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RESEARCH NOTE

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The Effects of Prescribed Burning on Soil and Litter Invertebrate Diversity and Abundance in an Illinois Oak Woodland

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ABSTRACT: The effect of 23 years of low intensity prescribed burning on soil and litter invertebrates was studied over 18 months. Samples were collected from 40 plots distributed among annually burned, periodically burned (every 3–4 yrs), and unburned areas of an oak woodland. A total of 26,416 invertebrates representing 21 classes and orders were extracted from soil core and litter layer samples using Berlese-Tullgren funnels. Invertebrates were 25 times more abundant in litter than soil, and Acari and Collembola were the most prevalent taxa, accounting for 76% and 17%, respectively, of the total collection. Statistical analyses of the Shannon entropy index for diversity and associated values of class and order richness, evenness, and abundance indicated that burning was not associated with significant changes in the broad invertebrate community. Average Shannon entropy indices (H) ranged from 0.73 to 0.78 across burn treatments for soil samples and from 0.43 to 0.46 for litter samples. However, within Acari, diversity indices were significantly lower ($P < 0.0005$) in annually burned plots (H = 0.72) versus unburned controls (H = 0.85), and periodic burn plots had an intermediate H value of 0.79. Taxa evenness was similar in all treatments (J = 0.40–0.57), reflecting the widespread distribution of Acari and Collembola and rare occurrence of several orders from which 20 or fewer individuals were collected. Fall sample dates had more diverse (soil and litter) and abundant (soil) invertebrate assemblages than the spring date ($P \leq 0.001$), reflecting large seasonal shifts in Acari. The average depth of the litter layer was similar, at 2.8–3.1 cm, in all three burn treatments, and was most varied in unburned plots. Collectively, the findings suggest that long term burning of the woodland for the purpose of vegetation management has not altered significantly the broadly classified invertebrate community. Possible influences of postfire recovery interval, low fire intensity, and remnant litter refugia are considered.

Index terms: Acari, arthropods, Collembola, litter, microfauna, mites, soil, springtails, urban woodland

INTRODUCTION

Prescribed burning has been used for decades as a management tool in temperate forest ecosystems. It reduces stem density of the understory and opens the tree canopy to aid recruitment of native, shade-intolerant tree species such as oak (*Quercus* spp.) (Abrams 1992; Schwartz and Heim 1996; Lorimer 2003). Dormant season burns are practiced regularly in northeastern Illinois urban forests and woodlands to improve oak recruitment, while reducing populations of exotic plants including garlic mustard (*Aliara petiolata* (Bieb.) Cavara Grande) and buckthorn (*Rhamnus cathartica* L.) (Anderson et al. 1996; Bowles et al. 2005; Heneghan et al. 2006; Pearson 2006). For over twenty years, selected areas of a 225-ha oak woodland of the Morton Arboretum outside of Chicago, where this study took place, have been burned annually or periodically (every 3–4 years). The management goals of burning the Arboretum's East Woods have been to increase canopy light levels and decrease the density of exotic plants and the mesophytic shade-tolerant natives, including maple (*Acer* spp.) and basswood (*Tilia americana* L.). The goals are shared by natural areas land managers throughout northern Illinois (Fahey et al. 2014). Previous studies indicate that annual burning has brought about a more open canopy and greater native forb diversity, soil nutrient availability, organic carbon content, and soil moisture (Bowles et al. 2007; Scharenbroch et al. 2012). While these changes benefit overall plant diversity, oak recruitment has not increased and invasive species remain a problem. Other woodland studies have found that annual burning is associated with negative outcomes, including oak tree mortality (Peterson and Reich 2001), soil compaction (Phillips et al. 2000), and in the Morton Arboretum East Woods, greater incidence of tree cankers and tree colonization by the root rot fungi *Armillaria* spp. (Jacobs et al. 2004). The possibility that burning each year may be too frequent led us to compare annual and periodic burning while examining the status of the soil and litter invertebrate community.

