Activity and Diversity of Collembola (Insecta) and Mites (Acari) in Litter of a Degraded Midwestern Oak Woodland

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Abstract

Litter-inhabiting Collembola and mites were sampled using pitfall traps over a twelve-month period from four sub-communities within a 100-acre (40-ha) oak-woodland complex in northern Cook County, Illinois. Sampled locations included four areas where future ecological restoration was planned (mesic woodland, dry-mesic woodland, mesic upland forest, and buckthorn-dominated savanna) and a mesic woodland control that would not be restored. Fifty-eight mite and 30 Collembola taxa were identified out of 5,308 and 190,402 individuals trapped, respectively. There was a significant positive relationship between litter mass and both mite diversity and the ratio of Oribatida to Prostigmata and a significant negative relationship between Collembola diversity and litter. Based on multivariate analysis, Collembola and mite composition differed by sub-community and season interaction.

Many oak-woodland ecosystems in the Midwestern United States are in a degraded condition due to the effects of fire suppression, invasive species, habitat fragmentation, past land use, and overabundant white-tailed deer (Lorimer 1985, Nuzzo 1986, Packard 1988, Laatsch and Anderson 2000). Recent research (Heneghan and Brundage 2002, Heneghan et al. 2004, Ashton et al. 2005, Suarez et al. 2006, Heneghan et al. 2007, Nuzzo et al. 2009) has shown that invasive exotic-plant species and Eurasian earthworms have dramatic negative impacts on litter layers and nutrient cycling in Midwestern oak communities. Sayer (2005) and Eisenhauer et al. (2007) have found that earthworm activity can also result in soil compaction. The combination of high-nitrogen leaf litter from exotic shrubs and the rapid incorporation of organic matter into the soil by exotic earthworms quickly degrades the litter environment. This degradation by earthworms occurs when surface litter becomes buried under large amounts of soil castings and also by pulling organic material directly into their burrows.

Microarthropods, such as soil mites and Collembola, are considered perhaps the most important animal components of temperate forest ecosystems (Moldenke and Lattin 1990, Hansen 2000) and are thought to account for nearly 95% of the soil arthropod fauna (Seastedt 1984). Their great abundance makes them important contributors to several soil processes, such as material and energy cycles, and soil formation (Manh Vu and Nguyen 2000). These organisms have been shown to affect litter decomposition through increased mass loss and mineralization of nutrients. As dominant mycophages of most terrestrial ecosystems, oribatid mites and Collembolans affect nutrient cycling processes in the sizable “nutrient reservoir” represented by the soil fungi, although to what extent is not clear (Seastedt 1984). Soil disturbances caused by earthworms, both chemical and mechanical, have been shown to negatively affect microarthropod community

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structure (Maraun et al. 2003, Migge-Kleian et al. 2006, Eisenhauer et al. 2007, McGrath and Binkley 2009, Burke et al. 2011). Due to low population growth rates and limited dispersal capacity of endophagous mites, faunal disturbance may have long-term repercussions (Hansen 1999).

The loss of the litter layer and perturbation to the soils, factors common to degraded oak woodlands of the Midwest, would suggest that microarthropod community structure and function have been compromised in these systems. Monitoring of the activity and diversity of the microarthropod component of the litter environment could provide information on this important functional group and provide a means by which effects of restoration on this fauna can be measured. The purpose of this investigation was to measure the diversity and activity of Collembolan and mite populations along a naturally occurring litter gradient within a degraded oak woodland community and to provide a baseline and potential reference community against which planned future woodland restoration can be measured.

Methods

Study Area. This study was conducted in Mary Mix McDonald Woods (N42.152°, W87.781°), a 40-ha oak-woodland/savanna complex comprising a variety of different sub-communities at the Chicago Botanic Garden in Glencoe, Cook County, Illinois. The study plots were chosen to represent degraded portions of the woodland. At the time of this study, these areas had received no management and generally had depauperate herbaceous layers with the exception of several exotic invaders. The five study plots represent the four following community types: upland forest, dominated by *Quercus alba* L. (white oak), *Q. rubra* L. (red oak) and *Acer saccharum* Marshall (sugar maple); mesic woodland, dominated by *Q. rubra and Q. alba*; dry-mesic woodland, dominated by *Q. alba* and *Fraxinus* spp (ash); and a savanna dominated by *Q. alba* and *Rhamnus cathartica* L. (common buckthorn). The amount of mesic habitat on the study site allowed for two mesic plots to be established. One of the mesic plots (mesic 1) will be restored and the other (mesic 2) will serve as an unrestored plot for future studies. The study plots were chosen to represent different community types, but also to take advantage of a naturally occurring gradient in litter structure. The upland forest had the most well-developed litter layer and the savanna had the least well-developed litter layer. The three remaining sub-communities represented intermediate conditions.

The soil types for the five sub-communities varied slightly. The upland forest represents Rawson loam with a sandy loam subsurface layer with 18-35 % clay and 40-60% sand and moderately acid to neutral pH. Based on the thick and distinct L and H horizons, this soil would be designated a mor or mor-moder while all the other sub-communities would represent a mull or mull-moder soil type due to the lack of an L or H horizon. The mesic 1 community has a Nappanee silt loam with a silt loam subsurface layer with 35-60% clay content that has a slightly acid to slightly alkaline pH. The mesic 2 plot represents a Bryce silty clay with a mottled silty clay subsurface layer with 42-52% clay and a moderately acid to slightly alkaline pH. The dry mesic community represents a St. Clair silt loam with a silt loam subsurface layer with 40-60% clay content and slightly acid to slightly alkaline pH. The savanna soil type is the same as the dry-mesic sub-community.

