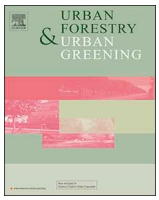
Urban Forestry & Urban Greening 53 (2020) 126676

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

journal homepage: www.elsevier.com/locate/ufug



Original article

Soil microarthropod communities of urban green spaces in Baltimore, Maryland, USA

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ARTICLE INFO

Handling Editor: Wendy Chen

Keywords:
Anthropogenic
Land use type
Arthropod
Remnant forest
Turf

ABSTRACT

Urbanization fundamentally alters soil physiochemical properties, but little is known on how this human effect alters soil biota. Microarthropods are important bioindicators due to their sedentary life form and sensitivity to environmental changes. Taxonomic richness, abundance, diversity, distribution of microarthropod communities were investigated in three urban land use types, remnant forests, low maintenance grass, highly disturbed open spaces, and were compared to deciduous forest stands outside the city, that served as reference. In general, habitats with more disturbed soil decreased the diversity of mites and springtails compared to the native vegetation sites. The leaf litter layer both in reference and remnant forests benefited the microarthropods through providing food resources and favorable habitats. Among soil properties soil organic carbon and bulk density had significant effects on mites (Acarina), while for springtails (Collembola), soil pH and soil moisture were significant factors. Soil temperature was the common significant constrained variable for both mites and springtails. Our study highlighted the effects of anthropogenic activities, especially that of soil disturbance in cities and the importance of retaining natural vegetation patches in urban green spaces.

1. Introduction

One of the most distinguishing features of the urban green space is its spatial heterogeneity driven by a multitude of biophysical factors and human actions. Urban land conversion destroys existing habitats and creates new ones, and subsequent management practices further diversify abiotic and biotic conditions (Leonard et al., 2018). Soil, often called “the most complex biomaterial on Earth” (Young and Crawford, 2004) exhibits high degree of heterogeneity even in relatively undisturbed settings. Due to the multifaceted human influences from city to local scale (Ossola and Livesley, 2016), the urban soil mosaic is probably the most diverse three-dimensional entity, ranging from relatively undisturbed conditions in remnant vegetation patches to completely engineered soils (Pouyat et al., 2017).

The drastic transformation of soil conditions during urban land conversion profoundly alters soil biota. Grading, mixing, filling, and soil transport are major disturbances directly affecting the belowground ecosystem. Altered hydrology, pollution, landscaping and management practices, and introduction of non-native species lead to further shift in soil community composition and function. In urban settings a multitude of direct and indirect anthropogenic effects further alters urban surface soils including physical disturbance (Pitt and Lantrip, 2000; Trammell et al., 2011), lawn maintenance (Tenenbaum et al., 2006; Zhu et al., 2006), compaction through trampling (Godefroid and Koedam, 2004), atmospheric deposition (Lovett et al., 2000; Rao et al., 2013), elevated soil temperature (Savva et al., 2010), and altered resources for decomposers (Szlavecz et al., 2018).

The highly altered urban soils provide the same ecosystem services as agricultural or naturally developing soils, although some of these services may conflict with each other (Setälä et al., 2014; Morel et al., 2015). The ability of the soil ecosystem to decompose organic matter, release nutrients, sequester carbon, enhance infiltration rates and other functions depends on the diversity and activity of soil biota from microorganisms to macrofauna. Knowledge of taxonomic and functional diversity enhances our ability to sustainably manage our soils yet huge knowledge gap exists in our understanding of the relationship between soil biodiversity and major functions. Large scale, coordinated soil biodiversity and ecosystem service assessments have been conducted in Europe (Krogh, 2010; Turbé et al., 2010; Pulleman et al., 2012), however, these efforts mostly focus on natural and agricultural systems, and

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https://doi.org/10.1016/j.ufug.2020.126676
Received 30 August 2019; Received in revised form 30 March 2020; Accepted 30 March 2020
Available online 05 May 2020
1618-8667/ Published by Elsevier GmbH.

generally avoid urban green spaces (but see Nagy et al., 2018). Even less studied is soil fauna diversity in North American cities (e.g. McIntyre et al., 2001; Grewal et al., 2011; Gardiner et al., 2013) especially microarthropods (but see Byrne and Bruns, 2004).

Soil microarthropod communities, dominated by mites (Acarina) and springtails (Collembola), are critical components of terrestrial ecosystems (Sauvadet et al., 2017). As a group, microarthropods exhibit diverse feeding habits from herbivores to predators and parasites. Detritivores and microbivores contribute to the decomposition of soil organic matter and nutrient cycling by feeding directly on decaying material and grazing on soil microbial organisms, respectively (Seastedt, 1984). Predatory microarthropods regulate populations of other consumers, and microarthropods themselves are food for other invertebrates. As such, microarthropods are embedded in the complex soil food web at several trophic levels and significantly influence ecosystem functions and soil health (Coleman et al., 2017; Lavelle et al., 2006). Due to their sedentary life, microarthropods are more sensitive to microenvironmental changes and thus can serve as bioindicators (van Straalen, 1998; Santorufo et al., 2012). There is an extensive literature examining the taxonomic richness and abundance of soil microarthropods in forests (e.g. Lindberg and Persson, 2004; Lindo and Visser, 2004; Lindo and Winchester, 2006; Eisenhauer et al., 2007), grasslands (Cole et al., 2005; Clapperton et al., 2002), and agricultural ecosystems (Joy and Chakravorty, 1991; Schrader and Lingnau, 1997; Cortet et al., 2002). However, the composition, distribution, and seasonal dynamics of microarthropod communities in urban green spaces under different land use scenarios have received limited attention (but see Rumble and Gange, 2013; Byrne and Bruns, 2004; Eitminaviciute, 2006a, 2006b).