Soil and litter invertebrates regulate essential ecosystem processes, including nutrient cycling and decomposition (Reichle 1977; Seastedt 1984; Wilson 1987; Lavelle et al. 2006). Nearly 80% of oak leaf litter is decomposed annually in temperate forests by micro- and mesofauna (Coleman et al. 2004). Certain orders including Oligochaeta (earthworms), Diplopoda (millipedes), and Hymenoptera (ants) mineralize nearly 50% of the nutrients for plant uptake (Nardi 2007). For these reasons, the diversity and abundance of soil and litter invertebrates is used to indicate ecosystem stability and also soil quality (Seastedt 1984; Stork and Eggleton 1992; Blair et al. 1996; Coleman et al. 2004; Nardi 2007). Efforts to manage woodland vegetation through prescribed burning ought to include assessments of soil and litter fauna, given their vital role in ecosystem processes. The objective of this study was to compare the soil and litter invertebrate community within annually burned, periodically burned (3–4 years), and unburned plots of the Arboretum's East Woods. The emphasis was on collecting and identifying as many microfauna as possible to a level of class and order, with hopes of obtaining an assessment of the broad invertebrate community.

METHODS

Site Description and Fire Characteristics

The study was conducted in the 225-ha East Woods of the Morton Arboretum, located in DuPage County, Illinois (41°48' N, 88°05' W). Average temperatures range from -4 °C in winter to 22 °C in summer, and mean annual precipitation is 93 cm (Calsyn 2001). An oak-hickory plant community dominates and includes three species of oak (*Q. alba* L., *Q. rubra* L., and *Q. macrocarpa* Michx.). Sugar maple (*Acer saccharum* Marsh.), American basswood (*Tilia americana*), and white and green ash species (*Fraxinus* spp.) represent most of the sub-canopy and sapling layer basal areas (Bowles et al. 2007). The area is best described as woodland according to Taft (1997), with a mixed understory of grasses, forbs, and woody species. Although variable, the canopy cover exceeds 80% in some areas (Bowles et al. 2007). The soils of the woodland are moderately well-drained Mollisols and Alfisols (Kelsey 2000).

Dormant season prescribed burning was initiated in 1986 with certain areas subjected to annual burns and others left unburned, or periodically burned, every 3–4 years. The burns are typically conducted in late fall/early winter, but weather conditions have necessitated an occasional February burn. The fires are low intensity, according to descriptions by Iverson et al. (2004) and Whelan (1995), with plant mortality confined to the understory and a patchwork of litter, ash, and charred woody debris remaining postburn. Flame temperatures were found to vary between 123 and 230 °C at the soil–litter interface (Jacobs et al. 2004). The last burn prior to sample collection occurred in November 2007 for annually burned areas, and November 2006 for periodically burned areas.

Plot Selection and Layout

Forty circular plots of 5-m radius each were located randomly within each of the burning treatment areas (Figure 1). Plots were intentionally positioned a minimum of 5 m from trails, roads, or ravines. The woodland is actively managed with fire, so it was not possible for the plots to be scattered throughout the landscape. The main source of environmental variation, aside from fire, is due to differences in soil type. Soils were classified as Ashkum silt loam, Beecher silt loam, and Ozaukee silt loam series prior to plot assignment in order to use soil type as a blocking variable. Twenty unburned plots, 10 annually burned plots, and 10 periodically burned plots were used with the three soil types fully represented within each burn treatment.

Soil Invertebrate Sampling and Extraction

Samples were collected three times—October 2008, May 2009, and October 2009—with all plots sampled within two days each time. Fifteen cores (subsamples) were collected from different azimuth positions within a 5-m radius of each plot center, and combined into one uniform composite sample per plot. The core samples were 2 cm in diameter, and 10 cm in depth (Oakfield Apparatus, Inc., Oakfield, WI). Composite samples were stored at 5 °C until invertebrate extraction, within one week.

A 100-gram subsample was taken from each composite soil sample and placed in a modified Berlese-Tullgren funnel (Brand and Dunn 1998). Funnels were extracted for three days, after which invertebrates were recovered in 70% ethanol until identified.

Litter Invertebrate Sampling, Extraction, and Litter Measurement

Litter samples were collected at the same time as soil by collecting three subsamples taken from different azimuth positions within 5 m of the plot center. Each subsample consisted of litter inside a 15-cm diameter metal cylinder that was lightly hammered into the ground. The depth of litter in each cylinder was measured down to mineral soil before collection into a seamless paper collection bag. Fresh weights of composite samples were done in the laboratory before being placed in their entirety into modified Berlese-Tullgren funnels as described for soils. Extractions were done for three days and specimens recovered were stored in 70% ethanol, as described for soil samples.