A previous study using the same sub-community plots (Heneghan et al. 2007) showed a negative correlation between litter biomass and abundance of an exotic shrub, *R. cathartica*, and Eurasian earthworms. For a more detailed description of the study site and its history, see Steffen and Draney (2009).

Mean monthly precipitation for 2002 and 2003 was 7.1 and 6.7 cm, respectively. Total snow cover was 95.5 and 39.6 cm, respectively. Mean high temperatures were 15.6 and 14.5°C and mean low temperatures were 4.8 and 3.5°C, respectively.

Sampling Methods. Pitfall trapping was used for microarthropod sampling because it is more efficient than other techniques, such as quadrat sampling, and can be performed year-round (Uetz and Unzicker 1976). However, it should be noted that, in spider populations, pitfall traps preferentially measure running-adapted species and underrepresent other groups (Uetz and Unzicker 1976, Coddington et al. 1996), which may also apply to microarthropod captures. A single point was randomly located within each study area and five pitfall traps were evenly spaced along a 20-m diameter circle around the point. The first pitfall trap was located by means of a random compass angle. Pitfalls each consisted of a 9-cm diameter, 12-cm deep plastic cup buried with its lip flush with the soil surface. A 22-cm square translucent fiberglass cover was positioned 2.5 cm above each trap. Wooden lath positioned from each corner to the center on the underside of the cover acted as drift fences to direct individuals into the cups. A 9-cm diameter, 6-cm deep cup was placed inside the larger pitfall and filled with water and a small amount of dish detergent to reduce surface tension. A small amount of ethylene glycol was added to the water during the coldest days in winter to prevent freezing. Ethylene glycol was found to attract mammals to the traps during earlier pitfall sampling of this site, which can result in significant loss of data (Fassbender 2002). For this reason, ethylene glycol was not used at other times in an effort to reduce disturbance by mammals. During periods of freeze and thaw, dry sand was added around the traps to fill in gaps between traps and adjacent soil due to expansion or contraction of the soil. This maintained a continuous surface for access to the traps.

Traps were deployed continuously from June 2002 through June 2003. Traps were emptied twice weekly during warm weather to avoid spoilage and less often during the winter months, and fresh solution placed in the traps. Individuals were sorted from trap contents and specimens were fixed to microscope slides utilizing CMC10 as a clearing agent and fixative. Nomenclature follows Christiansen and Bellinger (1998) for Collembola and Krantz and Walter (2009) for mites. All specimens are housed at the Chicago Botanic Garden.

In spring 2002, 10 quadrats (45-cm × 45-cm) were randomly located on a 50-m × 50-m grid to sample litter within each of the five sub-communities. Litter was removed down to mineral soil and the material dried at 49°C for a minimum of 48 hours in an electric plant drier before being weighed to the nearest gram.

Data Analysis. As our objective was to conduct a baseline survey of the Collembolan and mite fauna of the five sub-communities, we did not employ an experimental design with replicate sampling. For analysis, the data for each of the five pitfall traps in each sub-community were pooled for each collection. For both mites and Collembola, Simpson's reciprocal index of diversity ($1/D$), where 1 is the lowest measure of diversity; Shannon-Wiener diversity (H'); effective number of species (ENS) (Jost 2006); Pielou's evenness (J'); species richness (s); and total individuals (N) were calculated. The ENS is the effective number of species derived from H' or other diversity indices. The ENS makes it easier to compare diversity indices derived by different formulas. Also, because diversity indices are nonlinear, the ENS allows more effective comparisons between different diversity indices. Unless the species in a population are all equally abundant, the ENS value will be less than the richness because of dominance of one or more species within the population (Jost 2006).The formula for determining ENS differs depending on the diversity index used. For H', ENS is found by $\exp(x)$ where x is the value of H'.

An individual-based Coleman rarefaction (Coleman 1981, Coleman et al. 1982) was calculated for each sub-community utilizing the software EstimateS (Colwell 2006). This procedure standardizes the data, making it possible to compare species richness among populations composed of differing numbers of individuals. The ratio of abundance of Oribatida to Prostigmata was calculated for each sub-community and a graph of the relationship between this ratio and leaf litter mass was plotted.

Non-metric multidimensional scaling (NMS) ordination was performed to compare mite and Collembola composition in different sub-communities and at different times of year. The specimens collected in each pitfall trap were aggregated by season, yielding 100 samples (multiple collections from each of 5 pitfall traps within each sub-community were pooled to provide 5 samples for each sub-community 4 times over the year). Seasons were assigned as follows: winter (December – February), spring (March – May), summer (June – August), fall (September – November). Taxa found in <5% of samples were excluded as rare taxa can have disproportionate effects on ordinations (McCune and Grace 2002) (rare taxa were retained for all other analyses). The ordination was based on Bray-Curtis dissimilarity using two axes and data were relativized by species and samples. Sub-community and season effects were then tested by permutational multivariate analysis of variance (PERMANOVA), a multivariate analog of ANOVA (Anderson 2001). PERMANOVA was based on Bray-Curtis dissimilarity using 999 permutations and *P*-values were calculated by a Monte-Carlo procedure. Ordination was performed using the vegan package in R 2.13.1 and PERMANOVA using the program PERMANOVA (Anderson 2005, Oksanen et al. 2010, R Development Core Team 2011).

