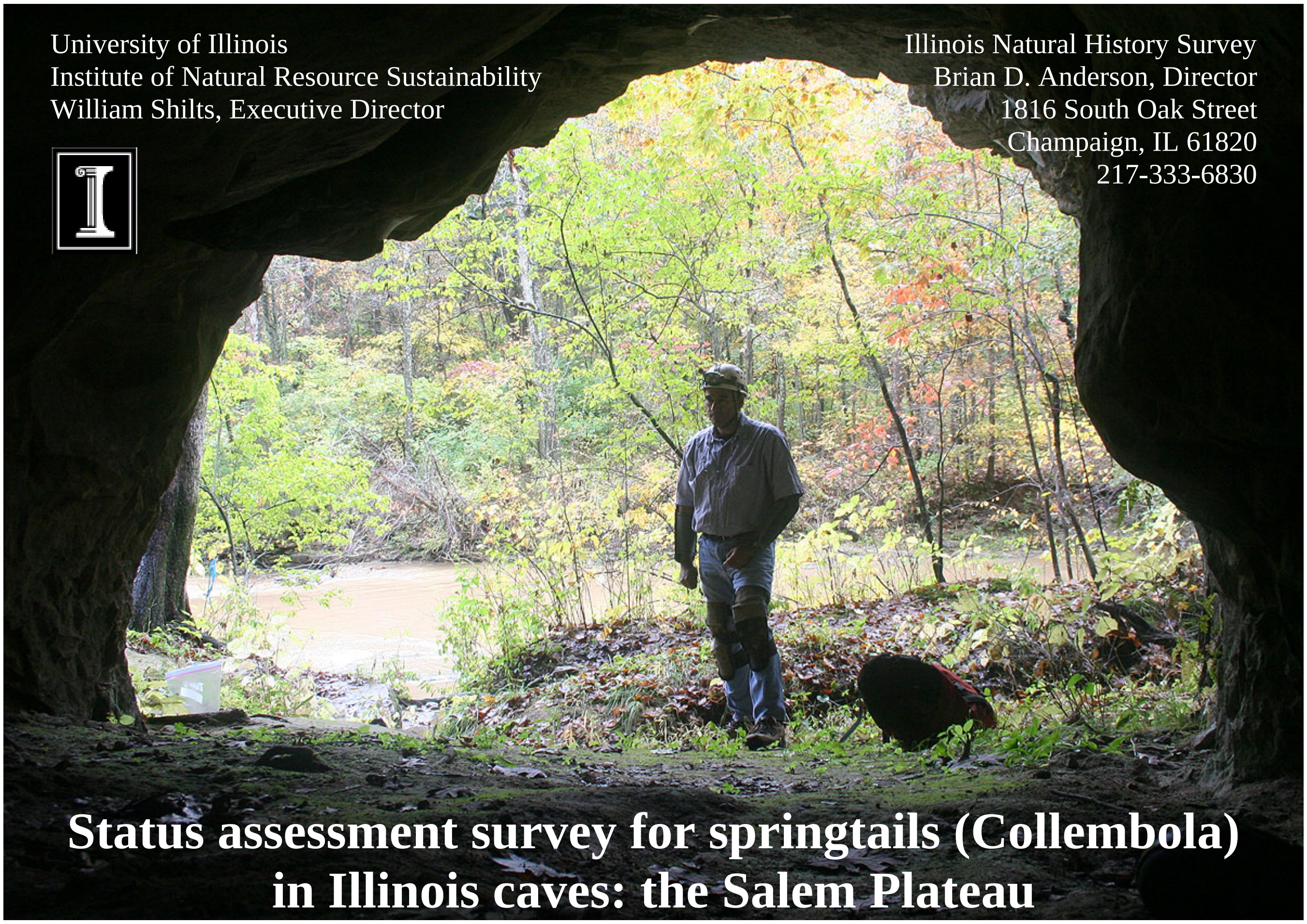

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Status assessment survey for springtails (Collembola) in Illinois caves: the Salem Plateau

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Abstract

Soto-Adames, Felipe N. & Steven J. Taylor. 2010. Status assessment survey for springtails (Collembola) in Illinois caves: the Salem Plateau. INHS Technical Report 2010 (13): 1-76.

