Diversity and Activity of Ground-Dwelling Spiders (Araneae) in Four Sub-Communities in a Degraded Oak Woodland at the Chicago Botanic Garden, Cook County, Illinois

James F. Steffen[1] and Michael L. Draney[2]

Abstract

Ground-dwelling spiders were sampled using pitfall traps over a twelve-month period from four sub-communities within a 40-ha oak woodland complex in northern Cook County, Illinois. Mesic and dry mesic oak woodland, mesic upland forest, buckthorn dominated mesic oak savanna and a mesic woodland control, where no restoration management is planned, were sampled. Fifty-five species within 44 genera and 18 families were trapped. The results suggest negative correlations between non-native spider abundance and spider species richness. Also, phenology of the various species indicates that a year-round inventory is necessary to adequately sample ground-dwelling spider assemblages. Possibilities of using *Bathyphantes concolor* (Wider) abundance as an indicator of oak woodland recovery are discussed. Three species, Linyphiidae: *Oreonetides vaginatus* (Thorell), *O. rotundus* (Emerton), and Thomisidae: *Ozyptila praticola* C. L. Koch), never before recorded for Illinois were documented. The non-native species, *Ozyptila praticola*, is also a new regional record.

Much of the oak woodland and savanna ecosystems in the Midwestern United States are in a degraded condition due to the effects of fire suppression, invasion by native and exotic species, fragmentation, past land use and an over abundant white-tailed deer population (Nuzzo 1986, Lorimer 1987, Packard 1988, Laatsch and Anderson 2000). Recent research (Heneghan et al. 2002, Heneghan et al. 2004, Ashton et al. 2005, Suarez et al. 2006, Heneghan et al. 2007, Corio et al. 2009) has shown that invasive exotic species, primarily common buckthorn (*Rhamnus cathartica*) and Eurasian earthworms, can have dramatic impacts on the structure and sustainability of the litter layer and nutrient cycling functions within oak dominated systems in the Midwest. The combination of high nitrogen leaf litter from exotic shrubs and the rapid rate at which exotic earthworms incorporate organic matter into the soil quickly degrades the litter environment.

Spiders and other macroarthropods can play a crucial role in the regulation of dead organic matter decomposition and nutrient cycling in the temperate forest ecosystem (Moulder and Reichle 1972, Hansen 2000). Although microarthropods, such as soil mites and collembola, are considered perhaps the most important animal components of the temperate forest ecosystem biota (Seastedt 1984, Moldenke and Lattin 1990, Hansen 2000), spiders have better potential as ecological indicators because they are larger and their taxonomy is better known (Willett 2001). This is a highly diverse group of organisms with a total of 68 families, 569 genera, and 3,700 species occurring in North America (Ubick et al. 2005). In addition, populations of the ground-dwelling portion of

[1]Department of Environmental Science, Chicago Botanic Garden, 1000 Lake Cook Road, Glencoe, Illinois 60022. (e-mail: jsteffen@chicagobotanic.org).

[2] Department of Natural and Applied Sciences and Cofrin Center for Biodiversity, University of Wisconsin-Green Bay, 2420 Nicolet Drive, Green Bay, Wisconsin 54311.

this large group are one of the top predatory guilds in the litter food web and are directly tied to microarthropod prey abundance and detritivore food webs (Crossley 1977, Toft and Wise 1999). Many studies have shown relationships between spider diversity and litter habitat structure (Uetz 1975, Uetz 1991, Brumwell et al. 1998, Wagner et al. 2003).

Many past studies have examined the recovery of spider assemblages from various disturbances such as logging (Huhta 1971, Willett 2001), burning (Huhta 1971, Koponen 1993) and succussion after clearing (Brumwell et al. 1998, Draney and Crossley 1999, Gajdos and Toft 2000, Pekar 2003, Mallis and Hurd 2005, Oxbrough et al. 2005). Few studies have looked at spiders in oak woodlands either undergoing invasion by exotic species or during the process of restoration (Wolff 1990, Draney et al. 2002). Investigations that examine phenology and diversity of spider populations over the course of a full year are uncommon and most occur only in warmer regions where winter temperatures are mild (Dorris et al. 1995, Draney 1997, Draney and Crossley 1999, Fassbender 2002). Only partial or very few complete inventories have been conducted in northern temperate regions of North America where winter temperatures are often sub-freezing and snow cover is common (Olynyk and Freitag 1977, Aitchison 1978, Aitchison 1984, Aitchison and Sutherland 2000).

The purpose of this investigation was to inventory the ground-dwelling spiders, over a twelve-month period, in four sub-community types within degraded sections of an oak dominated woodland displaying a naturally occurring gradient of litter structure. Three research goals were to 1) describe the ground-dwelling spider fauna of an oak dominated woodland in the Midwest, 2) establish a baseline against which future re-sampling could be used to evaluate the impacts of ongoing restoration efforts, and 3) to determine if there is a correlation between litter mass and abundance of non-native spider species and the richness and diversity of native ground dwelling spiders.

Methods

Study Area. This study was conducted in Mary Mix McDonald Woods (N42.152°, W87.781°), a 40 ha oak woodland/savanna complex comprised of a variety of different sub-communities at the Chicago Botanic Garden in Glencoe, Cook County, Illinois. The site has a history of logging and grazing. In 1917, the woodland was set aside as a forest preserve (Cook County (Ill.) Board of Forest Preserve Commissioners 1918). Since that time, second growth tree species, such as ash (*Fraxinus spp*.), elm (*Ulmus americana*) and ironwood (*Ostrya virginiana*) have filled in the understory. In 1918, the entire woodland area was considered second growth timber and intensive grazing destroyed the shrub and sapling layer (Schmoll 1919). Since the cessation of domestic grazing in the 1920's or 30's, numerous exotic woody species have also become established. While common buckthorn (*Rhamnus cathartica*) dominates, other exotics including privet (*Ligustrum vulgare*), glossy buckthorn (*Rhamnus frangula*), various Eurasian honeysuckles (*Lonicera* spp.) and oriental bittersweet (*Celastrus orbiculatus*) are also found on the site. The study subplots were chosen to represent degraded sections 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. These exotic herbaceous species include garlic mustard (*Alliaria petiolata*) with lesser percentages of Indian strawberry (*Duchesnea indica*), orchard grass (*Dactylis glomerata*) and bluegrass (*Poa* spp.) The five study subplots represent the four following community types: upland forest, dominated by *Quercus alba*, *Q. rubra* and *Acer saccharum*; mesic woodland, dominated by *Q. rubra and Q. alba*; dry-mesic woodland, dominated by *Q. alba* and *Fraxinus* spp.; and a mesic savanna dominated by *Q. alba* and *R. cathartica*. Two subplots were established in mesic woodland with one of the subplots representing a control in which no restoration management is planned.
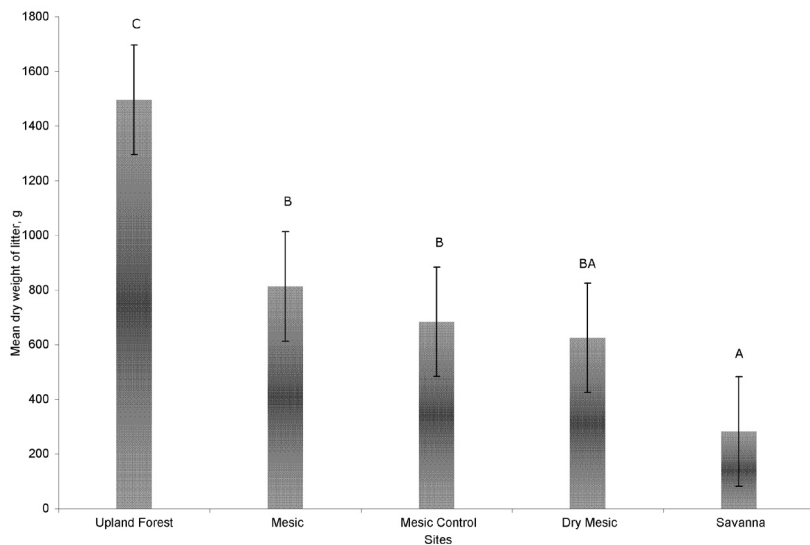
Figure 1. Mean oven dry weight for leaf litter for 10 45 × 45cm quadrats from five study subplots in Mary McDonald Woods, Chicago Botanic Garden, spring 2002. Whisker bars represent standard error. Letters show significance (p ≤ 0.05) relationships based on Tukey's mean separation test.