Results

The Collembola had the greatest number of individuals sampled, with a total of 190,122 for all sub-communities combined compared to 5,078 for mites. The upland forest sub-community comprised the largest sample for Collembola with 174,091 individuals (Table 1), with one species, *Hypogastrura concolor* (Carpenter 1900), dominating the sample with 149,384 individuals. The upland forest sub-community also comprised the highest mite sample with 1,278 individuals (Table 1), with *Eupodes* sp. being the most abundant taxon with 370 individuals. A total of 58 mite taxa (Table 2) and 30 Collembola taxa (Table 3) were identified. Rarefaction curves for mite diversity (Fig. 1A) showed the upland forest sub-community having the highest diversity of mites and the savanna sub-community the lowest. Collembola rarefaction curves (Fig. 1B) showed the mesic 2 sub-community having the highest diversity with the lowest in the upland forest.

The upland forest sub-community had the highest litter biomass and the

Table 1. Collembola and mite total number of individuals, richness (*s*), Shannon Weiner diversity (*H'*), Simpson's reciprocal index of diversity (1/D), evenness (J'), and effective number of species (ENS) for all sub-communities.

	Sub-community	**Individuals**	**s**	***H'***	***1/D***	***J'***	**ENS**
Mites	Savanna	901	22	1.5153	2.69736	0.49021	4.55078
	Mesic Control	1119	29	1.5212	2.68087	0.45175	4.57771
	Mesic	902	27	1.7457	3.57455	0.52966	5.72991
	Dry Mesic	878	23	1.917	4.75918	0.62018	6.80052
	Upland Forest	1278	42	2.4667	7.29294	0.66424	11.7835
Collembola	Upland Forest	174091	26	0.51168	1.33208	0.15705	1.6681
	Mesic Control	4054	28	1.99911	5.51174	0.59993	7.38248
	Mesic	4377	23	2.02568	5.81635	0.64605	7.58126
	Dry Mesic	3422	24	2.18229	6.37514	0.68667	8.86658
	Savanna	4178	23	2.34437	8.0238	0.74768	10.4267

Table 2. Counts of litter-dwelling mites by genera in McDonald Woods, Chicago Botanic Garden, Glencoe, Cook Co. IL. All individuals were caught in pitfall traps between 27 June 2002 and 25 June 2003. Family is used when determination to genus was not possible. UF = upland forest, M1 = mesic 1, M2 = mesic 2, DM = dry mesic, SA = savanna.

	Sub-Community Count Totals				
Taxon	**UF**	**M1**	**M2**	**DM**	**SA**
ORDER MESOSTIGMATA					
Uropodidae Berlese 1900	2	1	1	–	–
Parasitidae					
Paragamasus Hull 1918	3	3	1	1	–
Pergamasus Berlese 1904	14	70	69	114	82
Porrhostaspis Berlese 1904	6	16	16	–	6
Digamasellidae					
Dendrolaelaps Halbert 1915	–	–	–	1	–
Parholaspidae	–	1	–	–	2
Veigaiidae					
Veigaia nemorensis Koch 1839	1	3	4	–	1
Ameroseidae					
Epicriopsis Berlese 1916	1	–	2	–	–
Macrochelidae					
Macrocheles Latreille 1829	1	–	–	–	–
ORDER TROMBIDIIFORMES					
SUBORDER PROSTIGMATA					
Bdellidae					
Bdella Latreille 1795	–	2	3	7	7
Cyta von Heyden 1826	1	1	1	–	–
Cunaxidae					
Armasciurus den Heyer 1978	–	–	1	–	–
Eupodidae					
Cocceupodes Sig Thor 1934	1	–	–	–	–
Eupodes Koch 1835	390	476	701	281	566
Linopodes Koch 1835	97	181	146	274	121
Rhagididae	38	7	31	54	92
Anystidae					
Anystis von Heyden 1826	29	2	–	–	–
Cheyletidae Leach 1815	1	–	–	–	–
Calyptostomatidae Oudemans 1923	1	–	1	–	–
Trombidiidae					
Trombidium Fabricius 1775	115	8	23	23	23
Microtrombidiidae					
Microtrombidium Haller 1882	1	11	4	4	–
Tarsonemidae Canestrini & Fanzago1877	–	–	–	–	1
Scutacaridae					
Imparipes Berlese 1903	–	6	–	–	–
Lamnacarus Balogh & Mahunka 1963	2	–	–	2	2
Scutacarus Gros 1845	2	–	–	1	2
Microdispidae Paoli 1911	5	–	–	–	2
ORDER SARCOPTIFORMES					
SUBORDER ENDEOSTIGMATA					
Alycidae					
Alycus C.L. Koch, 1842	128	–	2	16	4
Pachygnathus Duges, 1834	–	–	–	15	5

Table 2. Continued.