Due to a combination of natural soil forming factors and anthropogenic effects that influence local conditions, the urban soil mosaic is diverse (Ossola and Livesley, 2016; Shaw and Isleib, 2017). In addition to the wide range of soil conditions, other environmental variables, plant cover, age and history of cities, and other factors also vary widely, making global scale comparisons difficult. To overcome some of these challenges and to facilitate participation of citizen scientists in urban soil research, the Global Soil Ecology and Education Network (GLUSEEN) has been established (Pouyat et al., 2017). The project has established protocols for site selection, soil and soil biota sampling and assessing soil processes. Additionally, based upon the degree of disturbance and management intensities, a soil habitat matrix that can be applied in a range of climatic conditions and urban ecosystems, has been proposed (Pouyat et al., 2017). These urban soil habitat types range from relatively low anthropogenic influences with naturally developing soil profiles, such as in remnant forests, to entirely disturbed soil profiles, such as in some vacant lots. Since the magnitude of anthropogenic disturbance is closely related to landscape changes aboveground, the soil habitat types and land use types are often highly correlated. In Baltimore City, tree canopy comprises 24 % and grass/shrub comprises 19 % of total land cover (O'Neil-Dunne, 2009). The diverse land uses and soil properties represent a variety of habitat conditions for soil biota, therefore differences in species composition and abundances are expected in the urban soil mosaic.

To gain a deeper insight into the combined effects of natural and anthropogenic soil forming factors on soil fauna, we assessed microarthropod richness, abundance, and community structure in four land use types in Baltimore, Maryland, USA. We hypothesized that: 1) the abundance and diversity of microarthropods would be highest at the least disturbed, reference forests, followed by increasing degree of disturbance and management; and 2) different microarthropod taxa would respond differently to soil environmental factors associated with disturbance. Additionally, we expected seasonal differences in community composition and abundance.

2. Material and method

2.1. Field site

The assessment of microarthropod fauna was conducted in urban and suburban areas of the Greater Baltimore Metropolitan Region (39° 17′ 57″ N, 76° 36′ 33″ W). Baltimore lies along the Chesapeake Bay, which is characterized by a warm humid climate with mean annual air temperature of 14.5 °C and 12.8 °C in the city and in the surrounding area, respectively, and a mean annual precipitation of 1075 mm. According to GLUSEEN protocol, four soil habitat/land use types (land use hereafter), reference (REF), remnant (REM), turf (TURF) and ruderal (RUD) have been chosen. The four types are described in more detail in Pouyat et al. (2015, 2017) and the GLUSEEN website (www.gluseen.org). Briefly, REM is a low disturbance /low maintenance site in the city that reflects the natural biome and has naturally developing soil profile, but may exhibit some urban influences, such as increased nitrogen deposition or higher proportion of non-native plants. In TURF sites soil is more disturbed, but maintenance is at medium level, meaning that the grass is mowed but not amended with fertilizers or pesticides. RUD sites are highly disturbed with no soil structure or profiles and herbaceous plant cover with variable grass-forbs mixture. REF sites have similar vegetation to REM, but are outside of the city with no urban influence.

All sampling sites were in the Piedmont physiographic province with mafic-ultramafic rock types as parent material and soils in the Ultisol suborder. The natural vegetation is deciduous forest with white oak (*Quercus alba*), red oak (*Q. rubra*) and tulip poplar (*Liriodendron tulipifera*) as dominant trees. We have sampled at the same sites selected by GLUSEEN for soil, microbial community and earthworm assessment (Pouyat et al., 2015; Epp Schmidt et al., 2017). Each of the four land use/soil habitat types was replicated five times. In the present study one of the REF sites had to be abandoned due to major disturbances in the past few years reducing the total number of sites to 19.

2.2. Collection of microarthropods

In spring (early May) and summer (early August) of 2018, soil samples for microarthropods extraction and analyses were collected from 19 sites each season. A sampling grid with dimensions of 1.5 × 2.0 m, consisting of 4 rows × 5 columns, was established at each study site (Pouyat et al., 2015). At each site, 10 soil cores were systematically collected along the second and third rows with 0.5 m intervals. Soil cores were sampled to a depth of 5 cm using a 1.9-cm-diameter corer. To fully reflect the soil community characteristics of land use type, when present, the thatch layer in open sites (TURF and RUD) or O horizon in forested sites (REM and REF) was included in the sample. The focus of the study is variability among land use types, therefore the 10 soil cores per site were pooled and treated as one sample. In the forested REF and REM sites three leaf litter samples from an area of 100cm^2 each were also collected. A total of 46 samples (19 composite soil samples and 27 litter samples) were collected from the field in each season. Samples were placed into a cooler, transported to the lab, and processed within 48 h. The samples were placed into modified Tullgren funnels to extract microarthropods. During extraction, all funnels were covered with 1 mm mesh to prevent the escape of arthropods. We followed the protocol of Bano and Roy (2016), but also conducted our own preliminary testing, which showed that most individuals were extracted within two days at 35 °C. Specimens were preserved in 80 % ethanol. Adult individuals were counted and identified to family level (Dindal, 1990), and larvae of insect were identified to order level (Yin, 1998). Immature mites were counted, but could not be identified to family level, thus they were not included in the community analysis. Soil

samples remaining from the extraction were oven dried at 105 °C for 24 h to calculate bulk density.

2.3. Soil properties

Basic physical and chemical soil properties were used to partially explain microarthropod distribution and abundance. Properties, such as organic carbon, total nitrogen, and pH, have been analyzed and reported previously (Pouyat et al., 2015) and refer to 0 − 10 cm depth of the mineral soil. Because REF sites had a 2 − 3 cm O layer, which is major habitat for microarthropods, the O layer was included in the bulk density calculations presented below. Additionally, soil temperature at 5 and 10 cm depths, soil moisture (ML-3 Thetaprobe, Delta-T Devices), and air temperature were recorded at each sampling site both in spring and summer.

2.4. Calculation and statistical analysis

Taxonomic group number (S), density (D), Shannon index (H), and Pielou index (J) were used to measure the richness, abundance, diversity, and evenness of microarthropods, respectively. The Acarina/Collembola ratio was calculated using absolute density (ind./m^2) of mites and springtails.

$$P_i = d_i/D \quad (1)$$

$$H = -\sum P_i lnP_i \quad (2)$$

$$J = H/\ln(S) \quad (3)$$

Where P_i is the relative density of family i of soil microarthropods for each land use type; d_i is the density of family i, which equals the density in litter layer plus the density in soil sample for each land use type; D is the density of whole soil microarthropod community for each land use type; S is the taxonomic group number for each land use type.

