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Final Report for Wildlife Preservation Fund contract # 98-050 to study the effect of burning on epigeic springtail insects of oak woodlands

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Introduction

Fire has been used as an effective tool in ecological restoration management for a number of years. Usually, it has been employed to eradicate unwanted exotic plant species that have invaded a native ecosystem. In both prairie and woodland restorations, prescribed burning has become an annual or regular feature of the management protocol. A few studies have focused attention on the effect of burning on arthropod populations as indicated in the references at the end of this report. In this study, comparisons are made of the diversity (richness) and abundance of springtail insects in the burned and unburned areas of two different woodland sites.

One site is the East woods of the Morton Arboretum, a second growth woods of hardwood species (oak, hickory,maple, linden, cherry, etc.), that has been set aside as a natural area since the founding of the arboretum in 1922. Many areas of these woods have become almost entirely composed of maple species. Partly as an experiment in an attempt to maintain a higher diversity of hardwood species, prescribed annual burning for over ten years has been used for a large section of the woods south of the main road (Forest Road) that goes through the woods at the East end of the arboretum. In most areas of the woods there is a closed canopy formed by the mature trees.

The other site is known as Lincoln Marsh in Wheaton, Illinois. In addition to the wetland areas, there are two oak woodland sections on the higher elevations. Most of the tree species are oaks (burr, white, red) with a few hickories and cherry. The plant diversity here (both herbaceous and canopy species) is much less than at the East woods of the arboretum. In addition, this site differs in that the canopy is more open and has been labelled a savannah on some of the maps of the area. The Wheaton Park District owns this property and has been attempting to restore part of it as a natural area. Fire as a management tool has been used in this area only since 1994.

Both heterotrophic and autotrophic species are integral components of the ecosystem. It is hoped that the results of this study, concentrating on one of the heterotrophic components, the springtail insects, will provide useful information for the future management of these woodlands, and perhaps others, where restoration attempts are in progress.

Materials and Methods

Samples of above ground vegetation and litter were collected from the two sites yielding a total of 108 samples, 54 from each site, with 27 from each site of burned and unburned areas.

Three seasons, spring, summer, and fall were represented in the samples obtained. The plant material and litter from two, foot-square quadrat samples was put into plastic bags and transported to the laboratory in ice-cooled chests. Modified Berlese funnels (Tullgren) were used to extract the invertebrates from the litter for a period of four days for long-term storage in jars of alcohol preservative. Initial sorting of springtails into species and counting of individuals was done using a low power binocular microscope. Higher magnification was sometimes required and some specimens were sent to consultants for identification and confirmation of species determinations. Following extraction of the invertebrates, the dried plant and litter biomass was weighed to the nearest gram for possible future use in correlation studies with the abundance of springtails. Data for the litter material and numbers of springtails were transformed from the two, square foot sampling units to per square meter values for comparison with published values in the literature. More details on materials and methods are included in the reprint of a recent publication enclosed with this report. Although this publication compared springtails in native and restored prairies, many of the procedures and methodology were similar to the present study (except for the statistical analysis).

Since enumeration data were involved in the number of species and in the number of individuals collected in each sample, a chi-square analysis was appropriate for the comparison of burned and unburned areas of the two sites. Although an ANOVA statistical analysis had been anticipated for the results of this study, it was not possible to use this analysis since a new version of the software, Statistix for Windows, replaced the former Statistix program in my computer and was unavailable for use at this time.

An unusually large number of springtails (e.g.- up to 3,000 per square meter) was encountered in the spring samples from the unburned areas of the East woods of the arboretum. Consequently, the time to complete the sorting and counting of these samples precluded an ANOVA analysis. It should be possible, however, to include additional sample data from the East woods from a previous study, carry out this type of analysis later this year, and submit a paper for publication of these results.

Results

Springtails.-- One measure of the diversity (richness component) of a habitat is the number of species it contains along with an indication of the variability within the sample The mean number of springtail species +/- the standard deviation per sampling unit (two square feet) for the 108 samples from both sites was 7.50 +/- 2.56 . For the 27 burned and 27 unburned areas of each site the results are summarized below:

Lincoln Marsh		East Woods	
Burned	Unburned	Burned	Unburned
7.19 +/- 2.32	7.29 +/- 2.45	6.52 +/- 2.49	9.00 +/- 2.42

Table 1 - Number of species per sampling unit

If the assumption is made that previous fires on the area have no effect on the number of species collected there later, a chi-square analysis can be used to test this assumption. For

Lincoln Marsh this assumption is obviously valid, but not for the East Woods where a chi-square of **5.36** with 1 d.f. is obtained (**.05 > p > .02 ***). When seasonal (spring,summer,and fall) effects are considered, there are no significant differences using chi-square analysis for the number of species in the burned and unburned areas of Lincoln Marsh. For the East Woods there are no differences in the fall in number of species for burned and unburned areas, but a chi-square analysis between spring and summer for burned and unburned areas resulted in a chi-square of **18.96** with 1 d.f. and **p < .01 ****.

In addition to the number of species, the identification of which species are present can be useful for comparative studies if other ecological information is available about any given species. The following table (Table 2) provides a list of the species identified in this study indicating which ones are common to both sites and which are found only at one of the sites. Lincoln Marsh did not have any species not found at the East Woods. Several forms are identified only to Genus at the present time. One species from the East Woods is new to science and will be described and submitted for publication by one of the consultants used in this study.