The study subplots were chosen to represent different community types, but also to take advantage of a naturally occurring gradient in litter structure (Fig. 1). A previous study involving these same subplots (Heneghan et al. 2007) found a negative correlation between gradient in litter mass and abundance of *Rhamnus cathartica* and Eurasian earthworms.

      Sampling Methods. Pitfall trapping was chosen as the method of sampling because it is more efficient than other techniques, such as quadrat sampling, and allows for year-round sampling (Uetz and Unzicker 1976). However, it should be noted that pitfall traps preferentially sample cursorial species (Uetz and Unzicker 1976, Coddington et al. 1996). A single point was randomly located within each study area and five pitfall traps were evenly spaced on a 20-meter 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 spiders 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 be a problem by attracting mammals to the traps with earlier pitfall tapping on this site and has been found to be a problem in other similar studies. This disturbance 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 any separation that formed

between the trap and adjacent soil due to expansion or contraction of the soil. This maintained a continuous surface for spider access to the traps.

Traps were run continuously from June 2002 through June of 2003. Traps were emptied twice weekly during warm weather to avoid spoilage and less often during the winter months, and fresh solution was placed in the traps. Spiders were sorted from trap contents by use of a binocular microscope and specimens were stored in 70% ethanol for subsequent identification. Nomenclature follows Platnick (2006) except for the species listed as *Diplostyla concolor* (Wider) in Platnick. Buckle et al. (2001) considers *Diplostyla* to be, at most, a subgenus of *Bathyphantes*, and we follow them by calling the species *Bathyphantes concolor* (Wider). Voucher specimens are being held at the Chicago Botanic Garden.

In the spring of 2002, ten 45 × 45 cm quadrats were randomly located to sample litter in each of the five subplots. Liter was removed down to mineral soil and the material dried at 120° F for a minimum of 48 hours in an electric plant drier before weighing to the nearest gram (Fig. 1).

Data Analysis. For analysis, the data for each of the five pitfall traps was pooled for each collection date for each subplot. Immature spiders were identified to family and to genus or species if possible, but were excluded from statistical analysis, since only adults can consistently be identified to species. Only taxa determined to the level of species were included in the statistical analysis. Shannon-Wiener diversity (H′), effective species number (ESN) (Jost 2006), Jaccard similarity index, richness (S), and Pielou's evenness (J′) were calculated for each subplot (Table 1). The ESN is the number of equally common species derived from H′ or other diversity indices and is a means of showing the true number of species represented by any of several diversity indices. The ESN makes it easier to compare diversity indices derived by different formulas. Also, because diversity indices are nonlinear, the ESN more effectively compares one value to another of a particular diversity index. Unless the species in a population are all equally abundant, the ESN value will be less than the richness because of dominance of one or more species within the population (Jost 2006).

Table 1. The shared number of species between subplots (above diagonal), Jaccard index of percent similarity based on number of species held in common (bold), Shannon Weiner diversity (H′), effective number of species (ESN), evenness (J′), richness (S), estimates of species richness using two Jackknife estimators using PC-ORD (Jack1 and Jack 2) and total number of individuals trapped for each plot.

Subplots	Upland Forest	Mesic	Mesic Control	Dry Mesic	Savanna
Upland Forest	-	15	15	11	10
Mesic	**0.42**	-	15	12	12
Mesic Control	**0.41**	**0.54**	-	10	14
Dry Mesic	**0.31**	**0.48**	**0.36**	-	10
Savanna	**0.23**	**0.36**	**0.44**	**0.33**	-
H'	1.991	1.062	1.189	0.638	1.420
ESN	7.32	2.89	3.28	1.89	4.14
S	30	21	22	16	24
J'	0.585	0.349	0.385	0.230	0.447
Jack 1	42	30	29	21	33
Jack 2	51	37	31	20	36
Total Ind.	616	428	425	749	412

The ratio of species to genera (S/G ratio) has been suggested by Edwards (1993) to serve as a possible generic diversity index when comparing communities. In general, a higher S/G ratio would seem to indicate more habitat complexity or greater number of potential available niches for the site being investigated. It should be noted that this taxonomic ratio is sample-size dependent (Gotelli and Colwell, 2001) and may lead to difficulties in interpretation. The S/G ratio was calculated for the data pooled from all of the subplots (Table 2).

Estimates of species richness were calculated using two Jackknife Estimators provided in the species area curves option of PC-ORD (Table 1). The first estimate is Jack1 = S + rl(n-l)/n (Palmer 1990; Heltshe and Forrester 1983) and the second estimate is Jack2 = S + rl(2n-3)/lm − r2(n-2)^2/(n(n-1)) (Burnham and Overton 1979; Palmer 1991). Where S = the observed number of species, rl = the number of species that occur in only one sample unit, r2 = the number of species that occur in exactly two sample units, and n = the number of sample units. A sample unit consists of the data pooled from the five pit traps in one subplot on one date. These estimates were determined for each subplot and for all subplots combined utilizing the sample units.

An individual-based Coleman rarefaction (Coleman 1981, Coleman et al. 1982) was calculated for each subplot (Fig. 2) utilizing EstimateS (Colwell 2006). This procedure standardizes the data, making it possible to compare species richness among populations comprised of differing numbers of individuals.

Graphs showing periods of activity for stenochronous species found only between November and May and for multivoltine species found in every month, N>20 are given to depict seasonality of occurrence (Figs. 3-5).