Invertebrate Identification and Measurement of Diversity

All invertebrate specimens collected from the funnels were poured into Petri dishes and examined using Nikon SMZ-2T and Motic SMZ-168 dissecting microscopes. Each specimen was examined and identified to class and order based on gross morphology using standard keys (Bland and Jaques 1978; Meyer 1993). Specimens of Acari and Collembola were further classified into suborders. Assistance in identifying specimens was also obtained from Drs. Raymond Brand and Fredric Miller (Research Associates, The Morton Arboretum) and Dr. Eric Peters (Zoologist, Chicago State University). Digital images were taken of representative specimens of each taxon, and voucher specimens stored with the primary author.

Shannon entropy (H) indices of diversity were calculated for each plot based on quantifying class and order richness, abundance, and evenness (Hutcheson 1970; Lande 1996; Stiling 2002). Diversity indices were also calculated for Acari subclasses collected at each sample date, and Collembola suborders collected from one sample date.

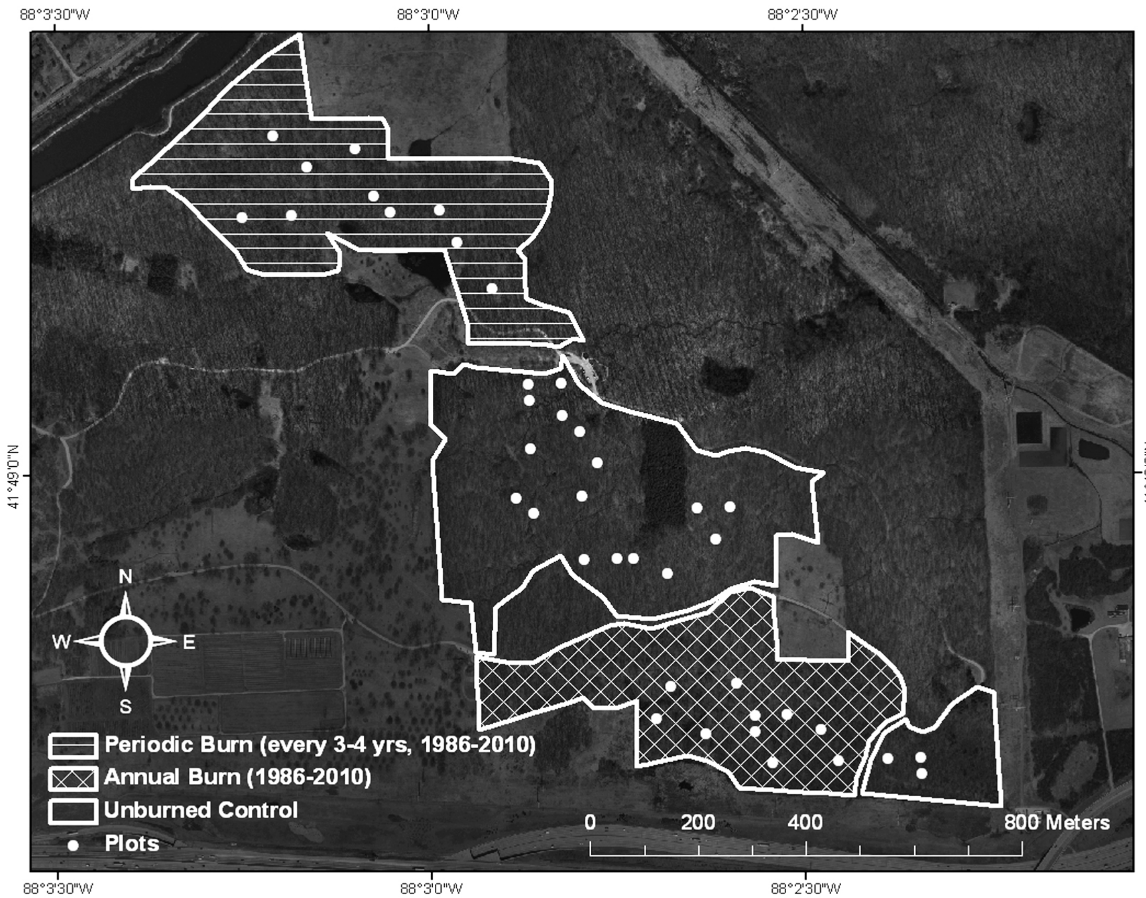

Figure 1. Map of East Woods showing annually burned, periodically burned, and unburned treatment areas and individual sampling plots (dots).