The primary goal of this study was to survey the springtail (Hexapoda: Collembola) fauna of caves in the Salem Plateau of southwestern Illinois using structured sampling protocols to provide semi-quantitative abundance data and to assess the completeness of our knowledge of Illinois cave springtails. In 2009, eight caves (Wizard Cave, Pautler Cave, Spider Cave, Wanda's Waterfall Cave, Illinois Caverns, Stemler Cave, Hidden Hand Cave and Bat Sump Cave) in Monroe and Saint Clair counties, Illinois, were sampled using a combination of methods, including pitfall traps, Berlese funnel processing of leaf and other plant litter, and hand collections by quadrat, on drip pools, free standing bait and random searches. Use of these varied sampling methods allowed us to evaluate the most effective survey methods for this group of arthropods. In total 49 species of springtails were found, of which 7 are new to science, 8 others represent new records for Illinois and 18 are new cave records for the species. This more than doubles the number of springtails species known from caves in the Salem Plateau region. More than half (29) of the species reported are ranked as rare at the state level (i.e., S1-S2). The ranking of a few species as rare in Illinois is probably an artifact of the relatively poor knowledge of the fauna of the state. Some other species ranked rare are probably actually rare in the state, as they represent populations at the limit of the distributional range of the species, yet others, such as the *Pygmarrhopalites* species, are probably truly rare and endemic to the region. The combination of pitfall trapping, random hand collections and Berlese funnel extractions accounted for more than 85% of the specimens counted and nearly 45% of the species collected. Examination of drip pools produced only 2% of the counted specimens, but 30% of the species reported. Three species accounted for 71% of all individuals collected and almost half (49.0%) the species were represented by only one or two specimens. Analysis of species accumulation curves using several estimators of species richness indicated that the rate of species accrual is far from asymptotic, suggesting our sampling is incomplete. The final estimates of the true number of springtail species ranged from 60.2 to 105.4, suggesting that an additional 11 to 56 springtail species may yet be detected in the region. Based on these results we conclude that pitfall traps, Berlese funnels and examination of drip pools and hand collections in other cave habitats are the four most effective ways to sample for cave springtails. We also conclude that the total number of species in Salem Plateau caves could be more than twice what we recorded in the present study, and that many more new species and state records will be found once caves in other Illinois karst regions are more thoroughly examined.

Status assessment survey for springtails (Collembola) in Illinois caves: the Salem Plateau

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Introduction

Illinois' karst is distributed across five regions (Figure 1) which contain numerous sinkholes, springs, and shallow groundwater conduits. Four of these regions – Driftless Area, Lincoln Hills, Salem Plateau, and Shawnee Hills – also contain caves accessible to humans. In addition to their hydrological, recreational, geological and cultural values, these caves contain fascinating assemblages of life. The fauna most familiar to the public are bats and salamanders, but caves also contain a wide variety of invertebrates. Among these are the Illinois Cave Amphipod (*Gammarus acherondytes*), which is federally listed as endangered, the Enigmatic Cavesnail (*Fontigens antrocetes*), a state listed species, and a single-site endemic Illinois cave beetle (*Pseudanophthalmus illinoisensis*). One cave springtail, *Pygmarrhopalites madonnensis* (Zeppelini & Christiansen, 2003) is listed as state endangered in Illinois. Numerous other invertebrate species occur in Illinois caves, including a variety of springtails (Collembola).