Table 2. The species to genus ratios (S/G) for McDonald Woods compared to twelve other pitfall trap studies from the United States and elsewhere. Choice of comparison was based on complete species lists presented for habitats or closely related groups of habitats. If not all species were determined; a genus was counted if no other species was found in that genus.

| S	G	S/G	Location/Habitat	Reference
55	44	1.25	IL/oak woodland	Steffen & Draney(this paper)
104	72	1.44	MA/ deciduous litter	Edwards, 1993
57	48	1.19	MA/ deciduous pitfall	Edwards, 1993
111	81	1.37	GA/ floodplain agroecosystem	Draney, 1997
94	57	1.65	Holland/ peat bog	Deeleman-Reinhold, 1990
50	39	1.28	UK/ pasture and plantation	Downie et al., 1996
90	52	1.73	UK/ mountain tops	Downie et al., 1995
55	34	1.62	NE/ prairie	Muma and Muma, 1949
100	69	1.45	Alberta/ populus forest	Buddle 2001
136	78	1.74	Finland/ spruce/pine/birch forest	Pajunen et al., 1995
60	46	1.30	Norway/ coastal heath	Hauge, 2000
57	37	1.54	Saskatchewan/ wheat field and grassy border	Doane and Dondale, 1979
130	67	1.94	FL/ Sand-pine dunes, pine woods, citrus grove, residential	Muma, 1973
88	51	1.73	Quebec/ mountain	Koponen, 1987
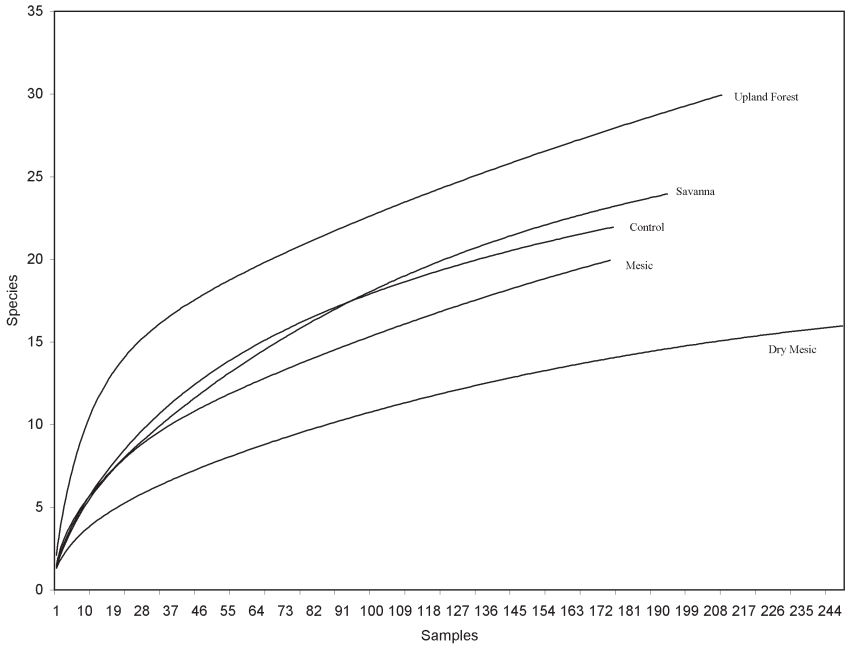
Figure 2. Individual-based Coleman rarefaction curves comparing species richness between the five subplots sampled.
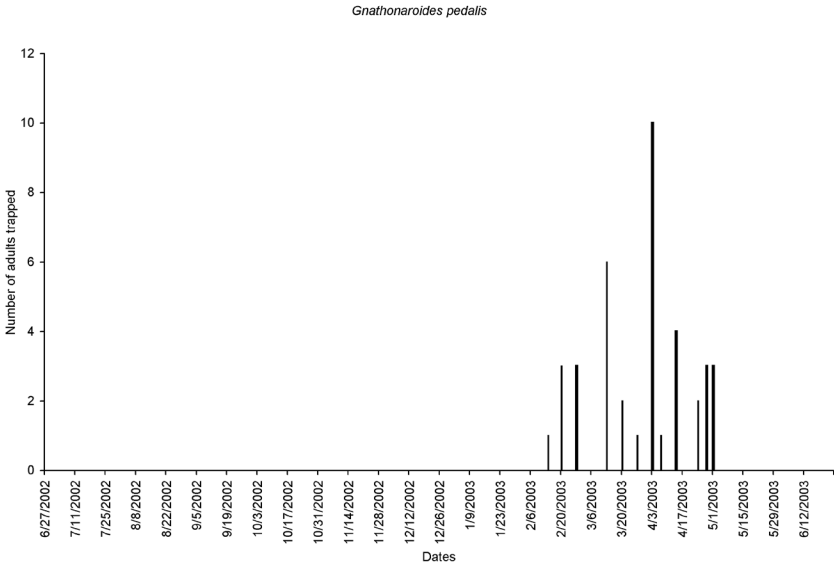

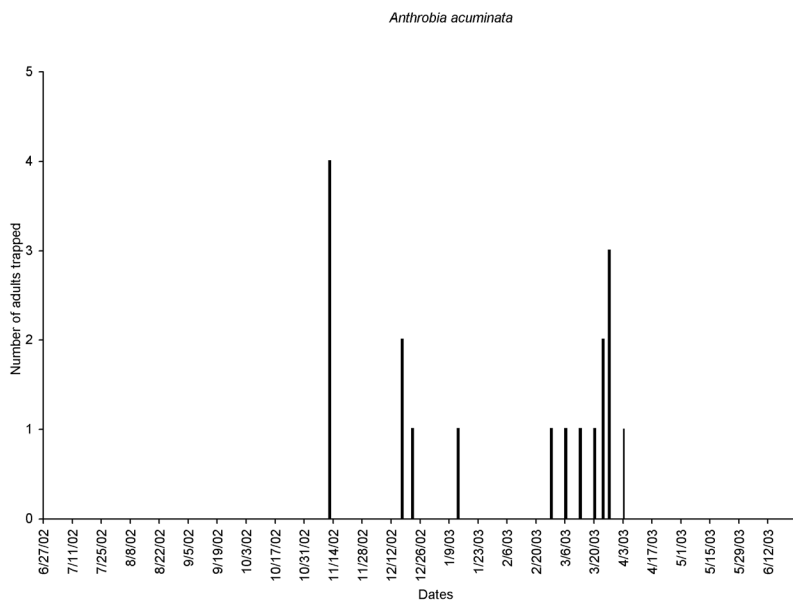Figure 3. Activity periods of *Gnathonaroides pedalis* displaying winter or early spring activity periods.

Anthrobia acuminata

Figure 4. Activity periods of *Anthrobia acuminata* displaying winter or early spring activity periods.
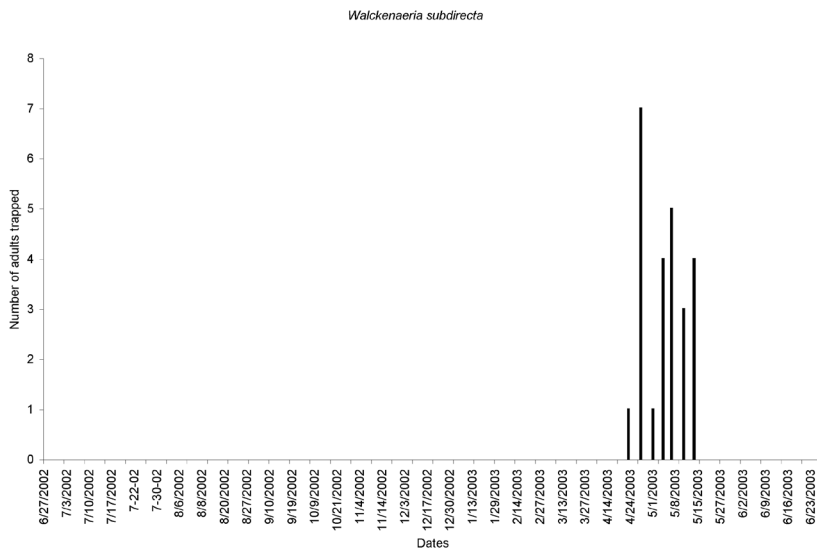
Walckenaeria subdirecta

Figure 5. Activity periods of *Walckenaeria subdirecta* displaying early spring activity periods.