Statistical Analyses

The study was analyzed according to a randomized complete block design with burn treatment (annual, periodic, and unburned) as the main effect and soil as a blocking variable. Diversity and associated parameters, as well as litter depths and weights, were checked for normality and analyzed for differences due to the burn treatment using ANOVA and Tukey-Kramer HSD mean separation tests. Litter diversity data were transformed with square root or natural-log transformations. Back-transformed data are presented in the Results section. Soil data could not be normalized and so were analyzed using nonparametric Kruskal-Wallis and Chi-square tests (SAS 2005).

RESULTS

The composition of the East Woods invertebrate community is based on a total collection of 26,416 invertebrates, representing a richness of 21 taxa (4 classes and 17 orders) (Table 1). Twenty-five times more individuals were collected from litter (25,359) than soil (1057). All but three taxa were found in both substrates. Absent from soil were Orders Isopoda, Orthoptera, and Gastropoda. The most abundant taxa were in the subclass Acari (mites) and class Collembola (springtails). The former represented 76% of all individuals collected, with order Oribatida alone accounting for 42%. Class Collembola represented 17% of the total collection, with order Entomobryomorpha being most common. Order Hymenoptera (ants, bees, wasps, sawflies) was the third most abundant, at 639 individuals or 2% of the total population. The remaining 18 classes and orders, together, represented just 5% of the total population. Six taxa were collected fewer than 20 times, and 15 taxa accounted for less than 0.01% of the total collection (Table 1).

Soil type was not found to cause a significant effect and so was dropped as a blocking variable for the results presented. The Shannon entropy index of diversity (H) was significantly greater ($P \leq 0.05$) in litter compared with soil samples (H = 0.75 vs. H = 0.45, respectively), but within each substrate, ANOVA and Chi-Square revealed burning was not associated with different invertebrate diversity indices

Table 1. Abundance by class/order of litter and soil invertebrates collected during 2008–09 from three burn treatments in the Morton Arboretum's East Woods.

Taxa	Annual Burn	Periodic Burn	Unburned	Total Abundance (relative proportion)
(Subclass) Acari	167.17	203.53	149.13	20069 (0.76)
Oribatida	85.77	119.23	80.90	11004 (0.42)
Mesostigmata	8.57	15.53	13.37	1525 (0.06)
Prostigmata + Other	72.83	68.77	54.87	7540 (0.29)
(Class) Collembola	30.20	38.53	39.35	4427 (0.17)
Entomobryomorpha [a]	3.30	10.90	6.20	266 (0.01)
Poduromorpha [a]	5.00	5.70	4.50	197 (<0.01)
Symphypleona [a]	0.30	1.10	0.35	21 (<0.01)
Other [a]	5.20	10.00	8.95	331 (0.01)
Hymenoptera	11.03	3.63	3.15	629 (0.02)
Coleoptera	1.80	1.83	1.32	188 (<0.01)
Diptera	1.90	0.97	1.42	171 (<0.01)
Thysanoptera	2.77	0.63	0.75	147 (<0.01)
Isopoda	1.67	1.27	0.75	133 (<0.01)
Araneae	1.43	1.40	0.78	132 (<0.01)
Pseudoscorpionida	0.53	0.97	0.93	101 (<0.01)
(Class) Oligochaeta	0.63	0.37	1.00	90 (<0.01)
(Class) Diplopoda	0.37	1.33	0.30	69 (<0.01)
(Class) Chilopoda	0.23	1.00	0.45	64 (<0.01)
Psocodea	0.37	0.07	0.07	17 (<0.01)
Protura	0.03	0.07	0.20	16 (<0.01)
Hemiptera	0.03	0.27	0.08	14 (<0.01)
Dipluran	-	0.07	0.08	7 (<0.01)
(Class) Gastropoda	-	-	0.03	2 (<0.01)
Orthoptera	0.03	-	-	1 (<0.01)
Cumulative Abundance	203.09	243.54	176.99	26416 (litter : 25,359) (soil: 1057)

Note: Values are averages from three sampling dates and 10 annually burned, 10 periodically burned, or 20 unburned plots. Taxa are arranged in descending order of total abundance.