All statistical analyses were conducted in R v3.5.0 (R core Team, 2018). Packages used were *MASS* (Ripley et al., 2019) for the generalized linear models (GLM) with the negative binomial distribution because of the overdispersion of the data (Convey et al., 2002); *multcomp* (Hothorn et al., 2019) for multiple comparisons after generalized linear models analyses; *vegan* (Oksanen et al., 2016) for multivariate dispersion and ordination analyses; and *indicspecies* (Caceres and Jansen, 2016) for indicator species analyses. Generalized linear models were used for the analyses with the negative binomial distribution for the richness and abundance data, gaussian distribution for the diversity indices, and Poisson distribution for the Acarina/Collembola ratio. Student's *t*-test was used to examine the seasonal effects on richness, abundance, Acarina/Collembola ratio, and diversity indices of soil microarthropods. Soil microarthropod community structure was analyzed based on density data. To visualize the differences in communities among four land use types as well as two seasons in one year, dataset for each land use type were graphed using non-metric multidimensional scaling (NMDS) with Bray-Curtis distance. To investigate the effects of land use type on microarthropod community for each season independently, PERMANOVA (Anderson, 2001) was used with 1000 permutations. Multivariate homogeneity of group dispersions was tested with Bray-Curtis distance to evaluate the dissimilarities of land use types in each season (Anderson et al., 2011). Relationship between microarthropod community and environmental factors was analyzed using canonical correspondence analysis (CCA) with soil properties including pH value, soil temperature, soil moisture, air temperature, total N, organic C, and bulk density as constrained variables based on two seasons (Appendix A). The following permutation tests with 999 permutations were used to test the significances of the overall models, the constrained axes, and soil properties. Indicator species analyses (ISA) based on the densities of microarthropods for different land use types were conducted for each season with 999 permutations to determine the possible association between microarthropods and land use types. The algorithm considers both frequency and abundance of microarthropods and provides a statistic and the respective P value for each possible indicator taxon (Queiroz et al., 2014).

3. Results

3.1. Abundance of soil microarthropod community

Abundances of whole microarthropod, mite, and springtail communities were significantly different among four land use types in both spring and summer (Table1, Fig.1). The abundance of microarthropods in native habitat type (REF) was the highest regardless of soil fauna group and season, followed by REM. In most cases, the abundances of microarthropods in open sites were significantly lower than in forested sites (Fig.1). Within the same land use type, mean densities of all microarthropods, mites, and springtails tended to be higher in summer than in spring, but the differences were not significant (Appendix B). In spring, ratio of mites/springtails was significantly higher only in TURF compared to RUD and REM (Appendix B).

The relative density of Oribatida was highest in REF, and the relative density of Mesostigmata was highest in REM regardless of the seasons. In addition, the relative densities of both Oribatida and Prostigmata were higher than Mesostigmata, and the density of Oribatida and Prostigmata accounted for 84.4 %–95.7 % of the whole mite community across the four land use types (Appendix C).

3.2. Diversity and community structure

Altogether, 78 microarthropod taxa were extracted with modified Tullgren funnels from a total of 92 samples, including mites, springtails, spiders, centipedes, millipedes, isopods, and some insects such as beetles and ants. The most abundant taxa were the mites with 45 families and springtails with 9 families (Appendix D), accounting for 57.7 % and 11.5 % of the total groups, respectively. The total number of mite and springtail families in REF was the highest (51), followed by REM (49), then RUD (36) and TURF (34), based on data for two seasons (Appendix D). In general, the richness of microarthropod communities in forested sites was significantly higher than in open sites regardless of seasons, with one exception of springtail which was not significantly different among four land use types (Table1, Fig.2).

Table 1
Results of testing for the effects of land use type on microarthropod density and diversity. χ^2 statistics for the likelihood ratio test and P values are reported.

Season		All microarthropod		Acarina		Collembola	
		Density	Richness	Density	Richness	Density	Richness
Spring	χ^2	11.201	19.911	8.581	14.445	14.438	3.832
	P	**0.011**	**< 0.001**	**0.035**	**0.002**	**0.002**	0.280
Summer	χ^2	28.585	48.110	21.642	36.261	27.207	7.473
	P	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	0.058

Note: degrees of freedom (df) = 15 in all cases. Significant P values are shown in bold ($\alpha = 0.05$).

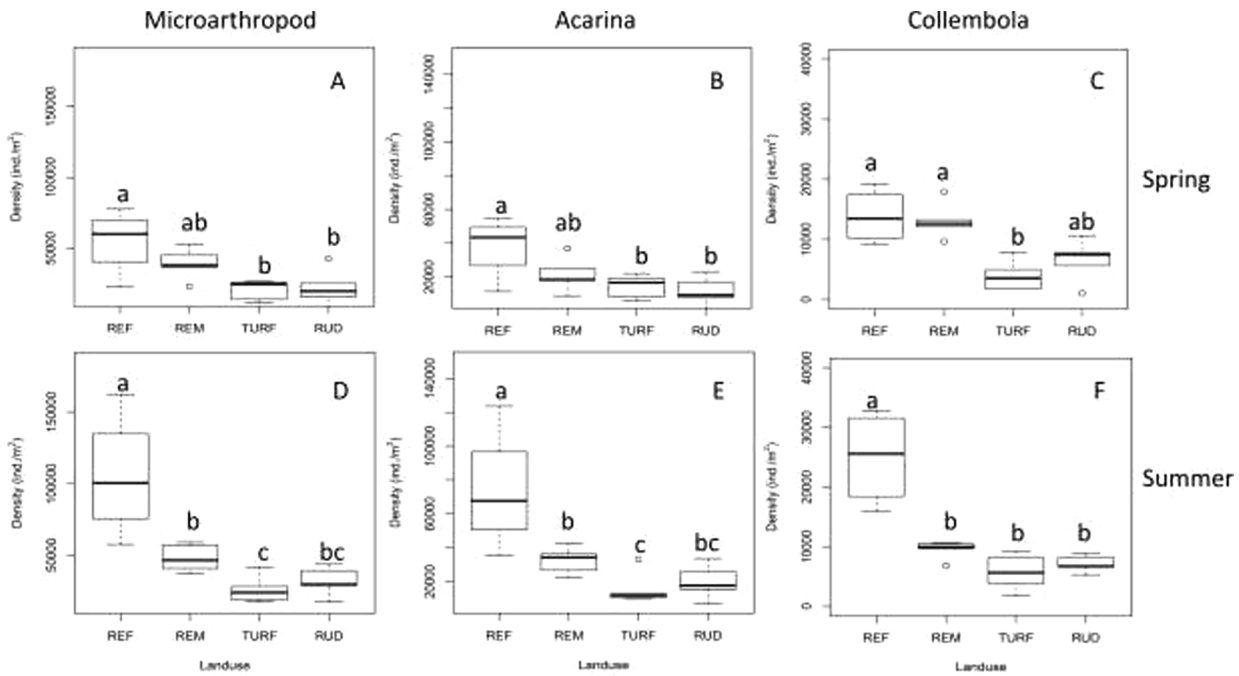

Fig. 1. Abundances of microarthropod communities in four land use types in spring (A-C) and summer (D-F). Note the different scales on the panels. Each box plot displays the median (bold lines), the interquartile range (box), minimum and maximum values (whiskers), and outliers (circles). Different lowercase letters indicate significant differences among land use types ($P < 0.05$). REF: reference, REM: remnant, TURF: grass, lawn, RUD: ruderal.