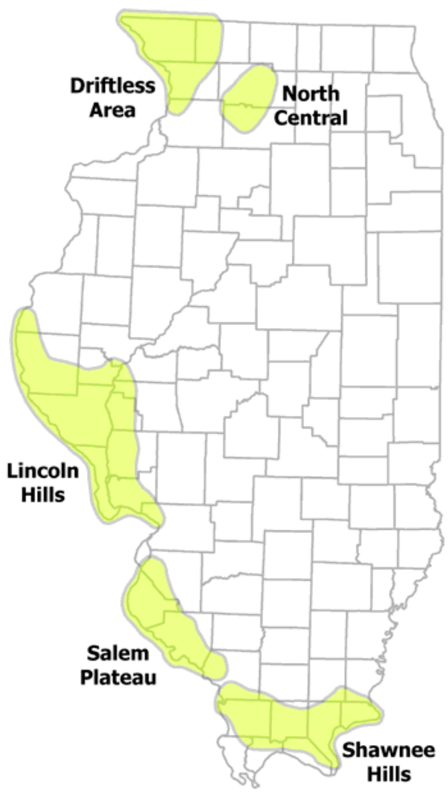

Figure 1. Distribution of karst areas in Illinois. The North Central karst is not known to contain any caves, and several caves occur in other areas of the state. Map modified after Weibel and Panno (1997).

Cover Photo: The entrance of Hidden Hand Cave (Monroe County, Illinois). 4 October 2009.

Springtails are small hexapods characterized by the presence of four-segmented antennae, six-segmented abdomen, a large vesicle (the collophore) on the ventral part of the first abdominal segment, and, in many species, a jumping organ complex formed by the tail-like furcula and the furcula catch or retinaculum (Figure 2). Springtails are most commonly found in soil and leaf litter, but they have invaded other specialized habitats, including caves. Many soil or leaf litter species are commonly found in caves as xenobionts, but some species are cave-adapted or cave-limited and do not sustain surface populations (Christiansen & Culver 1987).

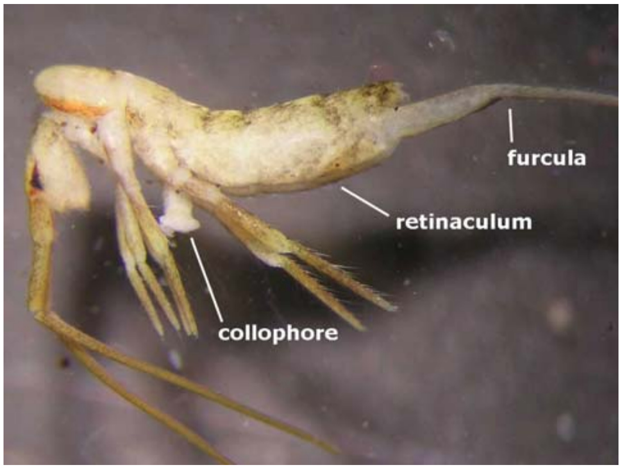

Figure 2. *Pogonognathellus elongatus*, a common leaf litter springtail found in Illinois

In Illinois the most common families reported from caves are Hypogastruridae, Onychiuridae, Oncopoduridae, Tomoceridae, Isotomidae, Entomobryidae and Sminthuridae (Figure 3). Of the 43 species of springtails previously recorded from Illinois caves (Table 1), slightly more than 25% (11 species) are either troglobites (completely restricted to caves, Figure 3) or troglophiles (may complete entire life cycle in caves, but are found in other habitats). The genera of troglophiles or troglobites reported from Illinois prior to our study are: *Typhlogastrura*, *Lethemurus*, *Oncopdura*, *Pseudosinella*, *Sinella* and *Arrhopalites*. Three species of cave springtails are endemic to Illinois (*Sminthurides weichseli*, *Arrhopalites sapo*, and *Arrhopalites madonnensis*). The last of these, *A. madonnensis* (the Madonna cave springtail), is a single-site endemic – known from only one cave –has recently been listed as state endangered. Although only three species are currently reported as endemic to the state, the actual number of endemics is probably considerably higher because most groups have not been studied in detail. For example, the genera *Typhlogastrura* and *Pseudosinella* have diversified extensively in caves elsewhere in North America and Europe, and although both are reported from Illinois caves no species have been identified for the state. In addition, some troglophiles and troglobites first thought to be widely distributed across karst regions are now known, upon closer examination, to represent complexes of species endemic to just a few caves. The most striking example of this is the *Onychiurus reluctus* species complex, which is now thought to include at least five species (Pomorski *et al.*, 2009).


Figure 3. *Arrhopalites sp.*, a troglobitic springtail. Two members of this genus, *A. madonnensis* and *A. sapo*, are endemic to Illinois caves.