[a] Collembola orders identified for one sampling date only (October 2009).

(Table 2). Neither did taxa richness, abundance, density, or evenness differ among burn treatments (Table 2). Average sample richness (S) was approximately two in soils across all burn treatments compared with seven in litter. Evenness (J) values were moderate to low overall, but greatest in soil compared with litter (soil J = 0.4–0.57; litter J = 0.3) (Table 2). Further analyses of diversity within the two most abundant taxa, subclass Acari and class Collembola, indicated that Acari order diversity was significantly less ($P = 0.0005$) in annually burned plots (H = 0.72) compared with unburned plots (H = 0.85). Periodic burn plots had an intermediate diversity index (H = 0.79) (Table 3). Diversity estimates among burn treatments did not differ within class Collembola, but this was only compared for one sample date.

Litter depth and weight varied substantially within each burn treatment, but no significant differences due to burning were detected ($P \leq 0.05$) (Table 4). Litter depths in unburned plots were most variable and ranged from 0.71 to 5.49 cm sample^{-1}. Likewise, air dried litter weights from unburned plots ranged from 38.8 to 270.6 g sample^{-1}.

The date of sampling was associated with significant changes in soil, but not litter invertebrate communities (Table 5). Both fall collections (October 2008, 2009) had significantly greater ($P \leq 0.01$) Shannon indices of diversity (H = 0.54), and average abundances (9.7 and 11.8, respectively) compared with the spring collection (May 2009) (H = 0.27; abundance = 3.90). Litter diversity indices did not change from spring to fall, but declined significantly ($P = 0.0002$) over the course of the study (H = 0.84–0.62) (Table 5). ANOVA did not detect changes in litter invertebrate abundance across sampling dates.

Acari population changes due to sampling date were similar to those found for the entire invertebrate community (Table 3). Soil diversity within Acari was significantly greater in fall collections (H = 0.29, 0.39) compared with spring (H = 0.09). Likewise, average Acari abundance in both fall collections (7.50, 9.13 individuals sample^{-1}) was significantly greater than in spring (2.83 individuals sample^{-1}). The sampling date did not appear to affect Acari diversity in litter, but abundance in litter was significantly lower ($P = 0.046$) in May 2009 than in either October collection (Table 3). The abundance of class Collembola was affected significantly by sampling date ($P = 0.0001$), but the trend was the reverse of that seen for Acari: spring Collembola had greater abundance (59 individuals sample^{-1}) compared with fall (30 and 20 individuals sample^{-1} for October 2008 and 2009, respectively). Diversity within class Collembola was calculated for one collection only (Fall 2009 only) and so potential sample date effects could not be assessed.

DISCUSSION

The long-term practices of annual and periodic burning in the Morton Arboretum East Woods were not associated with significant

Table 2. Average invertebrate diversity and related parameters from samples collected during 2008–09 from three burn treatments in the Morton Arboretum's East Woods.

	Burn Treatment				Analysis[a]	
	Annual	Periodic	Unburned	Combined		
Soil Invertebrates					X^2	Prob>X^2
Shannon Entropy Index (SE)	0.46 (.07)	0.43 (.08)	0.46 -0.06	0.45 -0.07	0.25	0.88 ns
Richness (S)	2.10	2.10	2.10	2.10	0.01	1.00 ns
Abundance	7.23	9.83	8.38		0.13	0.51 ns
Density (invertebrates • g substrate^{-1})	0.07	0.10	0.08	0.083	1.34	0.51 ns
Evenness (J)	0.50	0.40	0.57		1.03	0.60 ns
Litter Invertebrates					F Value	Prob>F
Shannon Entropy Index (SE)	0.73 -0.07	0.78 -0.07	0.74 -0.06	0.75 -0.066	0.22	0.80 ns
Richness (S)	7.57	7.83	6.95		1.07	0.35 ns
Abundance	214.10	247.83	192.38		0.50	0.61 ns
Density (invertebrates • g substrate^{-1})	2.51	2.67	2.35		0.01	0.99 ns
Evenness (J)	0.39	0.40	0.40		0.16	0.85 ns

Note: Values are averages based on composite samples taken from each of 10 annually burned, 10 periodically burned, and 20 unburned plots. SE = standard error. "ns" indicates variances were not significantly different across burn treatments at $P = 0.05$ level.