Code letter	Name of Species
EW	1. - Bourletiella russata
C	2. - Entomobrya sp.(undetermined)
C	3. - Folsomides parvulus
C	4. - Hypogastrura packardi (summer form)
C	5. - Isotoma notabilis
C	6. - Isotoma viridis
C	7. - Isotoma sp. (undetermined)
EW	8. - Katiannina macgillivrayi
C	9. - Lepidocyrtus fernandi
C	10. - Lepidocyrtus paradoxus
C	11. - Neanura muscorum
C	12. - Onychiuris sp. (undetermined)
C	13. - Sminthurinus elegans
C	14. - Sminthurinus henshawi
EW	15. - Sminthurinus new species A
C	16.- Tomocerus flavescens
C	17. - Tullbergia ruseki
EW	18. - Tullbergia sp. (undetermined)
C	19. - Xenylla grisea

Table 2 - List of species identified in this study
(Code = C = common to both sites; EW = East Woods only)

In addition to diversity, the abundance of a species is an important factor in assessing the role of that species in the ecosystem as a whole. The total number of springtails collected from the 108 samples in this study was 76,691. The mean number per square meter with the sample standard deviation was 710.1 +/- 709.8. If the assumption is made that there is no effect on the abundance of springtails collected from formerly burned or unburned areas, then a chi-square analysis can be performed for the two sites and for the different seasons during which sampling was done. A summary of these comparisons for the burned and unburned areas of both sites follows in Table 2.

Lincoln Marsh		East Woods	
Burned	Unburned	Burned	Unburned
N = 27	N=27	N= 27	N=27
# ind. = 15360	# ind. = 12912	#ind. = 14237	#ind. = 34182
Mean = 568.9	Mean = 478.2	Mean = 527.3	Mean = 1266.0
s.d. = 620.1	s.d. = 372.4	s.d. = 409.2	s.d. = 975.1

Table 2 - Numbers of springtails

Comparing all burned sites to all unburned sites, there were significantly more springtails collected at unburned sites (**X^2 = 39.92**, d.f.= 1, **p < .01 ****). At Lincoln Marsh there were significantly more springtails collected from the burned than the unburned areas (**X^2 = 211.97**, d.f. = 1, **p < .01 ****). In the East Woods the reverse occurred. There were significantly more springtails from the unburned than the burned areas (**X^2 = 8214**, d.f. = 1,**p < .01 ****)

If the numbers of springtails collected from burned and unburned areas are compared for the different seasons (spring, summer, and fall), there are significant differences at Lincoln Marsh for all three seasons. There are more from the burned areas in the spring and summer, but more from the unburned areas in the fall (**X^2 = 264.3 ; 231.5; 227.5**, d.f. = 1, **p < .01 ****) for all three comparisons. In the East Woods the only significant difference, seasonally, occurs in the fall where the number of springtails is greater in the burned than in the unburned areas (**X^2 = 257.4**, d.f. = 1, **p < .01****). For the spring and summer seasons the East Woods samples are not comparable since samples were obtained from the burned and unburned areas in different seasons. As indicated earlier, it should be possible to make these comparisons when additional data from a previous study is included. It seems likely that the large numbers of springtails from the unburned areas in the East Woods (see Table 2) will result in significant differences in the spring and summer seasons when such comparisons are made.

Litter and plant biomass -- The mean value in grams per square meter of the dried litter and plant biomass for the two sites for all samples collected (N = 108) was quite similar (Lincoln Marsh = 1924.9 +/- 792.4 and the East Woods = 1960.2 +/- 928.5). However, the assumption that that these two sites do not differ in plant litter and biomass can be discarded according to the results of a chi-square analysis (**X^2 = 17.3**, d.f. = 1, **p < .01****). Table 3 indicates the different amounts of biomass for the burned and unburned areas for the two sites. Both sites have significantly more biomass in the unburned areas.

	Lincoln Marsh		East Woods	
	Burned	Unburned	Burned	Unburned
N	27	27	27	27
Mean	1693.3	2156.4	1812.7	2107.0
s.d.	+/- 704.0	+/- 820.5	+/- 106.5	+/- 760.7

Table 3 - Litter and Plant Biomass (g/sq/m)

For all seasonal (spring,summer, and fall) comparisons of litter and plant biomass at both sites, there is more biomass in the unburned areas with one exception. This exception is the fall season in the East Woods where the burned area biomass is greater then the unburned.

Discussion

The use of prescribed burning has become an important management method in restoration ecology. Many of the projects that have been attempted to date have concentrated on the plant components to be restored without sufficient attention to the animal components. Although annual burning may have minimal effects on larger, mobile animals, the diversity of the smaller invertebrate fauna may be subject to frequent depletion. The past history of fire is problematic for most forest ecosystems (Dickman and Rollinger, 1998). Although natural fires obviously occurred in the past, the frequency and intensity are generally unknown, and prescribed fire regimes should be based on empirical evidence for the restoration site under study (Myers, 1997). In some cases, particular sites may harbour the entire population of a species in a given area as Panzer has shown for some of the rare or endangered species of Lepidoptera (Panzer, 1988). Of interest in this study is the fact that the new species of Symphypleonid was taken only from a few of the large permanent quadrats in the unburned areas of the East Woods. Over 80 specimens of this form were collected which suggests that either their distribution has not yet extended to the burned areas, or that pioneer emmigrants of this species beyond their present range have not been successful in establishing new population centers as a result of frequent burning.