	Sub-Community Count Totals				
Taxon	**UF**	**M1**	**M2**	**DM**	**SA**
SUBORDER ORIBATIDA					
Phthiracaridae					
Archiphthiracarus (Balogh & Mahunka, 1979)	–	–	2	–	–
Phthiracarus Perty, 1841	–	6	1	1	1
Euphthiracaridae					
Acrotritia Jacot, 1923	1	1	1	1	2
Cepheidae					
Ommatocepheus Berlese, 1913	3	–	–	1	1
Eremobelbidae					
Eremobelba Berlese, 1908	1	–	–	–	–
Basilobelbidae					
Basilobelba Balogh, 1958	2	–	–	–	–
Eremaeidae					
Eueremaeus Milhelcic, 1963	1	–	1	–	–
Astegistidae					
Furcoribula Balogh, 1943	27	–	–	–	–
Tectocepheidae					
Tectocepheus Berlese, 1896	29	2	2	–	1
Oppiidae					
Moritzoppia Subias & Rodriguez, 1988	1	–	–	–	–
Oppiella Jacot, 1937	7	1	–	–	–
Quadroppiidae					
Quadroppia Jacot, 1939	1	–	–	–	–
Suctobelbidae					
Suctobelba Paoli, 1908	2	–	–	–	–
Suctobelbella Jacot, 1937	1	–	–	–	–
Cymbaeremaeidae					
*Scapheremae*us Berlese, 1910	2	–	–	–	–
Eremellidae					
Eremella Berlese, 1913	1	–	–	–	–
Licnocepheus Woolley, 1969	–	–	1	–	–
Miceremidae					
Miceremus Berlese, 1908	1	2	–	2	–
Oribatulidae					
Oribatula Berlese, 1895	192	121	142	65	58
Haplozetidae	16	3	–	1	–
Haplozetes Wilmann, 1935	–	–	1	–	–
Peloribates Berlese, 1908	–	4	–	–	–
Scheloribatidae					
Scheloribates Berlese, 1908	–	–	1	–	1
Parakalummidae					
Neoribates Berlese, 1914	33	16	12	25	5
Parakalumma Jacot, 1929	43	2	4	16	1
Ceratozetidae Jacot, 1925					
Ceratozetes Berlese, 1908	–	1	3	–	–
Achipteriidae					
Anachipteria Grandjean, 1932	–	2	1	–	–

Table 2. Continued.

	Sub-Community Count Totals				
Taxon	**UF**	**M1**	**M2**	**DM**	**SA**
Oribatellidae					
Oribatella Banks, 1895	26	1	4	1	–
Galumnidae					
Orthogalumna Balogh, 1961	2	23	1	63	7
Galumna von Heyden, 1826	–	7	–	3	–

Table 3. Counts of species of litter-dwelling Collembola in McDonald Woods, Chicago Botanic Garden, Glencoe, Cook Co. IL. All individuals were caught in pitfall traps between 27 June 2002 and 25 June 2003. UF = upland forest, M1 = mesic 1, M2 = mesic 2, DM = dry mesic, SA = savanna.

	Sub-Community Count Totals				
Taxon	**UF**	**M1**	**M2**	**DM**	**SA**
Hypogastruridae					
Ceratophysella sp. Borner, 1932	3	–	5	–	1
Hypogastrura sp.	20354	–	–	–	–
Hypogastrura concolor Carpenter, 1900	149484	26	69	13	36
Hypogastrura packardi Folsom, 1902	44	1	2	2	9
Neanura muscorum Templeton, 1835	40	22	28	14	12
Isotomidae					
Proisotoma minuta Tullberg, 1871	16	19	19	27	93
Isotomurus sp. Bomer, 1903	5	88	53	124	117
Desoria flora Christiansen & Bellinger, 1980	–	8	8	9	22
Desoria notabilis Schaffer, 1896	4	1	2	–	10
Desoria uniens Christiansen & Bellinger, 1980	–	–	1	4	23
Isotoma viridis Bourlet, C., 1839	3	32	41	137	356
Entomobryidae					
Orchesella villosa Linnaeus, 1767	1899	1171	1216	885	862
Orchesella hexfasciata Harvey, 1895	37	19	25	42	9
Orchesella cincta Linnaeus, 1758	29	–	2	–	–
Entomobrya nivalis Linnaeus, 1758	1	1		1	48
Entomobrya clitellaria Guthrie, 1903	2	4	2	5	–
Homidia socia Denis, 1939	2	76	2	1	161
Lepidocyrtus beaucatcheri Wray 1946	–	1	–	–	–
Lepidocyrtus paradoxus Uzel, 1891	86	162	55	27	11
Lepidocyrtus fernandi Christiansen & Bellinger, 1998	32	859	609	756	685
Lepidocyrtus sp. Bourlet, 1839	1	1	2	1	2
Pseudosinella alba Packard, 1873	1	3	9	87	52
Pseudosinella violenta Folsom, 1924	3	10	4	273	384
Tomoceridae					
Pogonognathellus flavescens (Tullberg, 1871) Stach, 1929	636	866	612	322	260

Table 3. Continued.

	Sub-Community Count Totals				
Taxon	**UF**	**M1**	**M2**	**DM**	**SA**
Sminthuridae					
Sminthurinus elegans Fitch, 1863	37	169	40	124	438
Sminthurinus henshawi Folsom, 1896	310	352	433	501	672
Katianna macgillivrayi Banks, 1897	1224	3	36	2	7
Bourletiella sp. Banks, 1899	6	–	2	–	1
Ptenothrix atra Linnaeus, 1758	–	–	25	–	–

savanna sub-community the lowest (Fig. 2). The graph of the litter data suggests the savanna sub-community differed from the mesic 1, mesic 2, and upland-forest sub-communities. The mesic 1, mesic 2, and dry-mesic sub-communities did not appear to differ from each other while the upland forest sub-community appeared to differ from all other sub-communities. A significant positive correlation was found between richness (ENS) for mites and the average mass of litter in the sub-communities and a negative correlation for Collembola (Fig 3). A significant positive correlation was also found between litter mass and the ratio of Oribatida to Prostigmata abundance (Fig. 4).

The multivariate analyses showed significant differences among sub-communities and between seasons. Composition for mites differed significantly by season, sub-community, and season × sub-community interaction (Fig. 5). For Collembola, composition differed significantly by season, sub-community, and season × sub-community interaction (Fig. 6).