[a] Soil data were analyzed using Kruskal Wallis/Chi-Square; litter data were normalized with square root or log transformations and analyzed using ANOVA and Tukey Kramer tests. Data presented are back-transformed. Burn Treatment × Sample Date interaction effects were not significant ($P = 0.05$).

changes in abundance or diversity of the broadly classified soil and litter invertebrate community. This contrasts with a number of studies in temperate forests that have found invertebrate diversity, abundance, or both, declining after prescribed burning (Crossley et al. 1997; Siemann et al. 1997; Brand 2002; Moretti et al. 2004; Coleman and Rieske 2006; Ferrenberg et al. 2006; Bezkorovainaya et al. 2007). However, the studies mentioned collected samples soon after the burning event during what Coleman and Rieske (2006) have referred to as a "shock phase." Postfire faunal recolonization rates were documented, but ranged from several months (Siemann et al. 1997) to years (Crossley et al. 1997; Ferrenberg et al. 2006; Bezkorovainaya et al. 2007), depending on factors including fire intensity, stand structure, and edaphic conditions. Sampling was initiated in our study one year postburn in annually burned plots, and two years in periodically burned plots, opening up the possibility that the "shock phase," if it occurred, was missed. Nonetheless, it is still surprising that prolonged changes to the broadly classified invertebrate community of soil and litter were not evidenced despite 23 years of burning.

Another possible contributing factor leading to similar invertebrate communities, within burned and unburned treatments, is that the burns practiced in the East Woods are low intensity fires that leave a patchwork of litter, ash, and charred woody debris (Whelan 1995; Iverson et al. 2004). Higher intensity fires, in contrast, would cause more direct invertebrate mortality and combust the litter layer more completely, thus removing crucial refugia habitat and food sources for microinvertebrates (Neary et al. 2005). Boerner (2000) notes that for soil microinvertebrates to die, temperatures must surpass 70 ºC for at least 10 minutes. A prescribed burn in the East Woods was found to produce maximum flame temperatures of 230 ºC at the soil–litter interface (Jacobs et al. 2004), but when thermocouples were used to monitor soil temperatures during a fire, the temperature at 10-cm depth increased to just 17 ºC (Scharenbroch et al. 2012).

Table 3. **Acari and Collembola diversity and overall abundance from samples collected during 2008–09 from different burn treatments and sampling dates in the Morton Arboretum's East Woods.**

A) Acari

		Burn Treatment			Prob > F or X^{2a}
		Annual	Periodic	Unburned	
Abundance					
	Litter	162.1 a	195.2 a	142.9 a	0.69 ns
	Soil	5.07 a	8.30 a	6.28 a	0.41 ns
Shannon Entropy Index (H)					
	Litter	0.72 a	0.79 ab	0.85 b	0.0005**
	Soil	0.23 a	0.29 a	0.26 a	0.69 ns
		Sample Date[b]			
		October 2008	May 2009	October 2009	
Abundance					
	Litter	159.6 b	136.5 a	186.2 c	0.046*
	Soil	7.50 b	2.83 a	9.13 b	0.0001**
Shannon Entropy Index (H)					
	Litter	0.83 a	0.76 a	0.82 a	0.14 ns
	Soil	0.29 b	0.09 a	0.39 b	0.0001**

B) Collembolla

		Burn Treatment			Prob > F or X^{2a}
		Annual	Periodic	Unburned	
Abundance					
	Litter	29.47 a	37.93a	38.55 a	0.15 ns
	Soil	1.29 a	0.90 a	0.17 a	0.57 ns
		Sample Date[b]			
		October 2008	May 2009	October 2009	
Abundance	Litter	29.85 b	58.83 a	19.70 c	0.0001**
	Soil	0.74a	1.68 b	1.50 b	0.0001**

Note: Values are averages of composite litter and soil samples collected from 10 annually burned, 10 periodically burned, and 20 unburned plots at three sampling dates. Collembola diversity was not compared among sampling dates (see Methods). Different lowercase letters indicate means are significantly different at $P = 0.05$ level. * and ** indicate differences at $P \leq 0.05$ and $P \leq 0.01$ levels, respectively. "ns" indicates variances were not significantly different across treatments. Sampling Date × Burn Treatment interaction effects were nonsignificant ($P = 0.05$).