Results

Twenty-five pitfall traps were operated for 363 days for a total of 9075 trap days. A total of 2632 adult specimens was collected, representing 18 families, 44 genera, and 55 species of spiders (Table 3).

The number of taxa represented by a single individual (singletons) has been used as a measure of the thoroughness of a sample (Coddington et al. 1996). The relatively low percentage of singletons or doubletons represented in this study, 27.5% and 11.8% respectively, suggests a fairly complete inventory of the ground spiders was obtained. Glesne (1998) found what were considered to be low values for singletons between 15.8% and 17.4% for two different years in the Pacific Northwest, while Coddington et al. 1996 found values for singletons or doubletons (species represented in a sample by exactly two individuals) of 40% for an Appalachian hardwood forest and 62% for a Bolivian tropical forest. In the present study, members of the arboreal spider fauna that over winter on the forest floor, including araneids, philodromids, theridiids and salticids (Edwards 1993) represent many of the singletons, but are not important members of the ground living spider guild.

New Geographic Records. Two species of Linyphiidae new for the state of Illinois were recorded from the upland forest plot. *Oreonetides rotundus* (Emerton) and *O. vaginatus* (Thorell) were both found during late winter to early spring. *O. vaginatus* was represented by one individual while *O. rotundus* was represented by 19 individuals. These two species, more typical of boreal forest, tundra and alpine habitats, are at the southern limit of their range here.

A species of Thomisidae new to the Great Lakes region, *Ozyptila praticola* (C. L. Koch) (Sierwald et al. 2005), and apparently an introduction into North America (Dondale & Redner 1978), was found to be common in this study, with 40 individuals being found approximately equally distributed on all study subplots, with the exception of the upland forest subplot where only 1 individual was found.

Community Diversity. There was a noticeable difference in the distribution of species within families for the different subplots (Table 4). Members of the family Linyphiidae predominated in all subplots. The upland forest plot had 13 species of Linyphiidae, more than twice as many as in any other subplot, except the savanna, which had 7. The savanna had 6 species of Lycosidae, twice as many as any of the other subplots. The upland forest also had the highest number of total species with 35. The dry mesic plot had the lowest with 17.

The total number of species and genera recorded for all of the subplots combined was 55 and 44 respectively. This resulted in a S/G ratio of 1.25. This value was compared to S/G ratios reported for other pitfall data from North America and elsewhere (Table 2).

Table 3. Ground-dwelling spiders of McDonald Woods, Chicago Botanic Garden, Glencoe, Cook Co. IL. All species were trapped in pitfall traps between June 27, 2002 and June 25, 2003. Specimens were determined only to genus when no adult material was sampled. Species marked with an (*) are considered being non-native to the Great Lakes region.

Family	Species
Agelenidae	*Agelenopsis pennsylvanica* (Gertsch & Ivie, 1936)
Amaurobiidae	*Coras lamellosus* (Keyserling, 1887)
Anyphaenidae	*Anyphaena fraterna* (Banks, 1896)
	Anyphaena pectorosa L. Koch, 1866
	Hibana gracilis (Hentz,1847)

Table 3. Continued.

Family	Species
Araneidae	*Eustala emertoni* (Banks,1904)
	Mangora sp.
Clubionidae	*Clubiona abbotti* L. Koch, 1866
	Clubiona obesa Hentz, 1847
	Elaver excepta (L. Koch, 1866)
Corinnidae	*Castianeira cingulata* (C. L. Koch, 1841)
Dictynidae	*Cicurina brevis* (Emerton, 1890)
	Cicurina robusta Simon, 1886
	Dictyna / Emblyna sp.
Gnaphosidae	*Sosticus insularis* (Banks, 1895)
Liocranidae	*Phrurotimpus alarius* (Hentz, 1847)
	Phrurotimpus borealis (Emerton, 1911)
Linyphiidae	*Agyneta micaria* (Emerton, 1882)
	Anthrobia acuminata (Emerton, 1913)
	Bathyphantes alboventris (Banks, 1892)
	Bathyphantes concolor (Wider, 1834)
	Ceratinella brunnea (Emerton, 1882)
	Erigone autumnalis Emerton, 1882
	Gnathonaroides pedalis (Emerton, 1923)
	Islandiana flaveola (Banks, 1892)
	Lepthyphantes sabulosus (Keyserling, 1886)
	Microneta viaria Simon, 1897
	Neriene clathrata (Sundevall, 1830)
	Oreonetides rotundus (Emerton, 1913)
	Oreonetides vaginatus (Thorell, 1872)
	Mermessus jona Bishop & Crosby, 1938
	Mermessus maculata (Banks, 1892)
	Mermessus trilobata (Emerton, 1882)
	Walckenaeria atrotibialis (O. P. Cambridge, 1878)
	Walckenaeria subdirecta Millidge, 1983
Lycosidae	*Pardosa* sp
	Pirata minutus Emerton, 1885
	Schizocosa ocreata (Hentz, 1844)
	Trabeops aurantiaca (Emerton, 1885)
	*Trochosa ruricola (De Geer, 1778)
	Trochosa terricola Thorell, 1856
Mimetidae	*Mimetus* sp.
Philodromidae	*Philodromus* sp.
Pisauridae	*Pisaurina mira* (Walckenaer, 1837)
Salticidae	*Hentzia mitrata* (Hentz, 1846)
	Naphrys pulex (Hentz, 1846)
	Neon nellii Peckham & Peckham, 1889
Tetragnathidae	*Leucauge* prob. *venusta* (Walckenaer, 1842)
	Tetragnatha sp.
Theridiidae	*Enoplognatha caricis* (Hickert, 1876)
	*Enoplognatha ovata (Clerck, 1757)
	Steatoda americana (Emerton, 1882)
Thomisidae	*Ozyptila monroensis* Keyserling, 1884
	*Ozyptila praticola (C. L. Koch, 1837)
	Xysticus fraternus (Banks, 1895)

Table 4. Comparison of the number of spider species found in each family for the five study subplots in McDonald Woods. Both determined species and taxa listed as "sp." were included when no congener was listed.

Families	Total of all subplots	Upland Forest	Mesic	Mesic Control	Dry Mesic	Savanna
Linyphiidae	18	13	6	6	5	7
Lycosidae	6	2	3	3	3	6
Salticidae	3	3	1	2		1
Dictynidae	3	2	1	2		
Thomisidae	3	2	2	3	2	2
Theridiidae	3	2	1	1	1	2
Anyphaenidae	3	2	2	2	1	3
Clubionidae	3	1			1	1
Liocranidae	2	2	2	2	2	2
Tetragnathidae	2	2	1	2		
Araneidae	2		2			
Agelenidae	1	1	1	1	1	1
Amaurobiidae	1					1
Mimetidae	1	1				1
Philodromidae	1	1			1	
Corinnidae	1	1		1		
Gnaphosidae	1		1			
Pisauridae	1			1		1
Total Species	55	35	23	26	17	28
Total Families	18	14	11	12	10	12

Rarefaction curves (Fig. 2) show the upland forest having the highest richness with the dry mesic subplot having the lowest richness. The mesic and mesic control subplots have intermediate values while the savanna subplot is shown to have the second highest richness.