Discussion

One of the main goals of this study was to survey the litter-inhabiting portion of the mite and Collembola population among several sub-communities in a degraded oak woodland.

Our results indicated that there was a significant trend between litter mass and mite diversity. This affirmed our expectation that faunal diversity would be greatest where a larger effective habitat size is present. The higher mite diversity found in the upland forest sub-community may be explained by the presence of a greater mass of litter, which would represent a more stable environment for a group of organisms with a slow reproductive rate, low dispersion and high sensitivity to disturbance (Walters and Proctor 1999, Maraun et al. 2003, Gulvik 2007, Norton and Behan-Pelletier 2009). The lower mite diversity associated with the lowest litter mass in the savanna sub-community may be due to the fact that mites cannot easily escape impacts of disturbance, which can lead to species losses (Behan-Pelletier 1999). However, it should also be pointed out that, rather than being lost completely, many of the smaller species, especially those susceptible to drought conditions associated with litter disturbance (Sayer 2005) may move deeper into the soil (Wallwork 1983) and therefore become less likely to be sampled by pitfall traps.

We did not expect the Collembola community to show a negative relationship between litter mass and diversity. However, work by other researchers has found similar trends. Sulkava and Huhta (1998) found that faunal diversity was higher in patchy litter layers in comparison to mixed, continuous litter. Manh Vu and Nguyen (2000) found that while oribatid diversity decreased with increasing disturbance and loss of litter in a tropical forest, Collembola diversity

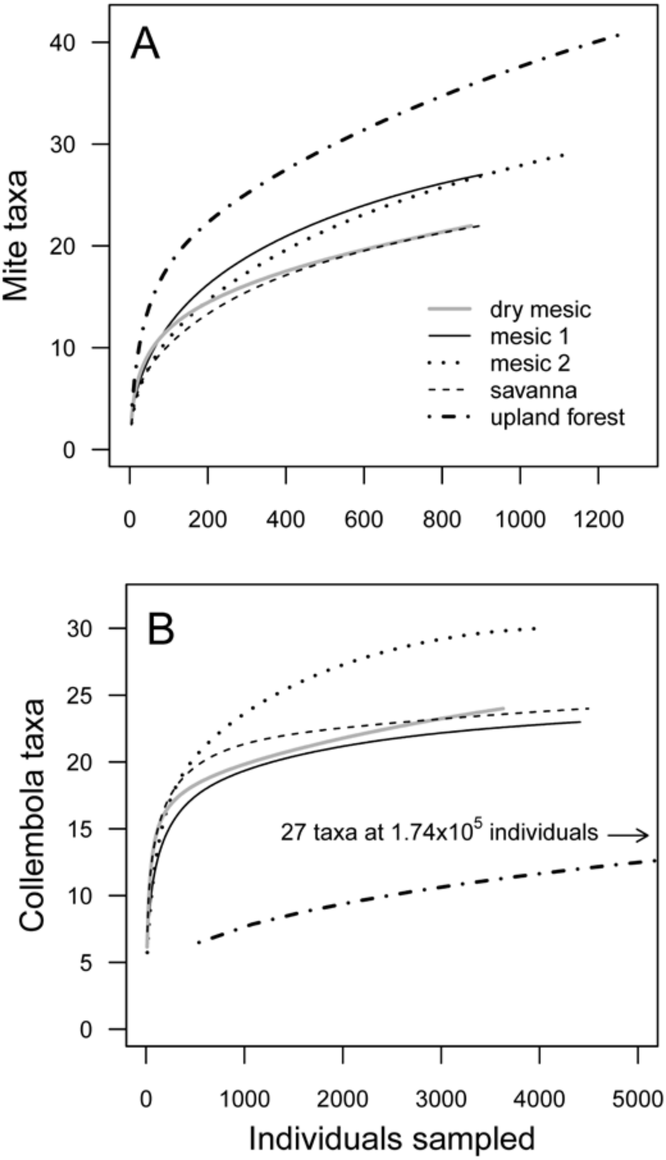

Figure 1. Individual-based Coleman rarefaction curves comparing mite (A) and Collembola (B) species richness for five sub-communities.

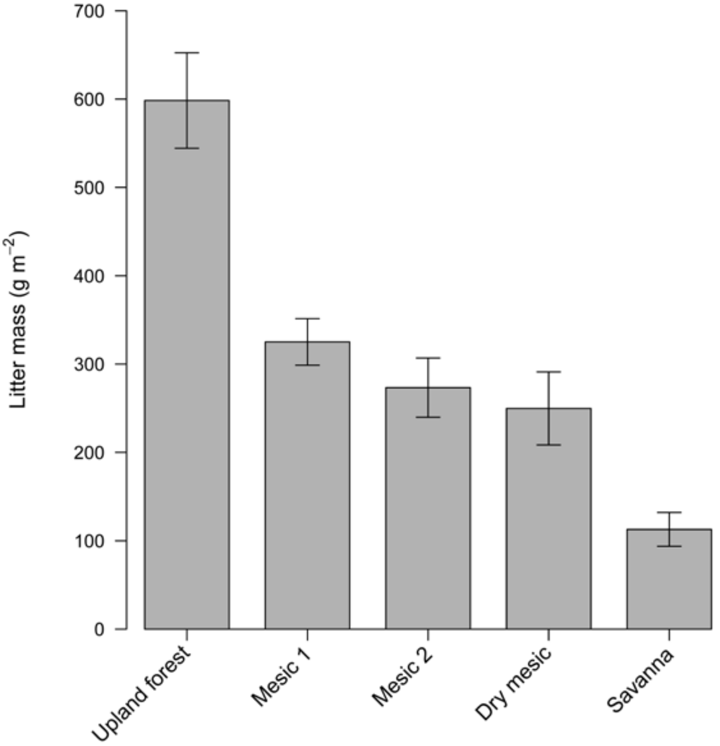

Figure 2. Mean oven dry weight for leaf litter for 10 45 × 45cm quadrats from five study plots in McDonald Woods, Chicago Botanic Garden, Cook Co, IL. Whisker bars represent standard error.