[a] Soil data were analyzed using Kruskal-Wallis/Chi Square tests and litter data were transformed to fit the assumption of normality, and then analyzed with ANOVA and Tukey-Kramer tests. Values presented are back-transformed.

[b] Sample date analyses are based on collections from 40 plots combined across burn treatments.

The litter depths measured in this study were nearly the same on average in all treatments, including unburned plots. Litter air dried masses were greatest in periodically burned plots, but similar in annually burned and unburned plots (Table 4). Litter provides both habitat and food for microfauna postfire (Iverson and Hutchinson 2002; Certini 2005; Neary et al. 2005), and litter mass, spatial arrangement, stage of decomposition, and nutritional quality have been shown to impact both invertebrate abundance and diversity (Crossley and Hoglund 1962; Mitchell 1978; Heneghan et al. 1999; Ponge 1999). Recently, Steffen et al. (2012) identified a positive relationship between the mass of woodland litter and mite diversity, as well as the ratio of mite suborders, as indicators of disturbance. While measurement of litter postburn has not been an objective of management in

Table 4. Depth and mass of leaf litter measured during 2008–09 in three burn treatments of the Morton Arboretum's East Woods.

	Average Depth (cm)				Average Mass (g) (g m^{-2})			
	Annual Burn	Periodic Burn	Unburned	Prob > F	Annual Burn	Periodic Burn	Unburned	Prob > F
Mean	2.77 a	3.09 a	2.92 a	ns	84.7 a	95.4 a	85.64 a	ns
				(P = 0.498)	(1500)	(1690)	(1518)	(P = 0.154)
Min.	1.29	1.48	0.71		49.00	55.00	38.80	
Max.	4.75	5.63	5.49		141.80	183.70	270.60	
Range	3.46	4.15	4.78		92.80	128.70	231.80	

Note: Values are from composite air-dried samples collected in 10 annually burned, 10 periodically burned, and 20 unburned plots at three sampling dates. "ns" indicates variances were not significantly different across treatments.

the "East Woods," it may be worthwhile to do going forward. Certainly the practice of leaving adjacent litter refugia is common when burning prairies to hasten invertebrate recolonization (Panzer 2002; Howard and Hill 2007; Doxon et al. 2011).

The seasonal differences found in invertebrate diversity and abundance from soil were expected and underscore the importance of interspersing sampling times between spring and fall. Numerous studies from a range of forest types have documented seasonal fluctuations in microinvertebrates (Ponge 1999; Arroyo and Iturrondobeitia 2006; Fagan et al. 2006; Wang and Tong 2012). Collembola populations in northeastern Illinois are more abundant in spring (Brand 2002), but other taxa, including Acari, increase in abundance during fall due to inputs from leaf drop (Behan-Pelletier and Walter 2000). Some taxa migrate downward in the soil profile (Dowdy 1944; Ponge 1999) and others die-off (Fagan et al. 2006; Wang and Tong 2012) as temperatures drop. It is worth noting that litter invertebrate diversity was apparently unaffected by season of sampling in our study, but instead varied from year to year. Diversity was greatest during the first fall (H = 0.84). A major difference between years was the amount of fall precipitation. The greatest cumulative rainfall on record (346.2 mm) was recorded for northeastern Illinois in September 2008, just prior to sample collection. In contrast, below average rainfall (26.2 mm) occurred the following September (data from NOAA 2010). Soil gravimetric pressure in the

Table 5. Soil and litter invertebrate diversity and abundance at different sampling dates.

	October 2008	May 2009	October 2009	Prob > F [a]
Litter Diversity (Shannon Entropy Index H)	0.84 a	0.79 a	0.62 b	0.0002 **
Litter Abundance (# individuals sample^{-1})	209.9 a	206.6 a	218.6 a	0.35 ns
				Prob > Chi Sq [a]
Soil Diversity (Shannon Entropy Index H)	0.54 a	0.27 b	0.54 a	0.0012**
Soil Abundance (# individuals sample^{-1})	9.65 a	3.90 b	11.83 a	0.0001**

Note: Values are averaged from 40 samples collected across burn treatments at each sample date. Different lowercase letters indicate means are significantly different at P = 0.05 level.

[a] Soil data were analyzed using Kruskal-Wallis/Chi Square tests. Litter data were transformed to fit normality assumptions and then analyzed with ANOVA and Tukey Kramer tests. Values presented are back-transformed. ** indicates highly significant difference at $P \leq 0.01$ level. "ns" indicates variances were not significantly different across sample dates.