Shannon and Pielou indices produced slightly different results. For mites, the diversity was significantly higher in forested than in open sites especially in summer (Appendix E). Springtail diversity was not significantly different. The evenness of microarthropods in open sites were usually significantly higher ($P < 0.05$) than in forested sites, except for springtails in summer which was not significantly different.

The densities of different microarthropod groups in two seasons exhibited NMDS separation among land use types (Fig.3). There was separation between forested and open sites, with no overlap between REF and REM and slight overlap between TURF and RUD (Fig.3). In general, the multivariate dispersions were not significantly different among land use types ($P > 0.05$) regardless of fauna community type

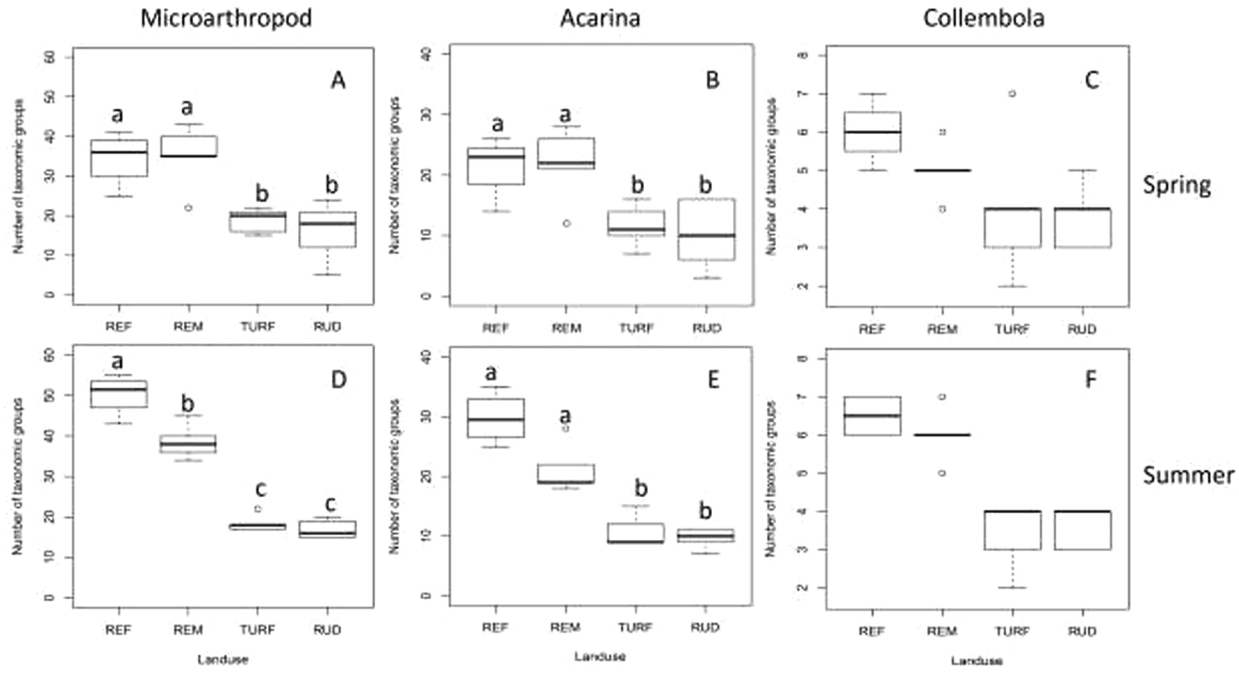

Fig. 2. Richness of microarthropod communities in four land use types in spring (A—C) and summer (D—F). Taxonomic group number is the number of families except insect larvae, which are at the order level. Note the different scales on the panels. Each box plot displays the median (bold lines), the interquartile range (box), minimum and maximum values (whiskers), and outliers (circles). Different lowercase letters indicate significant differences among land use types ($P < 0.05$). REF: reference, REM: remnant, TURF: grass, lawn, RUD: ruderal.

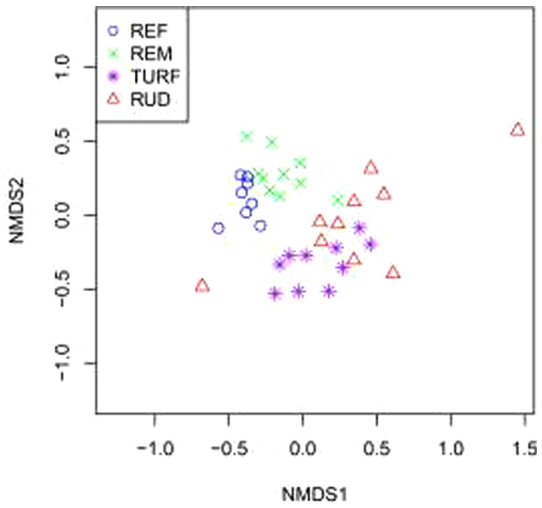

Fig. 3. NMDS based on Bray-Curtis distances of density data visualizing the distributions of four land use types. Density data for spring and summer are combined. REF: reference, REM: remnant, TURF: turf. RUD: ruderal.

and season (Table2). The results of PERMANOVA, which supported the NMDS results, indicated that the land use type had significant effects on soil microarthropod community structure ($P < 0.05$, Table2).