Table 1. Springtails (Collembola) previously recorded from Illinois caves, based primarily on published literature.

Family	**Species**
Hypogastruridae	*Thyplogastrura* sp.
	Ceratophysella denticulata
	Hypogastrura matura
	Hypogastrura packardi
Neanuridae	*Pseudachorutes* sp.
	Neanura persimilis
	Pseudachorutes saxantillis
	Sensillanura barberi
	Sensillanura illina
Onychiuridae	*Onychiurus* sp.
	Onychiurus reluctus
	Tullbergia clavata
Isotomidae	*Desoria* sp.
	Folsomia candida
	Folsomia elongata
	Folsomia nivalis
	Folsomia prima
	Desoria gelida
	Desoria trispinata
	Paritosoma notabilis
	Isotoma carpenteri
Oncopoduridae	*Oncopodura iowae*
Tomoceridae	*Lethemurus missus*
	Pogonognathellus bidentatus
	Pogonognathellus flavescens
Entomobryidae	*Pseudosinella* sp.
	Entomobrya intermedia
	Sinella avita
	Sinella barri
	Sinella cavernarum
Sminthurididae	*Sminthurides* sp.
	Sminthurides malmgreni
	Sminthurides weichseli

(continued)

Table 1. Concluded.

Family	Species
Arrhopalitidae	*Arrhopalites* sp.
	Pygmarrhopalites ater
	Pygmarrhopalites carolynae
	Pygmarrhopalites hirtus
	Pygmarrhopalites lewisi
	Pygmarrhopalites madonnensis
	Pygmarrhopalites pygmaeus
	Pygmarrhopalites sapo
	Pygmarrhopalites whitesidei
Dicyrtomidae	*Ptenothrix atra*

In Illinois, cave-inhabiting springtails have been recorded from the four karst regions listed above (i.e., not the North Central Karst) and shown in Figure 1. A detailed assessment of the available literature shows that 60% of these (26 species) have been recorded only from a single cave (Figure 4) and more than 88% (38 species) have only been recorded from caves in a single karst region (Figure 5). Indeed, springtails have been recorded from less than 10% of Illinois' caves (40 caves), and for those forty caves, most (55% or 22 caves) have only a single springtail species recorded from them. Using these data, and prior to conducting the current study, we further assessed the current state of knowledge by generating a species accumulation curve for springtails occurring in Illinois caves (Figure 6) and have used several estimators of true species richness (see Colwell and Coddington 1994, Schneider and Culver 2004), to make a preliminary guess as to how many species are expected to occur in Illinois caves. The species accumulation curve shows that we can expect many more species than have already been recorded, and 43 species may represent from 43.3% (Chao 1 estimator) to 49.1% (ICE and Jacknife 2 estimators) of the actual species richness estimators. No data are presently available on sampling completeness in the caves, but we can gain some anecdotal insights. The cave with the most species is Cave-in-Rock, a short cave (less than 200 feet in length) with a large, easy to access entrance via a paved path in a state park (Hardin County) – it has 12 species recorded from it. In contrast, Illinois Caverns (5.6 miles long and one of the state's longest caves, in Monroe County) has only three species recorded from it. Given these data, it is reasonable to presume that most caves have been under-sampled, and thus we believe there is an extremely high probability that additional sampling which is methodical and taxonomically focused (on springtails) will record new localities for species

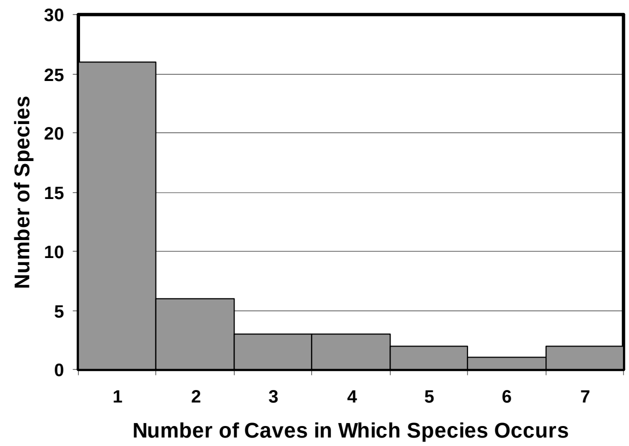

Figure 4. Summary of known distributions of springtails in Illinois caves, based on literature records.