increased along the same gradient. Also, since pitfall traps measure activity rather than abundance, the significant negative trend between litter mass and diversity in a mobile group, such as the Collembola, might be related to a more patchy distribution of litter resulting in greater likelihood of Collembola species encountering a pitfall trap while moving between scattered resource patches.

Several studies have documented declines in both diversity and abundance of Collembola and mites when litter is reduced by earthworms (Eisenhauer et al. 2007; Burke et al. 2011) or anthropogenic disturbance (Maraun et al. 2003). However, we did not find a significant correlation between microarthropod abundance and litter mass, although the upland forest sub-community did have the highest abundance for Collembola (Table 1) of any of the other sub-communities. Other researchers that have found a similar lack of correlation have tested experimental perturbation of litter supply by removing or doubling the litter amount in a forest ecosystem. These researchers found that abundance was unaffected although composition changed (Ponge et al. 1993). The greater abundance of Collembola in the upland forest sub-community might be related to a preference for the conidial fungi in litter as opposed to arbuscular mycorrhizal fungi in the soil. Kilronomos and Kendrick (1995a, 1995b, 1996) have shown that Collembola prefer the non-mycorrhizal fungi in decomposing litter. Less-degraded oak woodlands with a greater mass of litter may be expected to provide a more preferred and abundant food resource, thereby supporting higher

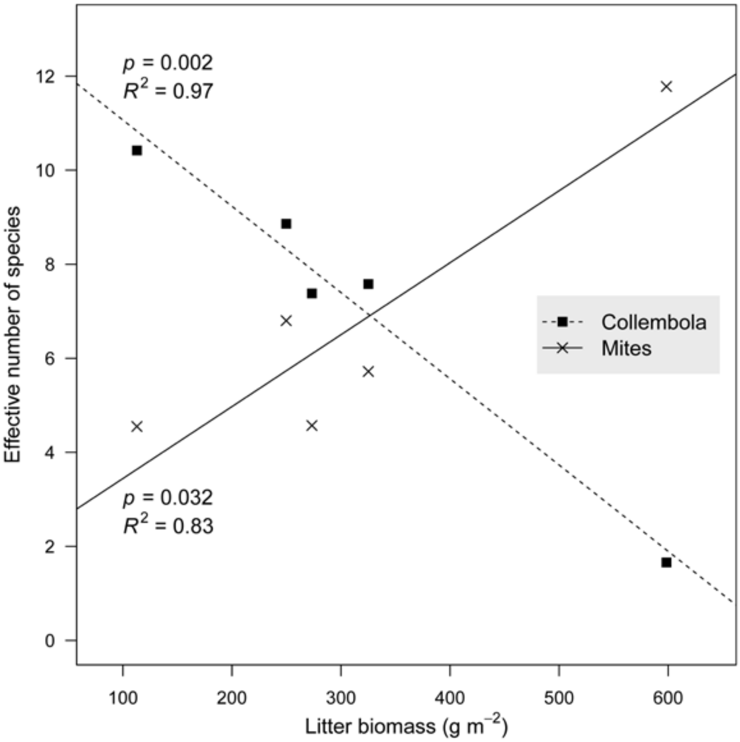

Figure 3. Correlation between mean dry litter mass and Effective Number of Species (ENS) for mites and Collembola.

abundances of microarthropods than woodlands with reduced litter. This shift in feeding preference with reduced litter availability may also be important in terms of the potential impact on mycorrhizal fungi-plant interactions in degraded woodlands.

Litter mass in this study site is negatively correlated with earthworm biomass (Heneghan et al. 2007). Invasive earthworms can change the abiotic properties of the litter environment, including its ability to protect against microclimatic fluctuations, erosion, and soil compaction (Sayer 2005), as well as loss of food resources (Burke et al. 2011). It would be expected that mites would be less able to adapt to the disturbance and litter loss associated with earthworm activity than would more-active Collembola. Support for this idea comes from Burke et al's. (2011) findings that invasion by exotic earthworms into northern temperate forests can reduce the richness, diversity, and abundance and alter composition of oribatid mites. The significant positive trend we found between Collembola diversity and earthworm-induced litter loss might be explained by research of Hamilton and Sillman (1989). In their research, they found greater numbers of Collembola associated with middens or defecated soil and litter on the soil surface at the mouths of earthworm burrows. Although we found an increase in Collembola and decrease in mite diversity with earthworm-induced litter loss, other responses have also been found. Maraun et al. (2003) and Eisenhauer et al. (2007) found that density and diversity of both oribatid mites