When considering only those individuals determined to the level of species, the upland forest subplot had the highest species richness (30) with 6 more species than the next closest subplot. The dry mesic subplot had the lowest with 16 species. The upland forest subplot had the highest diversity of all subplots and the lowest diversity was found on the dry mesic subplot. The upland forest also had the highest ESN value (7.32) of any of the subplots. The effectiveness of this measure is seen in comparing the diversity index for the upland forest and savanna subplots. The diversity index, represented by H´, is based on a nonlinear scale and therefore does not as clearly display the magnitude of the difference between these two communities. The upland forest had an H´ only 0.571 (29%) greater than that of the savanna, while the ESN was 3.18 (43%) greater. Values for ESN for the subplots range from a low of 1.89 (dry mesic) to a high of 7.32 (upland forest) (Table 3).

Simple observed number of species in a sample often underestimates the true value of richness at all sample sizes (Hellmann and Fowler 1999). Therefore, a first and second order Jackknife estimate was made for each of the subplots and all subplots combined (Table 1). Hellmann and Fowler (1999) found that for small sample sizes (less than ~25% of the community) the second-order jackknife was the least biased.

Diversity can be measured in a number of different ways to compare one site to another. It is important to note that in this study, all four subplots rank exactly the same for all four measures of diversity: ENS, H´, S, and J´ (Table 1). The upland forest subplot had the highest diversity, effective number of species, richness and evenness among any of the subplots. The dry mesic subplot had the lowest values with most of its total individuals represented by one species of Linyphiidae, *B. concolor*. The dry mesic subplot, with 749 individuals for all species combined, had nearly twice as many individuals captured compared to all other subplots, except for the upland forest, which had 616 individuals.

The upland forest subplot had the highest mass of litter per square meter as expressed in dry weight of any of the subplots with the lowest occurring in the savanna subplot. (Fig. 1). A one-way analysis of variance showed a highly significant difference in litter weights between subplots ($F = 23.3$, df = 49, $P = 1.7117$ E-10). The savanna subplot was significantly different from the mesic, mesic control and upland forest subplots. The mesic, mesic control and dry mesic subplots were not significantly different from each other while the upland forest subplot was significantly different from all other subplots.

A negative correlation was found between litter mass and percent abundance of members of the Lycosidae in the McDonald Woods study (Fig. 6).

A positive relationship was found between the relative abundance of *B. concolor* and the presence of three non-native spider species (*Trochosa ruricola* (DeGeer), *Ozyptila praticola*, and *Enoplognatha ovata* (Clerck) (Fig. 7). There was also a strong negative relationship found between abundance of three non-native species and species richness for each subplot (Fig. 8).

Trochosa ruricola, a wolf spider common in northern and central Europe and Asia, is the most abundant of three non-native species found on the study area. In a study of spider diversity on three forest preserve sites in Lake County, Illinois, approximately 20 miles north of McDonald Woods, Prentice (2001) found *Trochosa ruricola* occurring together with the native congener, *T. terricola* for the first time in Illinois. He reported them occurring in a ratio of 1:2.5 with the native species *T. terricola* being more abundant. In the present study, *T. ruricola* was found to outnumber *T. terricola* in a ratio of approximately 9.6:1 (48 *T. ruricola*, 5 *T. terricola*).
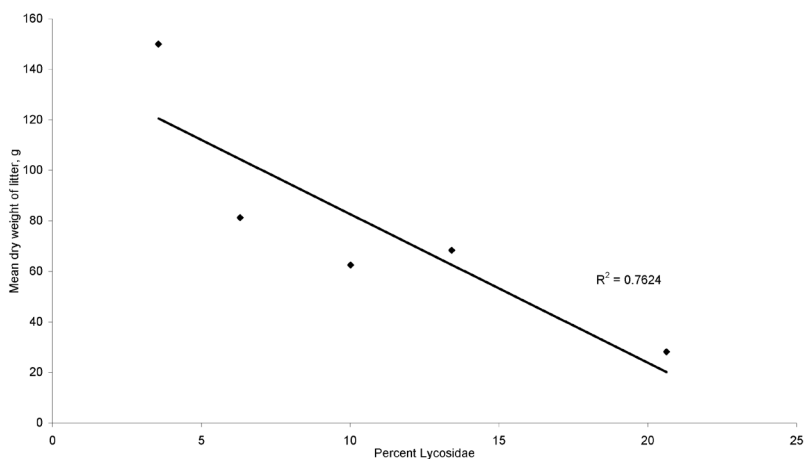

Figure 6. Correlation between the relative abundance of members of the family Lycosidae and the mean dry weight of leaf litter in grams for each subplot.
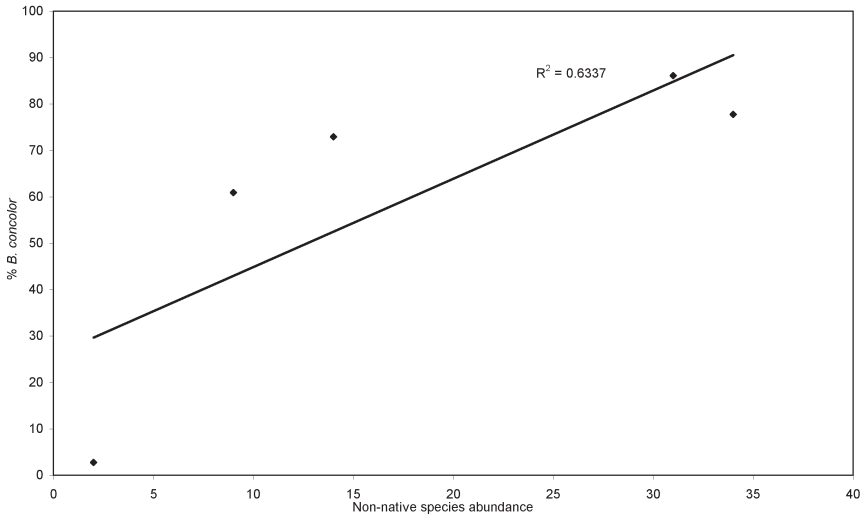
Figure 7. Correlation of percent of adult spiders represented by *Bathyphantes concolor* versus abundance of non-native spider species trapped in each subplot.
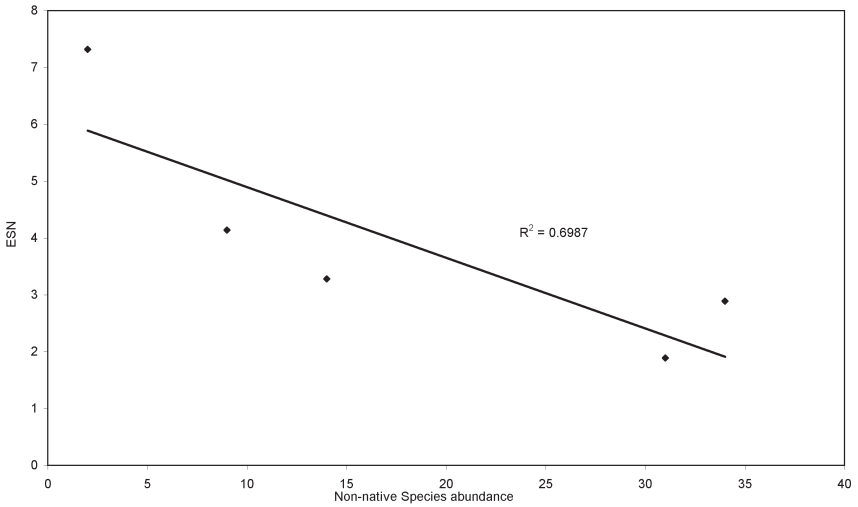