3.3. Environmental factors and microarthropod communities

To evaluate the relationship between environmental factors and soil microarthropods, canonical correspondence analysis (CCA) was conducted. The constrained axes explained 23.23 % and 19.78 % of the variance from mite and springtail models, respectively (Appendix F). Both overall models were significant ($P < 0.05$). For mites, soil temperature, soil organic carbon, bulk density, and air temperature had significant effects on communities ($P < 0.05$). In contrast, soil pH, soil moisture, and soil temperature had significant effects on springtail communities ($P < 0.05$, Appendix F). CCA plot for mites (Fig. 4A) indicated that communities separated according to land use types. REF and REM corresponded with soil organic carbon and air temperature, while TURF and RUD corresponded with bulk density and soil temperature. For springtails, the separation was less clear, and two RUD sites may have affected dispersion. Springtail communities correlated with soil temperature and pH value (Fig.4B).

3.4. Indicator species

Indicator species analysis (ISA) revealed a total of 11 indicator families in spring, 3 of which were for REM and eight for REF. In summer, 22 indicator families were found; 3 for REM 19 for REF. Seven indicator families were in common in both seasons. TURF and RUD land use types had no indicator taxa likely due to the lower richness and abundance of microarthropods (Appendix G).

4. Discussion

The urban soil mosaic is diverse, representing a wide range of conditions from relatively undisturbed soil profiles to structure-less fill. Vegetation cover also varies from remnant patches of natural biome to entirely landscaped and managed green spaces, to self-assembled plant communities in abandoned land. Time since establishment and last disturbance adds another dimension to the diversity of habitat patches

Table 2
P values of multivariate dispersion and PERMANOVA for land use type.

Season	All microarthropod		Acarina		Collembola	
	Multivariate dispersion	PERMANOVA	Multivariate dispersion	PERMANOVA	Multivariate dispersion	PERMANOVA
Spring	0.302	**0.001**	0.274	**0.003**	0.080	**0.001**
Summer	**0.030**	**0.001**	0.120	**0.001**	0.162	**0.002**

Note: Significant *P* values are shown in bold ($\alpha = 0.05$).

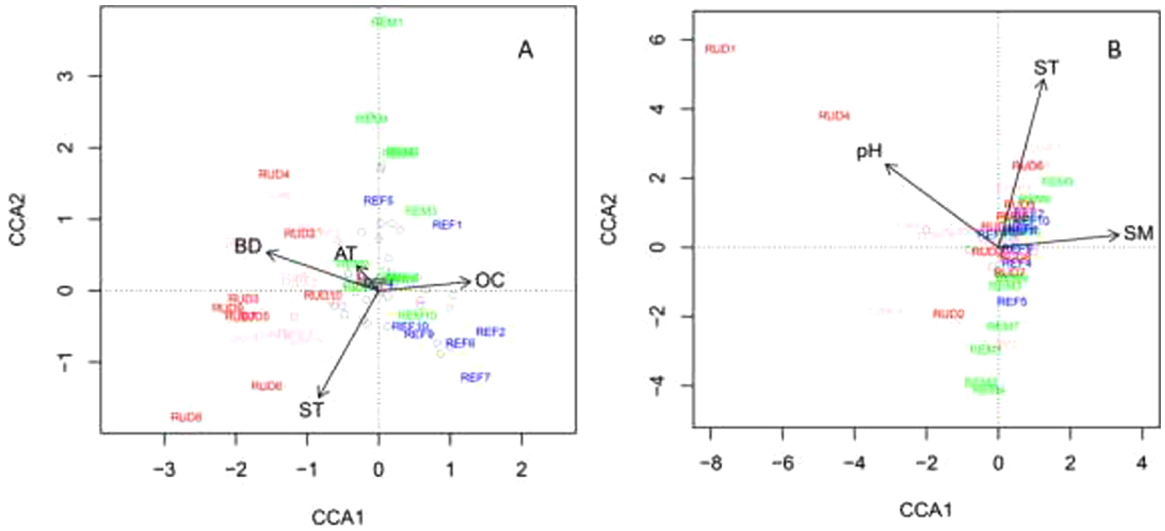

Fig. 4. CCA (canonical correspondence analysis) plot of mite (A) and springtail (B) community structures by soil properties. Different colors represent different land use types (blue: REF; green: REM; pink: TURF; red: RUD). Grey circles show the locations of different microarthropod families. AT: air temperature; ST: soil temperature; SM: soil moisture; pH: pH value; BD: bulk density; OC: soil organic carbon (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

(Setälä et al., 2017).

The habitat types in this study represented a distinct subset of human influences and the microarthropod community characteristics clearly reflected these differences. In general, both abundance (Fig.1A, D) and taxonomic richness (Fig.2 A, D) were highest in REF forests. Compared to other forest ecosystems, the average density of soil microarthropods in REF with natural biome was close to that in the temperate deciduous forest located in the similar latitude zone (Cakir and Makineci, 2015), which supported that the vegetation cover acts as a driver of soil biota through the quality and quantity of litter (Henneron et al., 2016; McCary et al., 2016). Density of all microarthropods in our urban green spaces was less than reported in two cities in Italy (Rota et al., 2015). Abundance for Collembola and Acarina in our study fall within the ranges reported elsewhere, however densities vary by an order of magnitude in both natural (Cole et al., 2005; Chernov et al., 2010; Joimel et al., 2017) and urban (Fountain and Hopkin, 2004; Kuznetsova, 2006; Fiera, 2009; Joimel et al., 2017) land uses. Similarly, in agricultural soils, abundances of soil microarthropods can be lower or higher than that of urban habitats in our study, depending on the type and intensity of farming activities such as tillage and application of chemicals (Cortet et al., 2002; Schrader and Lingnau, 1997; Joy and Chakravorty, 1991).

Furthermore, soil microarthropod community structure of the forested (REF and REM) and open (TURF and RUD) sites in our study clearly separated. The presence of litter layer, which provides food or favorable microenvironment for microarthropod taxa (David et al., 1991; Dighton et al., 2012), is one of the most important soil habitat features distinguishing the forested and open sites. However, REM patches are embedded in the urban landscape and more exposed to urban disturbance. While taxonomic richness was still high at REM, abundances of microarthropods tended to be similar to TURF and RUD. In eastern North America, the most important effect of past and present land use change on soil fauna is the loss of O horizon directly related to deforestation, conversion to agriculture (Compton and Boone, 2000; Foster and Aber, 2006; Yesilonis et al., 2016), and introduction of non-native earthworms (Bohlen et al., 2004; Szlavecz et al., 2011, 2018). Urban remnant forest patches with high abundance of earthworms have thin or no O horizon (Szlavecz et al., 2006). In such situation, abundance, rather than taxonomic richness might better indicate environmental change, as has been shown for soil invertebrates in polluted soils (Nahmani and Lavelle, 2002; Santorufo et al., 2012). Contrary to our expectation, the open TURF and RUD sites were similar. Regular mowing of turf might be a factor leading to the decreased abundance of soil microarthropods (Lemanski and Scheu, 2015), consistent with previous researches (Byrne and Bruns, 2004; Chollet et al., 2018; Lerman et al., 2018).