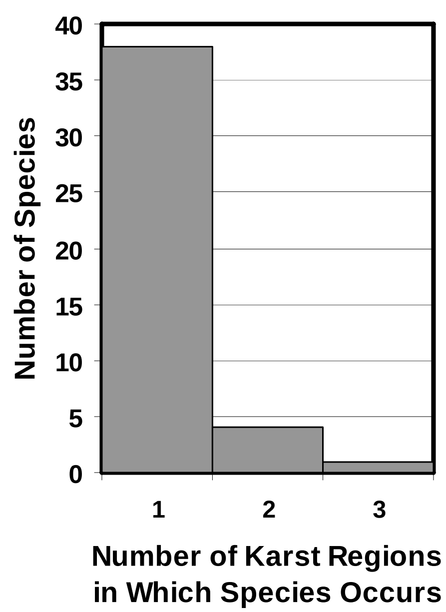

Figure 5. Summary of known distributions of springtails in Illinois caves, based on literature records. Number of Illinois karst regions in which species occur.

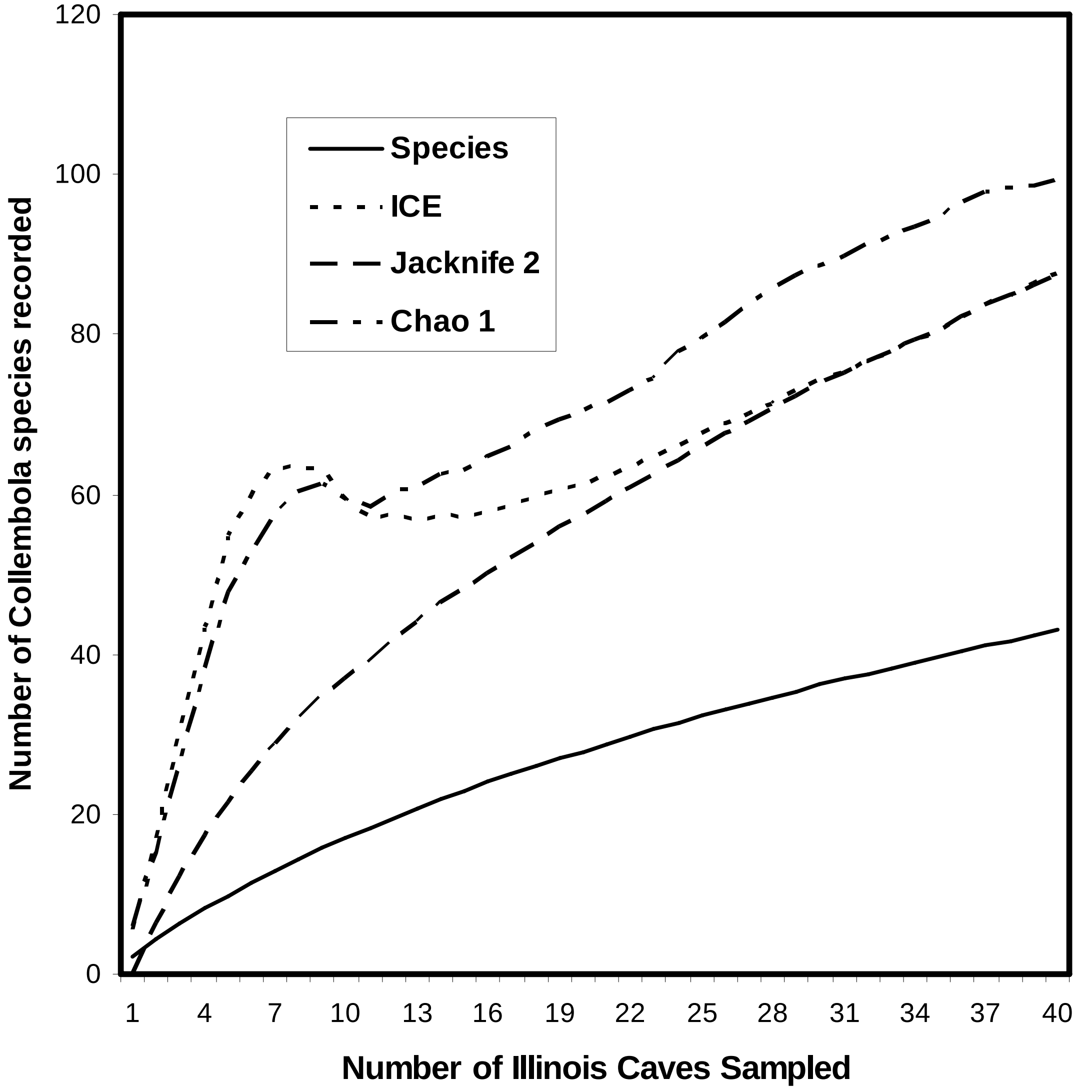

Figure 6. Species accumulation curves for number of species (43), and three estimators of species richness, ICE (87.58), Jackknife 2 (87.5), and Chao 1 (99.33), for Illinois springtail records compiled prior to the present study from the available literature.

with poorly known distributions, and likely could result in the collections of additional undescribed species.

The report represents the findings of part of a larger study which had been proposed to evaluate the status of springtails in caves of all of Illinois karst regions. Here we present data on the distribution and abundance data for cave-inhabiting springtails in select caves in Illinois' Salem Plateau.

Methods

Field sampling

Eight caves were selected for study in the Salem Plateau. Initially we had proposed Fogelpole Cave as one of these, but we were unable to secure a permit to work in Fogelpole Cave Nature Preserve due to concerns about white-nose syndrome of bats. All necessary permits required to conduct the research were obtained prior to the beginning of field work.

At each cave, the dominant habitat types in which Collembola might occur were sampled, with sampling technique varying by habitat. Techniques used are as follows:

A. Pitfall trapping: Pitfall containers were 1.5 ml microtubes (more commonly used for molecular biology lab work) standardized for size and repeatability. Traps were filled with 1-1.2 ml of ethanol, and baited with a small amount of limburger cheese, and then placed wherever there was suitable substrate – that is, substrate where a small hole could be made to place the trap and level the substrate up to or above the lip of the trap so that the lip of the container did not