Figure 8. Correlation of abundance of all non-native spider species and the Equivalent Species Number (ESN) for each subplot.
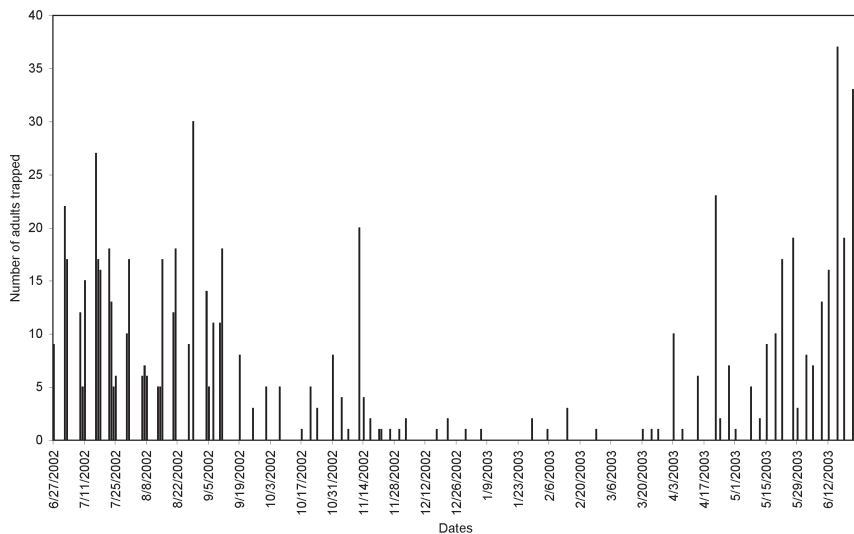
Bathyphantes concolor

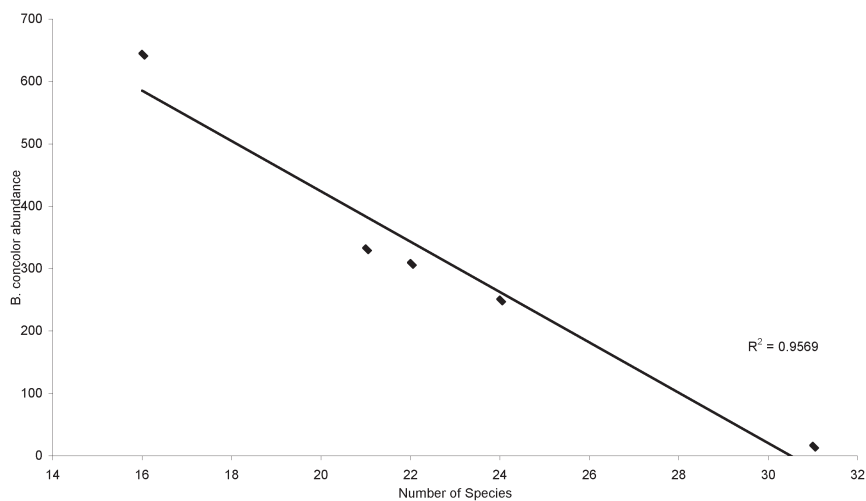Figure 9. Activity periods of a multivoltine species, *Bathyphantes concolor*.

Figure 10. The relationship between the abundance of *Bathyphantes concolor* and species richness for each subplot.

Phenology. In agreement with several other studies, (Huhta 1971, Muma 1973, Uetz 1975) the highest abundance for all subplots occurred in early summer to early fall, with the lowest abundance occurring during the winter months (Data not shown). The upland forest was different in that its highest abundance occurred in late winter to early spring.

Many members of the Linyphiidae are stenochronous, having very specific, rather narrow activity periods, and might be negatively affected if resources were lacking during specific time periods. Figures 3-5 depict some of the more abundant stenochronous species, which display winter/early spring active phenologies. These species are only found as adults and identifiable during winter/early spring.

In contrast, multivoltine species have adults present throughout the year and are therefore able to exploit irregularly abundant resources (Draney and Crossley 1999). It would be expected to find these species in degraded oak woodlands where litter resources are patchy and seasonally abundant. A good example of this phenology pattern is *B. concolor* (Fig. 9). This species comprised between 56 and 86 percent of the total individuals in each subplot with the exception of the upland forest in which it comprised only 3 percent. A strong negative correlation was found between *B. concolor* and species richness for all of the subplots (Fig. 10).

The phenological patterns plotted in this investigation revealed that a minimum of a twelve-month inventory is necessary to adequately sample the ground-layer spider fauna of oak woodlands in the Chicago region.

Discussion

Our findings suggest a negative relationship between native ground-living spider richness and both presence of several non-native spider species and abundance of an opportunistic native species, *B. concolor*. The findings also suggest a negative relationship between leaf litter mass and species richness in the family Lycosidae.

It is suggested that the dominance in this study of one opportunistic species, *B. concolor*, which is capable of reproducing whenever conditions are favorable or when arriving in a favorable environment, is indicative of the unstable, boom-bust resource availability associated with communities invaded by exotic plant species (Hansen 2000). The strong negative correlation between this species and total native species richness leads us to suggest that this species may serve as an indicator of the changing health of oak woodland being invaded by non-native species or in communities undergoing restoration management.

Heneghan et al. 2007, in a study of the impact of an invasive plant (*Rhamnus cathartica*) and earthworms on litter in the same subplots investigated in the present study, identified a positive correlation between degree of invasion of both *Rhamnus* and earthworms with loss of litter mass. Uetz (1979) has shown that spider species richness increases with both litter depth and complexity. The upland forest subplot had both the highest spider species richness and greatest litter mass. The savanna subplot, having been found to have the lowest litter mass of all the subplots, was found to have the second highest species richness. This divergence from the expected trend could not be explained. The savanna subplot was also found to have the greatest diversity of species in the family Lycosidae. This agrees with results found by Uetz (1979) where reduction in litter resulted in the increase in dominance by members of Lycosidae.

Edwards (1993) has suggested that the ratio of species to genera can provide some indication of the ecological "breadth" of the communities being compared. The S/G ratio for McDonald Woods was lower than all but one of the values calculated for pitfall trap results from twelve other studies (Table 2). This might

suggest that McDonald Woods, with its litter having been negatively impacted by invasive species, may possess fewer litter niches than those occurring in these other research sites. This is particularly interesting when noting that even wheat fields and their associated grassy borders and the ecotone between pasture and conifer plantation showed higher ratios, 1.54 and 1.28 respectively. It should also be noted that no mention was made of invasion by non-native species in any of the other studies.