East Woods was also significantly different between years (Scharenbroch et al. 2012). Because survival of many microfauna declines following periods of low rainfall (Staley et al. 2007), it seems worthwhile to consider soil and litter moisture levels at the time of sampling.

The most abundant class or order collected in the East Woods was Acari. This is not surprising given that mites account for over 80% of all arthropods in soil and litter worldwide (Osler and Beattie 2001; Nardi 2007). Despite no significant changes in Acari abundance among burn treatments, the Acari diversity in litter collected from annually burned plots was lower compared with unburned plots (and periodically burned samples were intermediate) (Table 3). Acari assemblages from annually burned plots had similar, but slightly lower, proportions of Oribatida (51%) and Mesostigmata (5%) than in unburned or periodically burned plots, and a higher proportion of "other" that included Prostigmata (43% vs. 33–36%) (Table 1). Oribatid mites feed upon detritus and fungi and are closely tied to decomposition in woodlands (Heneghan et al. 1999; Minor et al. 2004). They are generally slower to recover from disturbances than other mites (Lindberg and Bengtsson 2006), and so their similar proportional abundances across treatments supports the notion that annual burning is causing relatively minor disturbance to the woodland, and that decomposition and nutrient availability are stable (Neary et al. 1999; Camann et al. 2008). Measurements of greater soil particulate organic matter, organic carbon, and nitrogen availability within annually burned plots in the East Woods (Scharenbroch et al. 2012) further support this claim.

There is a tradeoff that comes with applying a broad taxonomic approach when evaluating invertebrate diversity. Moretti et al. (2004) note that identifying many classes and orders simultaneously helps avoid overly general conclusions based on results of one order, such as Oribatida. However, a broad focus will undoubtedly miss changes in species richness and shifts in species assemblages. For example, prescribed burning in western pine and Appalachian hardwood forests of the United States has been reported to reduce Acari species richness and diversity (Crossley et al. 1997; Camann et al. 2008). A review of Table 1 shows taxa that changed markedly, albeit not significantly, in abundance within burned versus unburned plots. One example is the order Entomobryomorpha (class Collembola), which was half as abundant in annually burned compared with unburned plots (Table 1), in accordance with Brand's previous results (2002). In contrast to springtails, orders Hymenoptera, Thysanoptera, and Araneae were more than twice as abundant in annually burned plots than unburned plots, supporting previous findings of Siemann et al. (1997), who detected significant postfire reductions in the same taxa. Having now attained a baseline assessment of the broad microfaunal community in the "East Woods," a meaningful, but target, assessment of the aforementioned taxa, or selected Acari species that are known to be fire sensitive (see Hanula and Wade 2003; Camann et al. 2008), could be undertaken. Another approach would be to compare ratios of Acari suborder abundances, as low Oribatida: Prostigmata ratios have been linked with higher levels of woodland disturbance (Steffen et al. 2012). These efforts would refine current burning (and other management) practices and better preserve ecosystem biodiversity.

CONCLUSION AND MANAGEMENT IMPLICATIONS

This is the first assessment of the broad soil and litter invertebrate community present in the "East Woods," and the influence of long-term annual and periodic burning on invertebrate assemblages. The findings suggest that little difference exists between the burned and unburned treatments, regardless of whether burning is done annually or every 3–4 years. The reason for the similarity among treatments remains unclear, but may be in part due to the low intensity fires and remaining refugia litter. There are important implications for land managers. Invertebrate assemblages and the ecosystem processes they regulate, such as decomposition, appear not to be compromised by long-term burning for vegetation management. However, there seems reason to favor periodic (3–4 years) burning over annual burning due to the reduced Acari order diversity found in annually burned plots, and prior findings of Brand (2002), who measured lower Collembola richness in annually burned plots. Annual burning can also cause stress and unintended injury to native vegetation, as noted in the Introduction. Fire return intervals of 2–3 years have been recommended in southern US and neotropical forests in order to maintain favorable microarthropod assemblages (Coleman and Rieske 2006; Vasconcelos et al. 2009). Lastly, postburn assessment of refugia litter amounts, along with tracking of selected Acari and Collembola as mentioned above, may be helpful in guiding the frequency and intensity of burns.

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