Springtails, unlike many other insects, have a thin exoskeleton and are restricted in habitat distribution to environmental conditions of adequate humidity. It is not only the high temperatures associated with fire, but the subsequent xeric conditions following burning that are inimical to their survival and establishment. In addition to their role in the decomposition process of breaking down plant material into smaller pieces through gut transport, they function as prey in the food web to many of the smaller invertebrate predators, especially spiders.

There were 19springtail species identified in the study which is somewhat below the 27 reported in a previous study of native and restored prairies (Brand and Dunn, 1998). However, that study covered a greater geographic area and was conducted in substantially different habitats.

For all the samples collected there were more total springtails from unburned than burned areas. At the Lincoln Marsh site the reverse was the case. A possible explanation for this may be that the burned areas there were closer to the cattail marsh wetland with more soil moisture and higher humidities than the unburned areas higher up on the knoll. In the study of the effects of fire on soil invertebrates in Australia, high intensity fires had adverse effects (Coy, 97). Although most taxa increased after fire in this study, the above ground fauna was not differentiated from the soil fauna. Coy also refers to several studies in Australia which obtained lower invertebrate numbers after fire.

With respect to the vegetation and plant litter, the mean values for the two sites are misleading since the Lincoln Marsh site has an open canopy and considerably less herbaceous vegetation than most of the areas of the East Woods of the Morton Arboretum. However, when the total weight of the litter for both sites is analzed further, using chi-square analysis, the greater weight for the East Woods litter is significantly different than that for the Lincoln Marsh.

Summary

In this study information is provided about the diversity and abundance of epigeic springtail insects from woodland habitats where fire has been used as a restoration technique to obtain a desirable mix of native hardwood and herbaceous species. Springtail insects are generally abundant in woodland habitats and are an important component of the decomposition process since they feed on decaying plant and fungal parts found in the litter layer.

Vegetation and plant litter was collected from two woodland sites in DuPage County, Illinois, Lincoln Marsh in Wheaton and the Morton Arboretum in Lisle. Of the total number of samples (108), an equal number was obtained from areas that had been burned and not burned in the past. The plant material was then placed in modified Berlese funnels (Tullgren) for four days to extract the invertebrates into small jars of preservative. Springtail insects were sorted, identified, and counted.

As one measure of the diversity of species, the mean number of species per sampling unit was obtained. For Lincoln Marsh there was no difference in the number of species from the burned and the unburned areas. However, in the East Woods of the arboretum there were more species of springtails from the unburned than the burned area. Lincoln Marsh had 15 different species, whereas the East Woods had these 15 plus four other ones for a total of 19, including a species new to science. Of interest is that all four of these that were different from those at Lincoln Marsh were species from the Suborder Symphypleona which contains the more complex forms of the Order Collembola.

Taking the total number of actual springtail insects collected (13,941) and multiplying by the transformation factor (5.38) to convert the sampling unit to square meters, over 75,000 springtail insects would have been in the study or an average of about 700 per square meter. More springtails were obtained from all unburned than burned ares from both sites. However, when each site is considered separately, samples from Lincoln Marsh reverse this, with more from the burned areas. The East Woods samples, where burning has been used for a much longer time, have more springtails from the unburned than the burned areas. Seasonal effecdts are more difficult to interpret since there are no clear seasonal trends one way or the other. Numbers of springtails do not appear to correlate positively with amounts of plant litter for the various seasons. Abundant food availability in both burned and unburned areas make food an unlikely limiting factor. Presumably, a more continuous and abundant litter layer in the unburned areas over time, resulting in higher moisture content, should provide an optimum habitat for proliferation of more springtails. This appears to be the case for totals of the entire study, but inconsistencies for the seasonal data suggest that additional studies should be considered before conclusions can be reached about seasonal effects.

The plant and litter biomass from the two sites appears to be quite similar in weight on a per ssquare meter basis with only a 35 gram difference in the means for all samples. Hoiwever, using a chi-square analysis, there is more plant and litter biomass in the mature, closed canopy East Woods than in the Lincoln Marsh woodland.

From these preliminary results of a one year study, it is suggested that the above ground springtail fauna and populations might be hindered if fire is used annually over a long period. Modifications such as burning every other year, providing refuge areas for invertebrates throughout the burn area, and similar protocols should be considered . Since the springtails are only one component of the invertebrate fauna, it is imperative for the health of the ecosystem that all elements be taken consideration when restoration management plans are formulated.