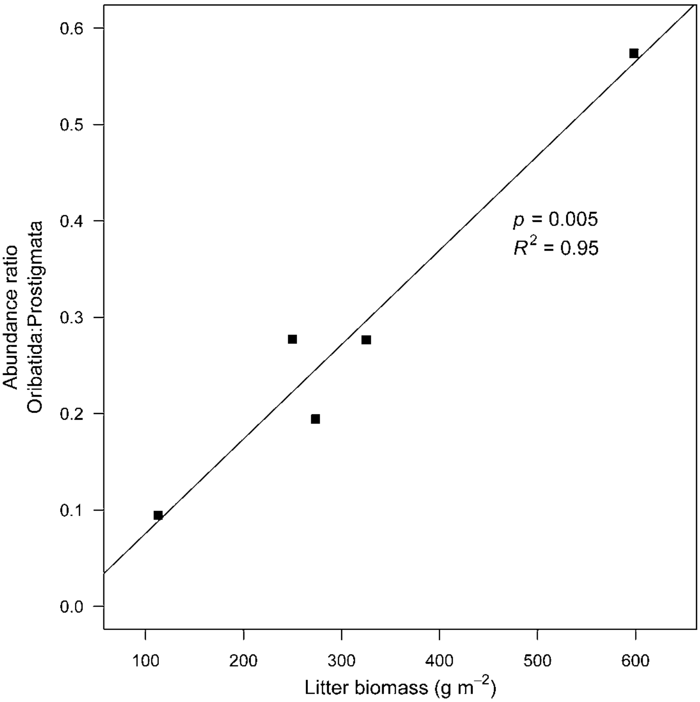

Figure 4. Correlation between Oribatida:Prostigmata ratio and litter mass.

and Collembolans were generally reduced by disturbance, including bioturbation by earthworms. Although we did not find a similar decline in diversity of Collembola with reduced litter, this may be the result of our having sampled only litter and not both litter and soil as was done in the above-mentioned studies.

The decrease in litter mass in midwestern temperate woodlands seems to be a common phenomenon in these earthworm-invaded systems (Migge-Kleian et al. 2006, Holdsworth et al. 2007, Madritch and Lindroth 2009, Loss et al. 2012). It is likely that this litter loss is stressing the microarthropod community and impairing the functional abilities of this group. Gulvik (2007) has suggested that a measure of the ratio of Oribatida:Actinedida(Prostigmata) mites could serve as an “early warning” criterion for stressed mite communities. We found a highly significant correlation between the ratio of Oribatida:Prostigmata and litter mass in our study (Fig. 4). The higher abundance of Prostigmata in the sub-communities where the litter is reduced by earthworm activity, could be explained by the higher number of Prostigmata found associated with earthworm castings at the soil surface (Gulvik 2007). The reduced ratio of Oribatida:Prostigmanta with loss of litter in this study could imply that the Oribatids are experiencing stress and perhaps functioning at lower capacity.

When viewing the interpretations of this data, the limitations of the sampling method should be kept in mind. Examination of soil core extraction data from these same sub-communities in a previous study (Steffen, unpublished data) revealed that the pitfall trapping in the present study does not adequately sample all taxonomic groups and is perhaps better suited to epegeic taxa. For example: concerning mite data, 150 and 0 Brachychthonius and 161 and 1 Moritzopia were sampled in soil cores and pitfall traps, respectively. Querner and Bruckner (2010)