Three non-native spider species were documented during this investigation, which together comprise about 3.4% of abundance and 6% of richness of the sampled species. Two of the species, *T. ruricola* and *O. praticola*, were found to be common and outnumbered species of native congeners. The third species, *E. ovata*, is mainly an inhabitant of forest forb/shrub layers. Although not adequately sampled by pitfalls, it has recently become quite abundant in many Great Lakes region forests (M. Draney, unpub. data). Other researchers have suggested that invasion by exotic species is not associated with historically natural disturbance (Sher and Hyatt 1999). Invasion of a natural community by non-native plant species could be viewed as an unnatural disturbance. In an investigation of the spider fauna of *Typha* spp. (cattail) marshes invaded by the European strain of *Phragmites australis* (Poaceae), a non-native spider, *Clubiona pallidula (*Clubionidae), was found to be the most abundantly collected species (as adults) in the study (Draney and Jaskula 2004). It is likely that the relatively recent invasion of oak woodland communities by several non-native plant species represents an unnatural disturbance, which might relate to the presence and dominance of the non-native spider species found in this study.

Research has shown that both exotic woody plant species and exotic earthworms have the ability to increase the microbial breakdown of leaf litter (Heneghan et al. 2002, Ashton et al. 2005, Heneghan et al. 2007). The accelerated mass reduction and simplification of litter structure has the potential to greatly disrupt nutrient cycling and predator-prey relationships within the litter environment. It is reasonable to assume that disruptions like these are likely to have negative impacts on organisms of a higher trophic level, like the spider fauna within these systems. Future research should investigate how ground-living spider richness is impacted both by the litter loss due to exotic species invasion and the common oak woodland management techniques of controlled burning and exotic plant removal.

Acknowledgments

Literature Cited

Aitchison C. W. 1978. Spiders active under snow in Southern Canada. Symp. Zool. Soc. Lond. 42: 139-148.

Aitchison, C. W. 1984. The phenology of winter-active spiders. J. Arachnol. 12: 249-271.

Aitchison, C. W., and G. D. Sutherland. 2000. Diversity of forest upland arachnid communities in Manitoba taiga (Araneae, Opiliones). Can. Field-Nat. 114: 636-651.

Ashton, I. W., L. A. Hyatt, K. M. Howe, J. Gurevitch and M. T. Lerdau. 2005. Invasive species accelerate decomposition and litter nitrogen loss in a mixed deciduous forest. Ecol. Appl. 15: 1263-1272.

Brumwell, L. J., K. G. Craig, and G. G. E. Scudder. 1998. Litter spiders and cara-bid beetles in a successional Douglas-fir forest in British Columbia. Northwest Sci. 72(2):93-95.

Buckle, D. J., D. Carroll, R. L. Crawford, and V. D. Roth. 2001. Linyphiidae and Pimoidae of America north of Mexico: Checklist, synonymy, and literature. Part 2, pp 89-191. *In* P. Paquin and D. J. Buckle (eds.), Contributions à la Connaissance des Araignées (Araneae) d'Amérique du Nord. Fabreries, Supplément 10.

Buddle, C. M. 2001. Spiders (Araneae) associated with downed woody material in a deciduous forest in central Alberta, Canada. Agric. For. Entomol. 3: 241-251.

Burnham, K. P., and W. S. Overton. 1979. Robust estimation of population size when capture probabilities vary among animals. Ecology 60: 927-936.

Coddington, J. A., L. H. Young, and F. A Coyle. 1996. Estimating spider species rich-ness in a Southern Appalachian cove hardwood forest. J. Arachnol. 24: 111-128.

Coleman, B. D. 1981. On random placement and species area relations. Math. Biosci. 54: 191-215.

Coleman, B. D., M. A. Mares, M. R. Willig, and Y. H. Hsieh. 1982. Randomness, area, and species richness. Ecology 63:1121-1133.

Colwell, R. K. 2006. EstimateS: Statistical estimation of species richness and shared species samples. Version 8.0. User's Guide and application published at: http//purl. oclc.org/estimates.

Cook County (Ill.) Board of Forest Preserve Commissioners. 1918. The forest preserves of Cook County, owned by the Forest Preserve District of Cook County in the state of Illinois. Published by Clohesey & Co., printers (Chicago).

Corio, K., A. Wolf, M. L. Draney, and G. Fewless. 2009. Exotic earthworms of Great Lakes forests: A search for indicator plant species in maple forests. For. Ecol. Manag. 258: 1059-1066.

Crossley, D. A., Jr. 1977. The roles of terrestrial saprophagous arthropods in forest soils: current status of concepts, pp. 49-56. *In* W. J. Mattson (ed.), The Role of Arthropods in Forest Ecosystems. Springer-Verlag, New York.

Deeleman-Reinhold, C. L. 1990. Changes in the spider fauna over 14 years in an industrially polluted area in Holland. Acta. Zool. Fenn. 190: 103–110.

Doane, J. J., and C. D. Dondale. 1979. Seasonal captures of spiders (Araneae) in a wheat field and its grassy borders in central Saskatchewan. Can. Entomol. 111: 439-445.

Dondale, C. D., and J. H. Redner. 1978. The crab spiders of Canada and Alaska (Araneae: Philodromidae and Thomisidae). Biosytematics Research Institute, The Insects and Arachnids of Canada 5: 1-255.

Dorris, P. R., H. W. Robinson, and C. Carlton. 1995. Spiders (Arthropoda: Araneae) from deciduous forest litter of the Ouachita Highlands. Proc. Ark. Acad. Sci. 49: 45-48.

Downie, I. S., J. E. L. Butterfield, and J. C. Coulson. 1995. Habitat preferences of sub-montane spiders in northern England. Ecography 18: 51-61.

Downie, I. S., J. C. Coulson, and J. E. L. Buttterfield. 1996. Distribution and dy-namics of surface-dwelling spiders across a pasture-plantation ecotone. Ecography 19: 29-40.

Draney, M.L. 1997. Ground-layer spiders (Araneae) of a Georgia piedmont floodplain agroecosystem: Species list, phenology and habitat selection. J. Arachnol. 25: 333-351.

Draney, M. L., and D. A. Crossley, Jr. 1999. Relationship of habitat age to phenology among ground-dwelling Linyphiidae (Araneae) in the southeastern United States. J. Arachnol. 27: 211-216.

Draney, M. L., P. Sierwald, and N. Sandlin. 2002.   Inventory of linyphiids from burned and unburned oak woodland/savanna habitats in Chicago, Cook Co., Illinois. Abstracts of the annual meeting, Am. Arachnol. Soc.

Draney, M. L., and J. M. Jaskula. 2004. Araneae and Opiliones from *Typha* spp. And *Phragmites australis* stands of Green Bay, Lake Michigan, and an exotic spider species newly reported from the U.S. Great Lakes region. Gt. Lakes Entomol. 37: 159-164.

Edwards, R. L. 1993. Can the species richness of spiders be determined? Psyche 100: 185-208.

Fassbender, J. L. 2002. Litter and ground dwelling spiders of mixed mesophytic forests in Southeast Louisiana. Masters Thesis. Department of Entomology, Louisiana State University. 72 pp.

Gajdos, P., and S. Toft. 2000. A twenty-year comparison of epigeic spider communities (Araneae) of Danish coastal heath habitats. J. Arachnol. 28: 90-96.

Glesne, R. S. 1998. Terrestrial riparian arthropod investigations in the Big Beaver Creek Research Natural Area, North Cascade National Park Complex, 1995-1996: Part III, Arachnida: Araneae. Technical Report NPS/NRNOCA/NRTR/98-03, Unites States Department of the Interior – National Park Service – Pacific West Region. 25 pp.

Gotelli, Nicholas J., and R. K. Colwell. 2001. Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. Ecol. Lett. 4: 379-391.