Mites and springtails are the two dominating groups of microarthropods, and thus their abundance and diversity drove the overall patterns. However, more detailed analysis reveals differences in the responses of specific groups, which supports our second hypothesis: taxonomic response to soil environmental factors associated with disturbance. In the past decades several soil quality indices based upon fauna data have been developed. One of them, the Acarina/Collembola ratio has been used as a bioindicator of environmental stability, which is often associated with soil disturbance and pollution levels (Santorufo et al., 2012; Simoni et al.;, 2013; Visioli et al., 2013; Joimel et al., 2017). Higher index is associated with higher soil quality, however, studies reported opposite trends (Santorufo et al., 2012; Simoni et al., 2013; Rota et al., 2015). In our study, the Acarina/Collembola ratios varied from 1.6 to 4.9, which were within the range, but varied less than reported in urban soils (Santorufo et al., 2012; Rota et al., 2015). The highest value occurred in TURF, which was due to the lowest density of Collembola, presumably resulting from the disturbance of mowing. Within mites (Acarina), Oribatida had the highest absolute and relative density in REF sites while relative density was lower in the urban habitats. Being detritus and fungal feeders, they typically inhabit the organic and leaf litter layers (Behan-Pelletier, 1999), thus their decline reflects loss of habitat and resources. Oribatid mites have long been considered to be *k*-selected organisms, with slow metabolism and low fecundity, and have little capacity to respond rapidly to environmental alterations. Consequently, their populations decline when their favorable habitats are disturbed (Lebrun and van Straalen, 1995; Siepel, 1996). Mesostigmatid mites are usually predators of other microarthropods, larvae, and nematodes (Wallwork, 1983; Norton, 1990; Koehler, 1997). Their flexible diet and shorter life cycle than those of oribatids (Minor and Cianciolo, 2007), allows them to better cope with environmental changes (Birkhofer et al., 2016), and recover from disturbances, which partially explain why their abundances were independent of land use types.

Springtail (Collembola) diversity is generally lower at the family level, thus land use patterns were more obvious for abundance than diversity. However, different springtail families are known to be adapted to different soil depths and microhabitat conditions (Hopkin, 1997; Alvarez et al., 2001; Byrne and Bruns, 2004). For instance, Onychiuridae, a typical eu-edaphic group with small antennae, lack of ocelli and reduced pigmentation, have been associated with thicker litter and organic layers (da Silva et al., 2012). As expected, we found more of them in the forested than in the open sites. In the open sites, Sminthuridae, a typical soil surface dwelling group was more abundant in spring than summer, presumably avoiding high temperature in the latter season.

Soil temperature, which is different in open and forested habitats, was the significant constrained variable both for mite and springtail distribution, but the two groups differed in their responses to other soil properties (Fig. 4). For mites, dominated by oribatids, organic carbon concentration and bulk density was a significant factor. Springtails responded to differences in soil moisture and pH, as has been shown previously (Verhoef and van Selm, 1983; da Silva et al., 2016)

Contrary to expectation, neither richness nor abundance values were significantly different between spring and summer. Soil conditions during the two sampling periods did not exhibit the expected seasonal trends: soil temperature was already high in spring, and volumetric soil moisture was around 10 % higher in summer due to the heavy rainfall events preceding the sampling days. Microarthropods are known to exhibit seasonal activity peaks in the temperate regions (Petersen and Luxton, 1982), but to describe these patterns, sampling has to take place in all seasons and preferably through several years.

The presence of thick leaf litter and O layer with high fungal abundance provides abundant resources for detritus and fungal feeders. As a result, the indicators, mainly mites and springtails usually regarded as detritivores or fungivores, were only identified in forested sites. Furthermore, REF sites with natural biome outside of the city had more indicators than REM sites, though they have similar vegetation, probably resulting from the thinner litter layer and bigger urban influence in remnant patches. No indicator taxa were produced for TURF and RUD, presumably due to the relatively impoverished richness and abundance of microarthropods. It also meant that no characteristic taxa such as those with high tolerance to frequent disturbances or lower organic matter were produced as indicators for open sites.

To provide useful information to practitioners, community data need to be connected to ecological functions. Our knowledge on feeding preferences and behaviors of soil mesofauna is still limited. This, coupled with the taxonomic resolution of the current study prevented us to further explore whether compositional differences translate to functional differences among the four land use types. To fully evaluate the role microarthropods play in a given belowground soil food web, and their responses to environmental changes, community data need to be complemented with stable isotope analysis of the feeding groups as well as a variety of food resources (Birkhofer et al., 2016; Potapov et al., 2019). As an example, stable isotope composition of collembola communities revealed an increasingly simplified food web along a disturbance gradient (Korotkevich et al., 2018), which makes this

approach especially suitable in anthropogenic systems, including urban habitats.

5. Conclusions

Urban soils should not be viewed as lifeless dirt, but instead, a complex biomaterial sustaining a diverse and abundant invertebrate community belowground. Yet, a combination of natural and anthropogenic drivers influences local soil habitats and thus its biota. Soil disturbance, associated with loss of leaf litter and organic layer, appears to drive the abundance and biodiversity of soil microarthropod communities in the urban green space. Soil mesofauna provides important ecosystem services mainly as decomposers and as regulators of the microbial community (Turbé et al., 2010; Pieper and Weigmann, 2008), thus an impoverished fauna can lead to altered biological/biochemical functions. For instance, in turf, which is a universal green space type in the urban landscape (Milesi et al., 2005; Byrne and Bruns, 2004), the richness and abundance of soil microarthropods was relatively low compared to forested sites. Urban turf grass has been shown to act as ecological corridors (Chollet et al., 2018; Klaus, 2013) playing an important role in biological conservation. Lawns can be relatively easily manipulated with detectable outcomes within a short time (Shi et al., 2006; Trammell et al., 2016). For belowground fauna, increased detritus, soil organic matter, and less fluctuating soil moisture are among favorable environmental factors. Therefore, lawn management promoting a thick thatch layer reduces evaporation rate. Additionally, leaving leaf litter on planting beds or under trees creates a favorable habitat and refuge during extreme conditions. In general, a diverse landscape aboveground enhances a belowground diversity while improving soil health in urban green spaces. Controlled experiments should reveal how specific management types affect soil microarthropod communities in urban environments.