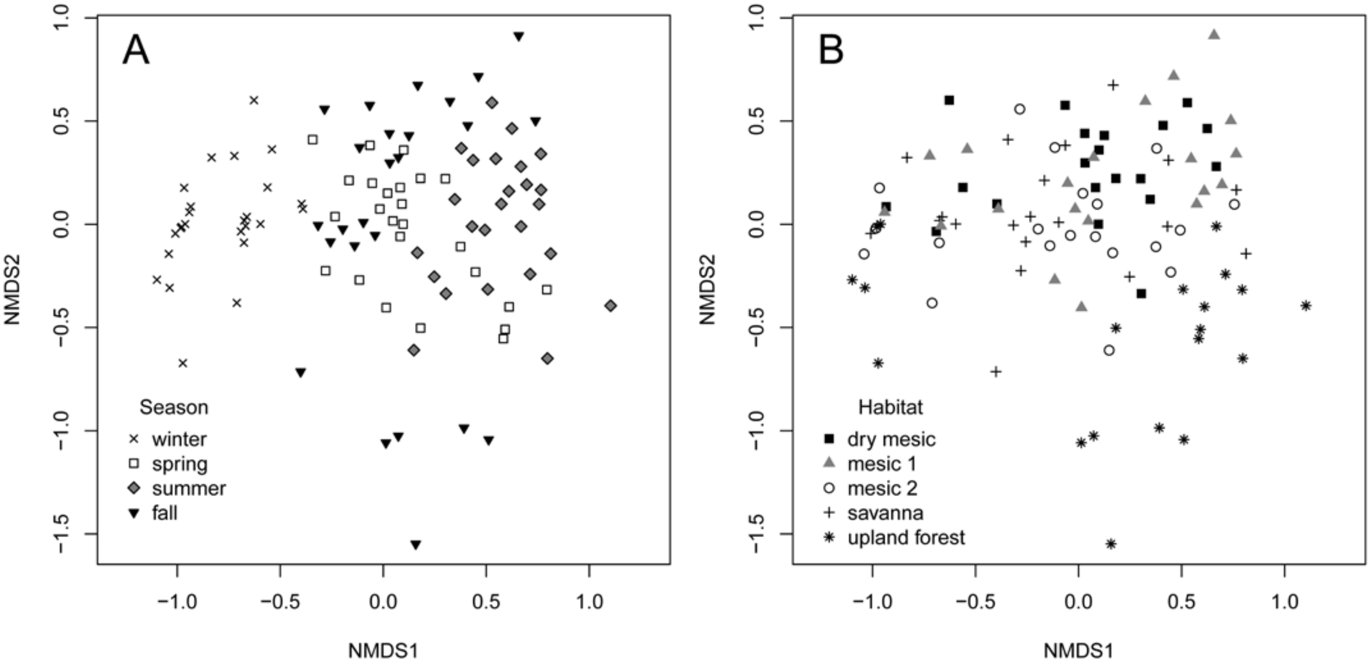

Figure 5. Non-metric multidimensional scaling (NMS) ordination of mite composition by season (winter = Jan-Mar, spring = Apr-Jun, summer = July-Sept, fall = Oct-Dec) (A) and sub-community (B) (2 axes, stress = 0.20). Composition differed significantly by season, sub-community, and season × sub-community interaction (PERMANOVA: $P = 0.0002$, 0.001, and 0.0002; respectively). All seasons differed in pairwise comparisons ($P = 0.001$–0.005) except spring and summer ($P = 0.062$). Among sub-communities, maple differed from control and buckthorn areas ($P = 0.013$ and $P = 0.018$, respectively) but other sub-communities did not differ ($P = 0.052$–0.42).

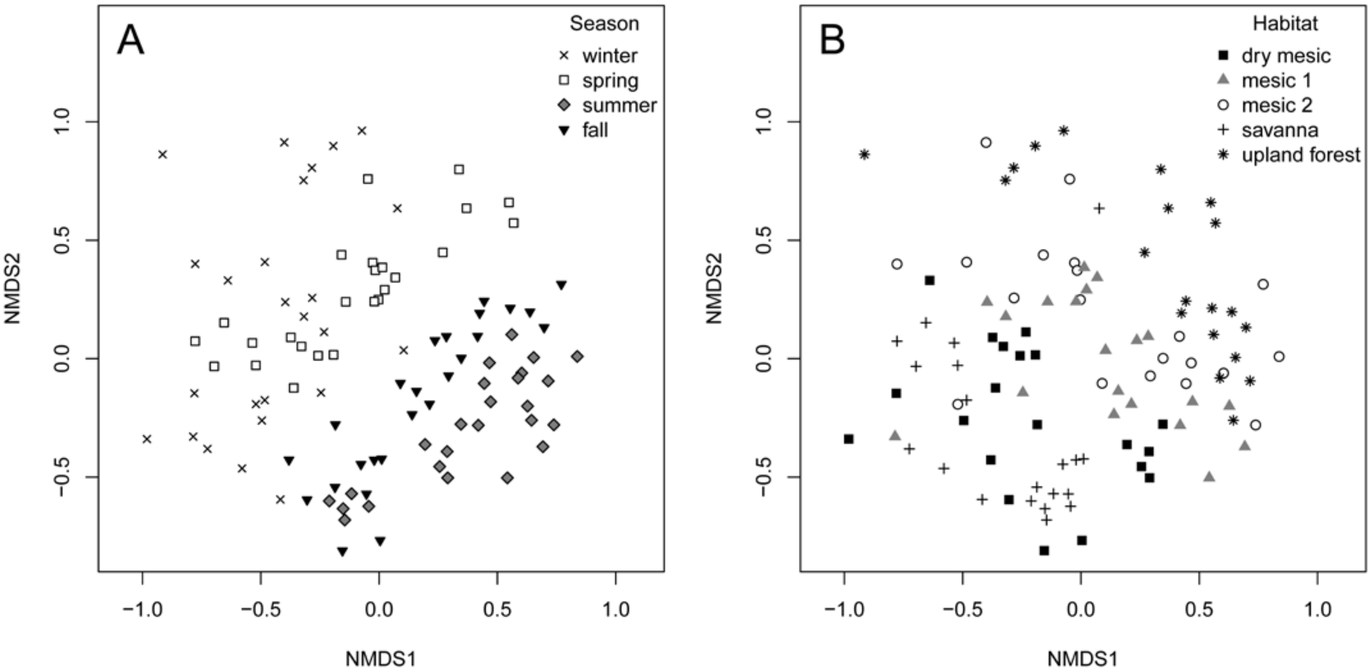

Figure 6. Non-metric multidimensional scaling (NMS) ordination of Collembola composition by season (winter = Jan-Mar, spring = Apr-Jun, summer = July-Sept, fall = Oct-Dec) (A) and sub-community (B) (2 axes, stress = 0.24). Composition differed significantly by season, sub-community, and season × sub-community interaction (PERMANOVA: $P = 0.0002$ for all). All seasons differed in pairwise comparisons ($P = 0.0002$ for all), as did all sub-communities ($P = 0.0002–0.016$).

also found that pitfall traps did not fully represent the Collembola fauna when compared with soil samples, but suggested that, although preferably both methods should be used, pitfall trapping required a much lower sorting and identification effort. However, since it was not our intent to perform an exhaustive inventory for the present study, we chose to utilize the pitfall traps for their efficiency.

Significant changes have occurred to the litter environment of Midwestern oak woodland communities as a result of the invasion of both exotic plants and animals. These changes, in combination with disturbances to litter invertebrate populations as a result of oak woodland management practices (Brand 2002), make it important to pay greater attention to this critical functional group of oak woodland systems.

We conclude that the abundance of Collembola and diversity of mites found in the upland forest, the sub-community with the highest litter mass, might serve as a reference against which future monitoring and management could be measured. We also suggest that the ratio of Oribatida:Actinedida might serve as a metric to assess woodland health and the effects of restoration management. As this woodland undergoes restoration, future research will investigate changes in microarthropod abundance and diversity with changes to litter structure and groundcover vegetation.

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