Hansen, R. A. 2000. Diversity in the decomposing landscape, pp. 203-219. *In* D. C. Coleman and P. F. Hendrix (eds.), Invertebrates as Web Masters in Ecosystems. CAB International Press, 352 pp.

Hauge, E. 2000. Spiders (Araneae) from square samples and pitfall traps in coastal heathland, western Norway. Habitat preference, phenology and distribution. Fauna Nor. 20: 31-42.

Hellmann, J. J., and G. W. Fowler. 1999. Bias, precision, and accuracy of four measures of species richness. Ecol. Appl. 9: 824-834.

Heltshe, J. F., and N. E. Forrester. 1983. Estimating species richness using the jackknife procedure. Biometrics 39: 1-12.

Heneghan, L., C. Clay & B. Cynthia. 2002. Observations on the initial decomposition rates and faunal colonization of native and exotic plant species in an urban forest fragment. Ecol. Restor. 20: 108-111.

Heneghan, L., C. Rauschenberg, F. Fatemi, and M. Workman. 2004. The impact of an invasive shrub (*Rhamnus cathartica* L.) on some ecosystem properties in urban woodland in Chicago, Illinois. Ecol. Restor. 22: 275-280.

Heneghan, L., J. Steffen, and K. Fagen. 2007. Interactions of an introduced shrub and introduced earthworms in an Illinois urban woodland: impact on leaf litter decomposition. Pedobiologia 50: 543-551.

Huhta, V. 1971. Succession in the spider communities of the forest floor after clear-cutting and prescribed burning. Ann. Zool. Fenn. 8: 483-542.

Jost, L. 2006. Entropy and diversity. Oikos 113(2): 363-375.

Koponen, S. 1987. Communities of ground-living spiders in six habitats on a mountain in Quebec, Canada. Holarct. Ecol. 10: 278-285.

Koponen, S. 1993. Ground-living spiders (Araneae) one year after fire in three subarctic forest types, Quebec (Canada). Mem. Queensl. Mus. 33: 575-578.

Laatsch, J. R., and R. C. Anderson. 2000. An evaluation of oak woodland management in Northeastern Illinois, USA. Nat. Areas J. 20: 211-220.

Lorimer, C. G. 1987. The role of fire in the perpetuation of oak forests. Eighth North. Ill. Prairie Workshop, May 2, pp. 59-75.

Mallis, R. E., and L. E. Hurd. 2005. Diversity among ground-dwelling spider assemblages: Habitat generalists and specialists. J. Arachnol. 33: 101-109.

Moldenke, A. R., and J. D. Lattin. 1990. Density and diversity of soil arthropods as biological probes of complex soil phenomena. Northwest Environ. J. 6: 409-410.

Moulder, B. C., and D. E. Reichle. 1972. Significance of spider predation in the energy dynamics of forest floor arthropod communities. Ecol. Monogr. 42: 473-498.

Muma, M. H. 1973. Comparison of ground surface spiders in four central Florida ecosystems. Fla. Entomol. 56: 173-196.

Muma, M. H., and K. E. Muma. 1949. Studies on a population of prairie spiders. Ecology 30: 485-503.

Nuzzo, V. A. 1986. Extent and status of Midwest oak savanna: Presettlement and 1985. Nat. Areas J. 6(2): 6-36.

Olynyk, J., and R. Freitag. 1977. Collection of spiders beneath snow. Can. Field-Nat. 91: 401-402.

Oxbrough, A. G., T. Gittings, J. O'Halloran, P. S. Giller, and G. F. Smith. 2005. Structural indicators of spider communities across the forest plantation cycle. For. Ecol. Manag. 212(1-3): 171-183.

Packard, S. 1988. Chronicles of restoration: Restoration and rediscovery of the tallgrass savanna. Restor. Manag. Notes 6: 13-22.

Pajunen, T., Y. Haila, E. Halme, J. Niemalä, and P. Punttila. 1995. Ground-dwelling spiders (Arachnida, Araneae) in fragmented old forests and surrounding managed forests in southern Finland. Ecography 18: 62-72.

Palmer, M. W. 1990. The estimation of species richness by extrapolation. Ecology 71: 1195-1198.

Palmer, M. W. 1991. Estimating species richness: the second-order jackknife reconsidered. Ecology 72: 1512-1513.

Pekar, S. 2003. Change in the community of epigeal spiders and harvestmen (Araneae, Opiliones) with the age of an apple orchard. Plant Soil Environ. 49(2): 81-88.

Platnick, N. I. 2006. The world spider catalog, Version 6.5, The American Museum of Natural History. http://research.amnh.org/entomology/spiders/catalog/INTRO2.html (accessed 11/17/2006).

Prentice, T. R. 2001. Distinguishing the females of *Trochosa terricola* and *Trochosa ruricola* (Araneae, Lycosidae) from populations in Illinois, USA. J. Arachnol. 29: 427-430.

Schmoll, H. M. 1919. Ecological survey of forests in the vicinity of Glencoe, Illinois. Trans. Ill. State Acad. Sci. 30: 208-233.

Seastedt, T. R. 1984. The role of microarthropods in decomposition and mineralization processes. Annu. Rev. Entomol. 29: 25 46.

Sierwald, P., M. L. Draney, T. Prentice, F. Pascoe, N. Sanlin, E. M. Lehman, V. Medland, and J. Louderman. 2005. The spider species of the Great Lakes states. Proc. Indiana Acad. Sci. 114: 111-206.

Sher A. A., and L. A. Hyatt. 1999. The disturbed resource-flux invasion matrix: a new framework for patterns of plant invasion. Biol. Invasions. 1: 107–114.

Suarez, E., T. Fahey, J. Yavitt, P. Groffman, and P. Bohlen. 2006. Patterns of litter disappearance in a northern hardwood forest invaded by exotic earthworms. Ecol. Appl. 16: 154-165.

Toft, S., and D. H. Wise. 1999. Growth, development, and survival of a generalist predator fed single- and mixed-species diets of different quality. Oecologia 119: 191-197.

Ubick, D., P. Paquin, P.E. Cushing, and V. Roth (eds). 2005. Spiders of North America: an identification manual. Am. Arachnol. Soc. 377 pp.

Uetz, G. W. 1975. Temporal and spatial variation in species diversity of wandering spiders (Araneae) in deciduous forest litter. Environ. Entomol. 4: 719-724.

Uetz, G. W. 1979. The influence of variation in litter habitats on spider communities. Oecologia 40: 29-42.

Uetz, G. W. 1991. Habitat structure and spider foraging, pp. 325-348. *In* S. S. Bell, E. D. McCoy, and H. R. Mushinsky (eds.), Habitat Structure: The Physical Arrangement of Objects in Space. Chapman and Hall, London.

Uetz, G. W., and J. D. Unzicker. 1976. Pitfall trapping in ecological studies of wandering spiders. J. Arachnol. 3: 101-111.

Wagner. J. D., S. Toft, and D. H. Wise. 2003. Spatial stratification in litter depth by forest-floor spiders. J. Arachnol. 31: 28-39.

Willett, T. R. 2001. Spiders and other arthropods as indicators in old-growth versus logged redwood stands. Restor. Ecol. 9: 410-420.

Wolff, R. J. 1990. Diversity of wandering spiders (Araneae) collected by pitfall traps in Northern Illinois prairies and woodlands. Proc. Twelfth North Am. Prairie Conf. pp. 67-69.