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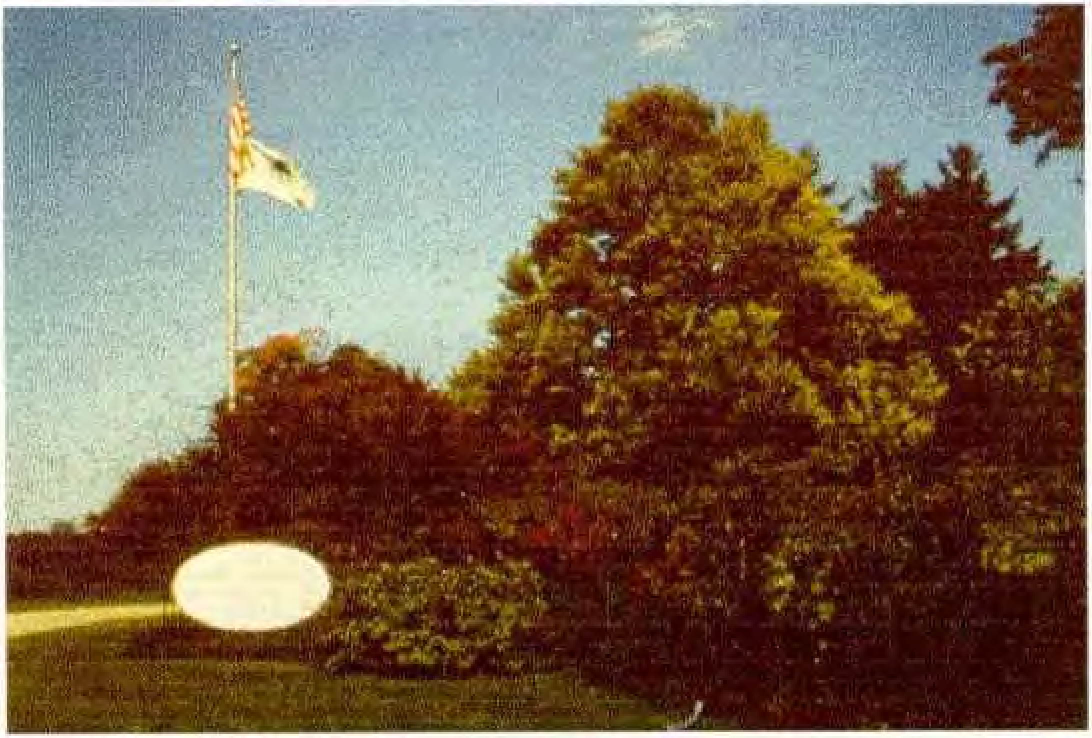
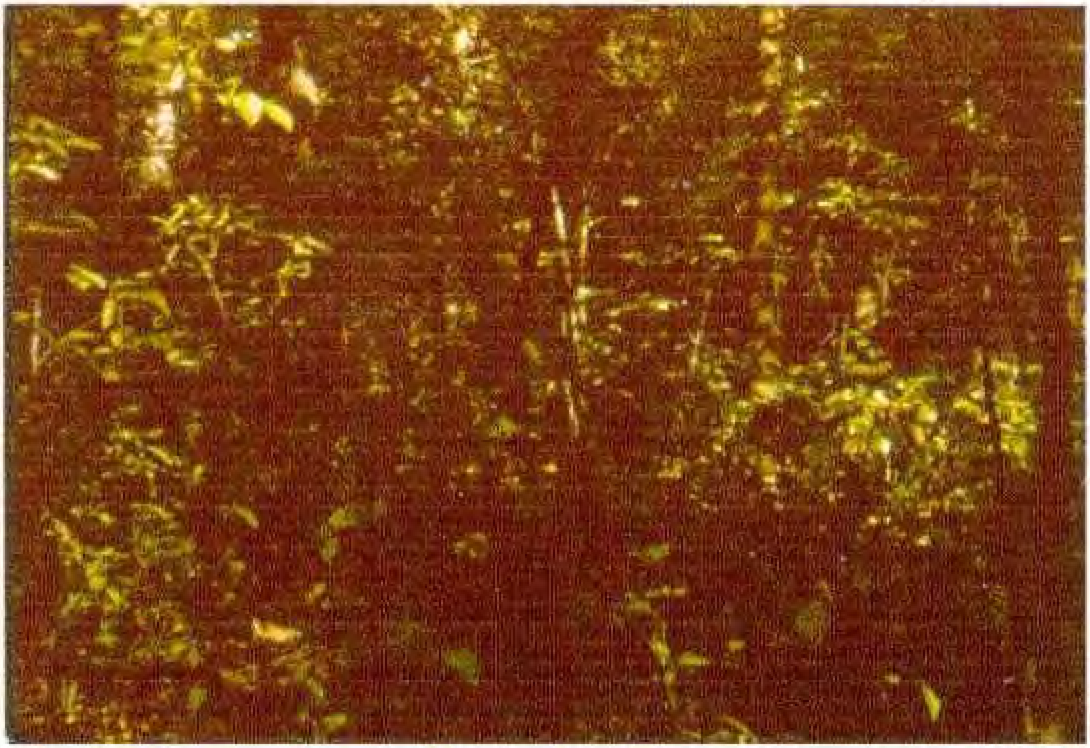
Oak Woodland at Lincoln Marsh