Declaration of Competing Interest

There is no conflict of interest.

Acknowledgement

We are grateful to Elliott Strahan and Erin Baggs for their help in the field and laboratory. We also thank Xu Yang for his help with the statistical analyses. Comments by two anonymous reviewers greatly improved the manuscript. This study was supported by the State Scholarship Fund of China and by NSF DEB-1027188.

Appendix A

Table A1

Table A1
ANOVA of soil properties of land use types.

Landuse	pH (H_2O)	OC (g 100 g^{-1})	TN (g 100 g^{-1})	BD (g cm^{-3})	AT (°C)		ST (°C)		SM (%)	
					Spring	Summer	Spring	Summer	Spring	Summer
REF	4.71 ± 0.5a	2.82 ± 0.4b	0.15 ± 0.0ab	0.60 ± 0.1a	32.2 ± 2.3a	28.0 ± 0.8b	18.4 ± 1.1ab	23.0 ± 0.6ab	26.1 ± 3.3a	28.3 ± 4.4a
REM	5.31 ± 0.9a	2.74 ± 0.6b	0.19 ± 0.0b	0.81 ± 0.1b	29.5 ± 3.0a	23.9 ± 0.5a	15.6 ± 2.0a	22.9 ± 0.3a	28.0 ± 3.5a	32.8 ± 4.9a
TURF	6.35 ± 0.7b	2.40 ± 0.7ab	0.18 ± 0.1ab	0.86 ± 0.1b	31.4 ± 0.7a	27.9 ± 1.2b	20.1 ± 1.4b	27.4 ± 0.9ab	25.3 ± 5.8a	32.2 ± 5.2a
RUD	7.04 ± 0.5b	1.59 ± 0.7a	0.12 ± 0.0a	0.86 ± 0.1b	29.8 ± 3.3a	28.7 ± 1.6b	21.6 ± 3.1b	27.6 ± 1.3b	22.9 ± 5.4a	32.6 ± 4.6a

Note: OC: soil organic carbon; TN: total nitrogen; BD: bulk density; AT: air temperature; ST: soil temperature; SM: volumetric soil moisture. Dunn's test was used when data did not meet the requirement of normality before or after the data transformation. The different lowercase letters indicate significant differences among land use types, $\alpha = 0.05$.

Appendix B

Table A2

Table A2
Density of microarthropods (mean ± sd, ind./m^2) and ratio of mites/springtails in different land use types and seasons.

Landuse	All microarthropod		Acarina		Collembola		Acarina/Collembola ratio	
	Spring	Summer	Spring	Summer	Spring	Summer	Spring	Summer
REF	55264.8 ± 23193.1Aa	105268.5 ± 43528.9Aa	38147.0 ± 18596.9Aa	73681.8 ± 36738.9Aa	13816.0 ± 4466.4Aa	24996.5 ± 7903.3Aa	2.7 ± 1.1Aab	2.9 ± 1.0Aa
REM	39171.2 ± 10965.7Aab	48130.2 ± 9696.9Ab	21375.6 ± 10405.5Aab	32380.0 ± 7939.7Ab	13086.0 ± 3008.0Aa	9527.0 ± 1556.6Ab	1.7 ± 1.0Bb	3.4 ± 0.8Aa
TURF	20706.6 ± 7222.6Ab	26077.6 ± 9730.0Ac	14275.6 ± 7052.0Ab	15689.2 ± 9861.3Ac	3957.8 ± 2516.0Ab	5724.4 ± 3033.3Ab	4.9 ± 4.4Aa	4.0 ± 3.5Aa
RUD	21554.8 ± 14246.4Ab	31872.8 ± 10144.4Abc	11590.0 ± 8507.7Ab	19929.4 ± 10126.7Abc	6501.0 ± 3521.3Aab	7137.8 ± 1377.7Ab	1.6 ± 0.6Ab	3.0 ± 1.6Aa

Note: The different lowercase letters indicate significant differences among land use types in the same season, and the different capital letters indicate significant differences between two seasons in the same land use type, $\alpha = 0.05$.

Appendix C

Fig. A1

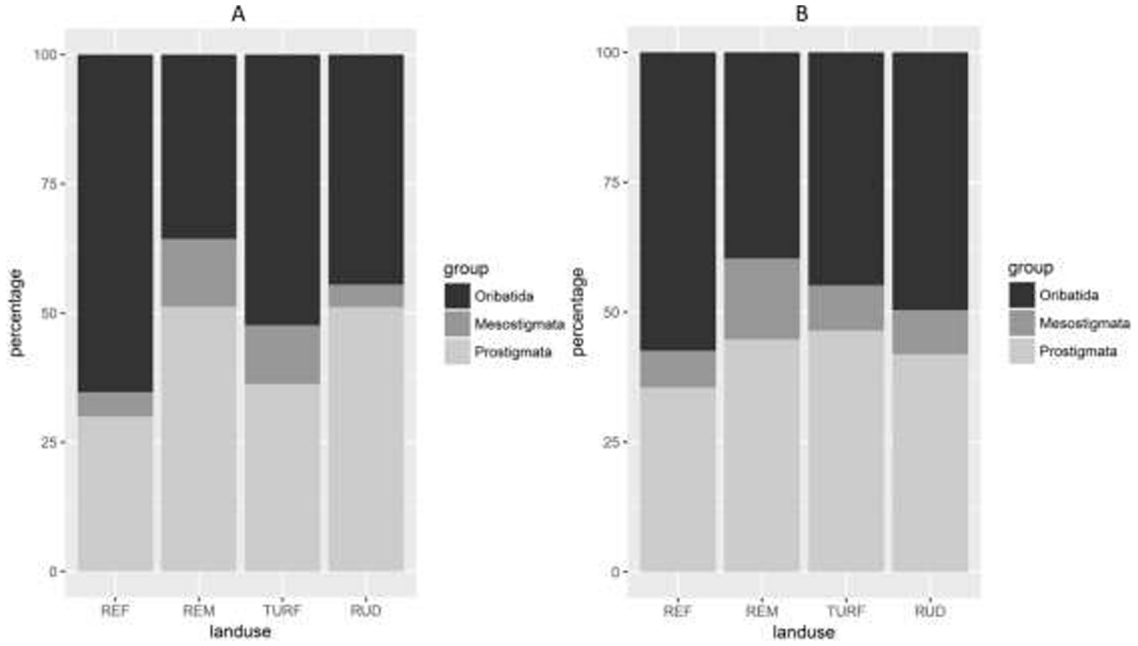

Fig. A1. Compositions of Acarina community in spring (A) and summer (B). Percentage values were relative density of each group.

