem dependent: insight from a cross-site study. Global Change Biol., 20: 2631-2643. doi:10.1111/gcb.12522

Teague W.R., Dowhower S.L., Baker S.A., Haile N., DeLaune P.B., Conover D.M. 2011. Grazing management impacts on vegetation, soil biota and soil chemical, physical and hydrological properties in tall grass prairie. Agric. Ecosyst. Environ., 141: 310-322. doi:10.1016/j.agee.2011.03.009

Winchester N.N., Behan-Pelletier V., Ring R.A. 1999. Arboreal specificity, diversity and abundance of canopy-dwelling oribatid mites (Acari : Oribatida). Pedobiologia, 43: 391-400.

Winchester N.N., Behan-Pelletier V.M. 2003. Fauna of suspended soils in an Ongokea gore tree in Gabon. In: Basset Y., Novotny V., Miller S.E., *et al.*, (Eds). Arthropods of tropical forests: Spatio-temporal dynamics and resource use in the canopy. Cambridge: Cambridge University Press. pp. 102-109.