Head and antennae of Tomocerus flavescens



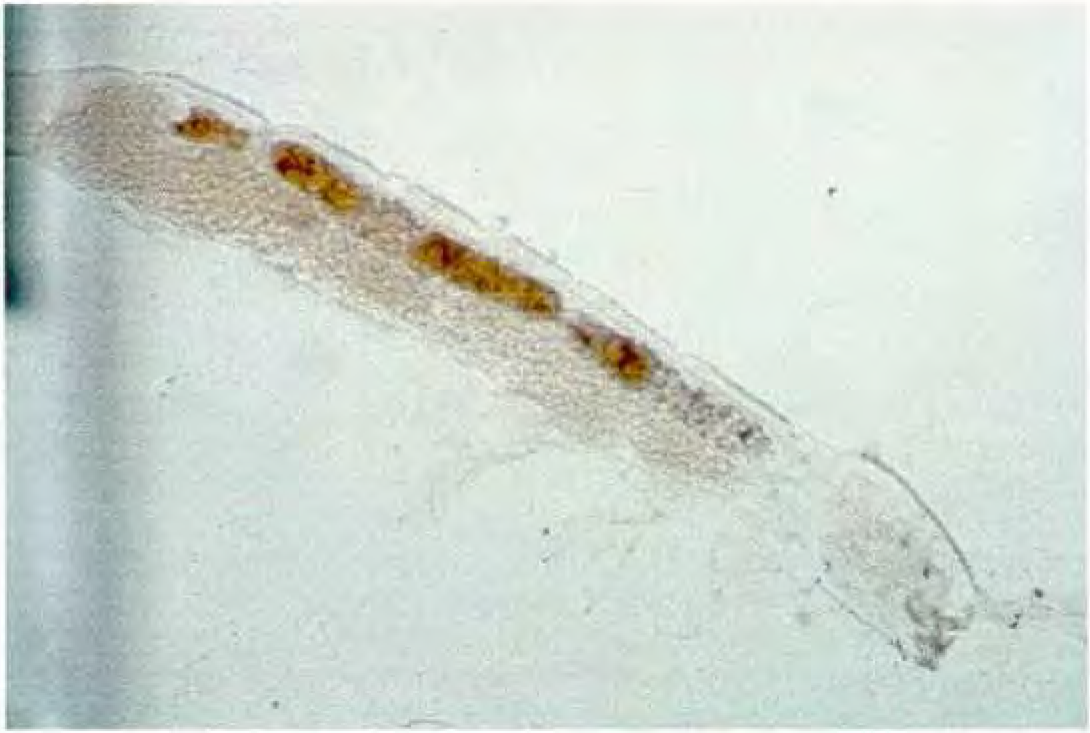
Entrance Sign at the Morton Arboretum

Berlese Funnel Set-up



Unburned Area of East Woods

Burned Area of East Woods



Folsomides PARVULUS

Foot Complex of Folsomides PARVULUS

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Diversity and Abundance of Springtails (Insecta: Collembola) in Native and Restored Tallgrass Prairies

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ABSTRACT.—This study suggests that heterotrophic components of prairie ecosystems can be used with autotrophic components to assess the degree to which a restored prairie approaches the biotic complexity of a native prairie. Springtails (Collembola) were collected from prairie vegetation and litter samples from 13 prairie sites (seven native and six restored) located in southwestern Michigan and northeastern Illinois. The diversity and abundance of these insects and the plant and litter biomass were compared. There were 27 different taxa of springtails in the 225 samples collected. Native prairies had the greatest species richness with 26 species. The oldest restored prairie had 17 species. Three common species were *Hypogastrura boletivora, Isotoma viridis,* and *Lepidocyrtus pallidus. Neanura muscorum, Xenylla grisea,* and *Pseuduosinella rolfsi* were rare. *Tomocerus flavescens* was found primarily in native prairies with only one occurrence in the oldest restored prairie in this study. Native prairies and restored prairies of 17 and 24 yr did not differ significantly in numbers of springtails.

Differences in springtail numbers did occur, however, between restored prairies of <6 yr and native prairies, and between younger (<6 yr) and older (17 and 26 yr) restored prairies. An analysis of plant and litter biomass indicated significant differences among the prairie sites sampled. These results suggest that all components of the prairie ecosystem are useful for making restoration management decisions.

INTRODUCTION

Before European settlement in the 1800s, much of the midwestern landscape was dominated by native tallgrass prairies. The northern and central sections of Illinois were approximately 60% prairie (Transeau, 1935). In more recent times, industrialization, transportation routes, agriculture and increasing human populations have decreased the amount of Illinois prairie to less than 0.01% of its original expanse (Iverson, 1988). One response to the disappearance of prairie communities has been an effort to re-establish these communities in protected areas. Both professional ecologists and volunteer prairie enthusiasts have attempted restorations in many parts of the Midwest (Curtis, 1959; Schulenberg, 1970; Betz, 1986). One of the largest Illinois efforts (over 400 acres) began in 1975 inside the high energy particle accelerator ring at the Fermi National Accelerator Laboratory (Fermilab), Batavia, Illinois (Betz, 1986). An earlier, smaller restoration of 32 acres, known as the Schulenberg prairie at the nearby Morton Arboretum, Lisle, Illinois, was initiated in 1962 (Schulenberg, 1970).

Most effort expended on restoration of prairies has concentrated on establishment of prairie grasses and forbs to form a matrix for the development of a complex community (Betz, 1986). Although natural communities consist of both floristic and faunistic elements, the latter have not generally been emphasized in evaluating restoration success.

This paper presents the results of a 5-yr ecological study of the epigeic springtail insects (Collembola) occurring in 13 native and restored prairie communities in northeastern Illinois and southwestern Michigan (Chapman and Pleznac, 1982). Seven of these sites were native prairie remnants ranging in size from 1 to over 40 ha. Six of the sites were located in two restored prairies; *i.e.,* Fermilab and The Morton Arboretum.