Appendix D

Table A3

Table A3
Compositions of mite and springtail communities for 4 land use types.

Group		Family	Landuse			
			REF	REM	TURF	RUD
Acarina	Oribatida	Euphthiracaridae	+	+	+	+
		Parakalumnidae	+	+	+	+
		Haplozetidae	+	+	+	+
		Tectocepheidae	+	+	+	+
		Oppiidae	+	+	+	+
		Damaeidae	+	+	–	–
		Carabodidae	+	+	–	–
		Epilohmanniidae	+	+	+	+
		Lohmanniidae	+	+	–	–
		Perlohmanniidae	+	+	–	–
		Gustaviidae	+	+	+	+
		Liacaridae	+	+	+	–
		Eremulidae	+	+	–	–
		Phthiracaridae	+	+	–	–
		Nothridae	+	+	+	+
		Malaconothridae	+	–	–	–
		Brachychthoniidae	+	–	–	+
		Palaeacaridae	+	+	–	+
		Hypochthoniidae	+	+	+	–
		Hermanniidae	–	+	–	–
		Camisiidae	+	+	+	+
	Mesostigmata	Ascidae	+	+	+	+
		Zerconidae	+	–	–	+
		Parholaspididae	+	+	+	+
		Laelapidae	+	+	+	+
		Veigaiidae	+	+	+	+
		Rhodacaridae	+	+	–	+
		Eviphididae	+	+	+	+
		Epicriidae	+	–	–	–
		Parasitidae	+	+	+	+
		Podocinidae	+	–	–	–

(*continued on next page*)

Table A3 (*continued*)

Group	Family	Landuse			
		REF	REM	TURF	RUD
Prostigmata	Rhagidiidae	+	+	+	+
	Bdellidae	+	+	–	–
	Cunaxidae	+	+	+	+
	Caligonellidae	+	+	+	+
	Pygmephoridae	+	+	+	+
	Cryptognathidae	+	+	–	+
	Raphignathidae	+	+	+	+
	Stigmaeidae	+	+	+	–
	Cheyletidae	+	+	+	+
	Scutacaridae	+	+	+	+
	Erythraeidae	+	+	–	+
	Xenocaligonellidae	+	+	+	–
	Anystidae	+	+	+	+
	Trombidiidae	–	+	–	–
Collembola	Tomoceridae	+	+	–	–
	Poduridae	+	+	+	+
	Cyphoderidae	+	+	+	+
	Neelidae	–	+	–	–
	Entomobryidae	+	+	+	+
	Isotomidae	+	+	+	+
	Sminthuridae	+	+	+	+
	Neanridae	+	+	+	+
	Onychiuridae	+	+	+	+
Total taxonomic group number		51	49	34	36

Appendix E

Table A4

Table A4
Multiple comparisons of Shannon and Pielou indices of mite and springtail communities in different land use types and seasons.

Season	Landuse	Acarina		Collembola	
		Shannon	Pielou	Shannon	Pielou
Spring	REF-REM	ns	ns	ns	ns
	REF-TURF	ns	**−0.014**	ns	ns
	REF-RUD	ns	**−0.001**	ns	ns
	REM-TURF	ns	ns	ns	**−0.043**
	REM-RUD	ns	**−0.037**	ns	ns
	TURF-RUD	ns	ns	ns	ns
Summer	REF-REM	ns	ns	ns	ns
	REF-TURF	**+0.002**	**−0.001**	ns	ns
	REF-RUD	**+0.001**	**−0.015**	ns	ns
	REM-TURF	ns	**−0.008**	ns	ns
	REM-RUD	**+0.001**	ns	ns	ns
	TURF-RUD	ns	ns	ns	ns

Note: “ns” means no significant difference. Significant *P* values are shown in bold, $\alpha = 0.05$. “+” means the value of land use type on the left is higher than one on the right, whereas “-” has the opposite meaning.

Appendix F

Table A5

Table A5
Canonical correspondence analysis results.

Microarthropod group	Variability explained (%)	*P* values								
		Reduced model	Axes		ST	AT	SM	BD	pH	OC
			CCA1	CCA2						
Acarina	23.23	0.001	0.001	0.001	0.001	0.028		0.001		0.001
Collembolan	19.78	0.001	0.002		0.039		0.020		0.001	

Note: ST: soil temperature; AT: air temperature; SM: soil moisture; BD: bulk density; pH: pH value; OC: organic C. Significant *P* values were shown ($P < 0.05$).

Appendix G

Table A6

Table A6
P values of indicator taxa for land use types in two seasons.

Indicator taxa		REF		REM	
		Spring	Summer	Spring	Summer
Acarina	Laelapidae			0.047	
	Xenocaligonellidae	0.003	0.001		
	Eremulidae	0.002	0.004		
	Brachychthoniidae	0.007			
	Oppiidae	0.013	0.004		
	Damaeidae	0.015	0.001		
	Scutacaridae	0.036	0.012		
	Tectocepheidae	0.040	0.015		
	Ascidae				0.034
	Cheyletidae		0.007		
	Euphthiracaridae		0.025		
	Cryptognathidae		0.011		
	Podocinidae		0.035		
	Veigaiidae		0.050		
	Camisiidae		0.05		
Collembola	Neanuridae			0.016	
	Onychiuridae	0.029	0.004		
	Tomoceridae		0.006		
	Cyphoderidae		0.024		
	Isotomidae		0.001		
Others	Lygaeidae			0.005	
	Trachelipidae				0.004
	Phlaeothripidae				0.016
	Cheiridiidae		0.046		
	Japygidae		0.022		
	Pauropodidae		0.035		
Total number of indicator families		8	19	3	3

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