Springtails are primarily herbivores or detritivores. Only a few species, such as *Proisotoma* *grandiceps*, are known to be carnivores (Christiansen, 1964, 1992). Rarely have any species become agricultural pests, but their important ecological role (Christiansen, 1964), along with other microarthropods in preparing organic material for later decomposition processes, is widely recognized (Zinkler and Stecken, 1985). Collembola also eat moss protonema (Varga, 1992), transport fungus spores, and consume bacterial plant pathogens (Christiansen, 1964; Wiggins and Curl, 1979). Their dispersal rates may be much slower than winged insects (Christiansen and Bellinger, 1980). However, their small size and minimal mass contribute to their dispersal by wind and other animals and they are found in almost all ecosystems throughout the world (Christiansen and Bellinger, 1995). A thin, chitinous exoskeleton limits their distribution within ecosystems to sites with adequate moisture (Christiansen, 1992). Ascertaining which springtail taxa are native and which are introduced can be difficult because documented zoogeographic information is lacking for many Nearctic species (Christiansen and Bellinger, 1994). However, some information on geographic origin is available for many species in the most complete taxonomic publication on North American Collembola (Christiansen and Bellinger, 1998).

The specific purpose of this study was to compare the species richness and abundance of springtails present in native prairies to those in various stages of restored prairies, and to ascertain if any species or the diversity of species might serve as indicators of well-established prairie conditions. As Kremen (1992) notes, no single taxon is sufficient to serve as an indicator of "naturalness" because soil conditions, diversity of plant species and other heterotrophic components of the community must also be considered in natural area monitoring. That a correlation exists between plant and insect species diversity has been shown for homopteran insects and old-field communities (Murdoch *et al.*, 1972).

METHODS

Study sites.—The seven native prairies included in this study contain a rich diversity of plant and animal species. For example, over 500 native flowering plant species have been identified on the West Chicago Prairie in DuPage County, Illinois, and soil samples have provided no evidence of past agricultural or soil disturbance (Kelsey and Hootman, 1992). On the Dayton Prairie in Berrien County, Michigan, the number of flowering plant species has not been documented but over 200 insect species have been identified (Ewert, 1989). The remaining five native prairies are smaller remnants that have not received intensive study but are floristically similar to the larger native prairies in a general field survey of the areas (Chapman and Pleznac, 1982).

The six restored prairie sites in DuPage County are in various stages of restoration. The Fermilab restoration began in 1976 and had 115 species of native flowering plants within 10 yr. (Betz, 1986). Samples from the Fermilab site were collected from three site age classes, Ra = 2 to 5 yr (younger), Rb = 6 to 11 yr (intermediate), and Rc = 14 to 19 yr (older). In the case of the sites at The Morton Arboretum, the prairie restoration project began in 1962 and had over 200 native plant species by 1968 (Schulenberg, 1970). Since then, species lists indicate 303 native species (Wilhelm and Masters, 1994). The three age classes available for sampling at The Morton Arboretum were as follows: Rd = 17 yr, Re = 19 yr, and Rf = 24 yr. For the remainder of this paper in both text and tables, the older restored prairies refer to Fermilab Rc and to all Morton Arboretum sites (Rd, Re, and Rf; Table 1), all more than 16 yr old. Management regimes for all prairie sites involved burning on a regular, often annual, basis but accurate records were not available for all sites. At the Fermilab site annual burning did not commence until after the 3rd growing season in 1979.

Data collection and analysis.—Samples of 0.2 m^2 of plants and surface litter were collected each year over the 5-yr period from 1987 to 1991 during the middle of the growing season

TABLE 1.—Study sites, number of samples (N), plant biomass g mean ± SE, springtail numbers/m^2 mean ± SE, number of springtail species (Sp), and Simpson diversity index (D)

Location	Site	N	Biomass	Springtails	Sp	D
Native prairies						
Newaygo, Mich.	Na	09	427.7 ± 54.7	9.57 ± 20.6	04	NA
Markham, Ill.	Nb	18	573.2 ± 45.6	22.4 ± 30.6	07	2.7
Lawton, Mich.	Nc	09	1016.0 ± 136.8	36.5 ± 45.4	07	NA
Bakertown, Mich.	Nd	09	1757.4 ± 159.0	188.9 ± 101.1	14	NA
Buchanan, Mich.	Ne	18	1186.1 ± 116.8	273.9 ± 204.1	17	6.6
West Chicago, Ill. (A)	Nf	18	874.3 ± 62	498.3 ± 142.5	17	7.5
West Chicago, Ill. (B)	Ng	18	850.7 ± 72.4	422.9 ± 358.4	17	3.5
Restored prairies						
Batavia, Ill. (A)	Ra	24	485.9 ± 29.9	46.1 ± 88.1	09	5.6
Batavia, Ill. (B)	Rb	24	820.6 ± 104.8	27.2 ± 47.8	12	6.3
Batavia, Ill. (C)	Rc	24	1295.9 ± 118.8	171.8 ± 252.5	13	5.7
Lisle, Ill. (A)	Rd	18	703.8 ± 66.7	34.6 ± 36.7	08	2.6
Lisle, Ill. (B)	Re	18	984.3 ± 98.2	361.8 ± 340.5	10	3.5
Lisle, Ill. (C)	Rf	18	1378.8 ± 109.8	80.1 ± 82.9	12	5.8

(June or early July) by clipping all growing and dead plants at ground level. This material was placed in plastic bags in ice-cooled, insulated, polyethylene chests for transport to the laboratory. A total of 225 randomly selected samples were obtained from the 13 sites ranging from 9 to 24 samples per site. Modified Tullgren funnels were used to extract the organisms from the field samples of vegetation by placing the samples on cheese-cloth covered screens inside the funnels. Springtails and other invertebrates were collected over a 4-day period (starting on the day the field samples were obtained) in bottles of Van Torne's preservative (Christiansen and Bellinger, 1980) placed at the base of the funnels. A gradient of humidity was established by placing pans of water on the floor between the funnels to facilitate the downward migration of invertebrate organisms to higher humidity levels. Light bulbs of 60 and then 40 watts were turned on for 2 days each in the reflectors at the top of the funnels to create a temperature gradient to attract the organism to the cooler temperature near the floor. Springtails were presorted into different kinds—under a low power binocular microscope—into small vials of 99% isopropyl alcohol. Identification to genus or species was made using higher magnifications of either an Olympus research microscope or a Nikon phase contrast microscope. A scanning electron microscope was also used to photograph particular morphological features necessary for the identification of some species. Permanent voucher slides for representative specimens are stored at The Morton Arboretum. Some taxa could only be identified to genus, but these are known to be different species from the congeneric species listed in that genus.

Following the funnel extraction process for obtaining the invertebrates, each sample of dried plants and litter was weighed to the nearest gram. Data were analyzed statistically using the software program, Statistix Version 4.1 (Analytical Software, 1994). Preliminary analysis indicated that the data were not normally distributed and the variances were heterogeneous. As these results did not meet the assumptions of a standard parametric ANOVA, data were analyzed with a Kruskal-Wallis one-way nonparametric method appropriate for non-normal distributions. For any result in which a null hypothesis was rejected, a parametric ANOVA was applied to ranked data for multi-group comparisons (Zar, 1984). Data

TABLE 2.—Species occurrence distribution[a]

Taxon	Native sites							Restored sites						Springtail
	Na	Nb	Nc	Nd	Ne	Nf	Ng	Ra	Rb	Rc	Rd	Re	Rf	abundance
Hypogastruridae														
Hypogastrura boletivora	x	x	x	x	x	x	x	x	x	x	x	x	x	c
H. sp. 2		x	x	x	x	x	x				x	x	x	c
Xenylla grisea						x	x							r
Neanura muscorum				x	x									r
Onychiuridae														
Tullbergia granulata					x	x			x	x	x	x	x	c
Onychiuris sp. 2						x			x	x				i
Isotomidae														
Isotoma viridis	x	x		x	x	x	x	x	x	x	x	x	x	c
I. sp. 2			x	x	x	x	x			x	x			i
I. sp. 3			x	x		x						x		i
Folsomides americanus						x	x		x	x				i
Folsomia sp.		x		x	x	x	x					x	x	c
Proisotoma sp.										x				r
Entomobryidae														
Lepidocyrtus pallidus	x	x	x	x	x	x	x	x	x	x	x	x	x	c
L. paradoxus				x	x	x	x							i
L. violaceus	x		x						x					i
Entomobrya quadrilineata		x	x						x					i
E. purpurascens							x		x					r
E. sp. 3		x		x	x		x		x	x		x	x	c
Orchesella hexfasciata							x				x	x	x	i
Pseudosinella rolfsi			x									x	x	r
Tomocerus flavescens				x	x	x	x			x				i
Sminthuridae														
Sminthurides pumilis				x	x		x							i
S. sp. 2					x	x	x						x	i
Sminthurinus henshawi					x	x	x			x				i
S. sp. 2				x		x								r
Bourletiella sp. 2			x		x	x	x		x		x	x	x	c
Arrhopalites amarus					x									r
Number of species	4	7	7	14	17	15	18	5	11	11	7	10	10	

[a] Abbreviations for native and restored sites defined in text; for abundance, c = common (taxon occurs in 7 or more sites, i = intermediate (3 to 6 sites), r = rare (fewer than 3 sites)

from the Newaygo, Michigan, prairie site were omitted from the statistical analysis since only two of nine samples contained springtails. Simpson's diversity index was calculated for sites with 18 or more samples (Simpson, 1949).

RESULTS

Springtails.—Twenty-seven springtail taxa were identified from all sites. Six taxa obtained from native prairies did not occur on restored prairies, and only one taxon, *Proisotoma* sp., was found exclusively on restored prairies (Table 2). Three species were common at most sites: *Hypogastrura boletivora* (Packard), *Isotoma viridis* (Bourlet), and *Lepidocyrtus pallidus* (Router). Three other species were rarely encountered, being taken at only two of the 13 sites: *Neanura muscorum* (Templeton), *Xenylla grisea* (Axelson), *Pseduosinella rolfsia* (Mills). Of these latter species, *N. muscorum* and *X. grisea* were taken only at native prairies. Two other species, *Lepidocyrtus paradoxus* (Uzel) and *Tomocerus flavescens* (Tullberg) were mainly restricted to native prairies, although *T. flavescens* was also taken at the oldest restored Fermilab site (Rc). The remaining 18 species have no apparent affinity or restriction to the native or restored prairies studied.

No clear trends were found in Simpson's index of diversity for each site (Table 1). A scale of presence of each species was based on their occurrence at the study sites according to the following criteria: rare (r) = found at fewer than three sites; intermediate (i) = found at three to six sites; and common (c) = found at seven or more sites (Table 2). Furthermore, a null hypothesis of no difference in springtail numbers among the sites was rejected using the Kruskal-Wallis nonparametric analysis ($H = 74.85$, $df = 11$, $P < 0.001$). Ranked data, analyzed with ANOVA, indicated a significant difference for the multigroup comparison ($F = 22.43$, $df = 3$, $P < 0.001$), with the number of springtails being greater in native vs. all restored prairie sites ($F = 7.59$, $df = 1$, $P < 0.006$) and in younger vs. older restored prairie sites ($F = 23.49$, $df = 1$, $P < 0.001$); but not significantly different in native vs. older restored prairie sites ($F = 0.12$, $df = 1$, $P > 0.732$).

Plant and litter biomass.—Plant plus litter mean dry weights of the prairie sites sampled were significantly different using the Kruskal-Wallis test ($H = 83.63$, $df = 12$, $P < 0.001$; Table 1). The two oldest restored prairie sites, Fermilab Rc and The Morton Arboretum Rf, differed significantly in plant and litter biomass analyzed with ANOVA from the most productive and diverse native prairies, Dayton and West Chicago ($F = 37.76$, $df = 1$, $P < 0.001$). Younger restored prairies also differed significantly in plant plus litter biomass from older restored and native prairies ($F = 16.09$, $df = 1$, $P < 0.001$). Plant and litter biomass increases steadily from younger to older restored prairie sites at both Fermilab and The Morton Arboretum prairies (Table 1).

DISCUSSION

The 27 epigeic springtail taxa encountered in the vegetation and litter are fewer than might be expected considering that in 1996, Waltz and Hart reported 216 species for the state of Indiana (Waltz and Hart, 1997). In an earlier study of arthropods in three northeastern Illinois prairies, 21 or 23 species of springtails were present (Hamilton and Stathakis, 1987). However, the majority of soil-dwelling forms, except for a rare litter emigrant, were not included in this study, whereas all habitats were included in the Waltz and Hart study, and pit traps rather then Berlese funnels were used in the Hamilton study. In the present study, *Lepidocyrtus paradoxus*, although originally from Europe (Gisin, 1960) and apparently introduced into northeastern United States about 1950 (pers. comm., Peter Bellinger, 1990), was collected only from native prairie sites. *Tomocerus flavescens* was found on four of the native prairie sites but not on restored sites except the oldest restored Fermilab prairie. This latter species was also collected during previous studies of old field habitats that had not been used agriculturally for over 60 yr (Brand, 1989). These results suggest that these two species could be considered as indicator species of native prairie conditions. However, other studies show that these species occur in a variety of other habitats (Zinkler and Stecken, 1985; Christiansen, 1964). Like *T. flavescens*, two other taxa (*Hypogastrura* sp. 2, and *Folsomia* sp.) were found only in native prairies and the older restored prairies (Table 2). Of all the springtail species identified in the study, only six species were not found in restored prairie samples. Apparently, many springtail species can survive the transition process from an agricultural field to restored prairie, or they can disperse from nearby old fields or native prairies within a relatively short time. In at least one other study, the species richness of the collembolan community in rehabilitated forested areas is positively correlated with plot age (Greenslade and Majer, 1993).

A number of ecological differences occur between native and restored prairies (*e.g.*, soil conditions, microclimate, plant cover), but perhaps one of the most critical for springtails is the amount of moisture. In this study, the dense summer growth of grasses and forbs in both native and restored prairies provided high humidities during at least some of the periods of the day when samples were collected. In an earlier study of springtail populations, time of sampling was shown to be important, with optimum sampling times being in the early mornings and 1 or 2 days after substantial rains (Brand, 1979). Following periods of prolonged drought, any surviving epigeic forms apparently remain in the top, loose soil surface or in the tangled mat of vegetation and litter close to the soil surface. Early stages of restored prairies have less dense plant growth with many patches of bare ground. With time, plants fill in these spaces, humidity increases, and available food sources become more abundant for springtail immigration and survival (Jastrow, 1987). Thus, in later stages of restored prairies the environmental conditions become increasingly similar to native prairies. In addition to humidity, the vertical migration of some springtails (*e.g.*, *Onychiurus subtenuis*; Bauer and Christian, 1993) within the litter layer is partly dependent on the presence of palatable microorganisms and is not simply a reaction to moistening and desiccation (Bauer and Christian, 1993).

Management implications.—The difference in numbers of springtails between the native and restored prairies shown is of interest in evaluating prairie restoration. Despite high variability in the sample numbers from restored and native prairies, there was a significant difference in numbers of springtails between native and all restored prairies, and between younger and older restored prairies. No difference, however, could be shown between native prairies and the subset of oldest restored prairies (*i.e.*, those older than 16 yr). This result, along with the increasing diversity of plant species described by others (Betz, 1986; Wilhelm and Masters, 1994) and the increased soil aggregates in older restored prairies (Jastrow, 1987) are indications that the efforts to restore native conditions have had some measure of success.

Biomass of plant and litter samples was variable and showed patterns similar to the springtail numbers for native and restored prairies. Thus, for plant and litter biomass, there were significant differences between native and all restored prairies. It is also of interest that the average gain in plant plus litter weight for the two oldest restorations at Fermilab and The Morton Arboretum over the same interval in years is remarkably similar despite the difference in location and management methods. This suggests that the methods employed in collecting plant and litter samples were appropriate for the purposes of the study. As information accumulates about the process of prairie restoration and management, it is hoped that the results of this study will encourage others to focus on the invertebrate animal component in conjunction with present emphases on plants. Another study has already demonstrated that a species-rich collembolan fauna is positively correlated with plant species richness and diversity (Greenslade and Majer, 1993). Such results provide direction for those involved in assessing the degree of prairie restoration achieved.

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