constitute a barrier to springtail movement (Figure 7). Traps were placed in arrays of 5 traps, in an area roughly equal in area and proportions to the quadrat (Figure 8), when the nature of the substrate dictated otherwise, we distributed the traps over a similar sized area, but with differing proportions (Figure 9). Traps were left in place 2 days, then recovered, closed, and returned to the laboratory for sample sorting.

B. Quadrat searching: A pvc pipe quadrat was placed on the substrate (e.g., clay, gravel, bedrock floors or walls) and a trained expert (one of the PIs) searched the entire area, recording the amount of time needed to search the quadrat (Figure 10). We attempted to collect any springtails observed using an aspirator, preserving them in 95% ethanol.

C. Drip pools: Individual drip pools (Figure 11) were visually searched, recording the amount of time needed to search the pool. We attempted to collect any springtails observed using an aspirator or by hand, preserving them in 95% ethanol.

D. Litter samples: Where accumulations of leaf litter were available, samples were collected into 3-4-liter ziplock bags (Figure 12) and removed from the cave for extraction using a Berlese funnels or similar litter extraction device. Samples were extracted for three days.

Figure 7. An individual microtube pitfall trap containing ethanol and baited with limburger cheese. Wanda's Waterfall Cave, Monroe County Illinois, 2009. The trap has been inserted deeply in the clay substrate so that the lip of the microtube is not a barrier to springtail movement.

Figure 8. An array microtube pitfall traps in a sandy area, constituting a single pitfall trap sampling event. Illinois Caverns, Monroe County Illinois, 2009.

Figure 9. An irregularly distributed array of pitfall traps in a clay filled joint in Wanda's Waterfall Cave, Monroe County, Illinois, in 2009. Note accumulations of organic debris in foreground..

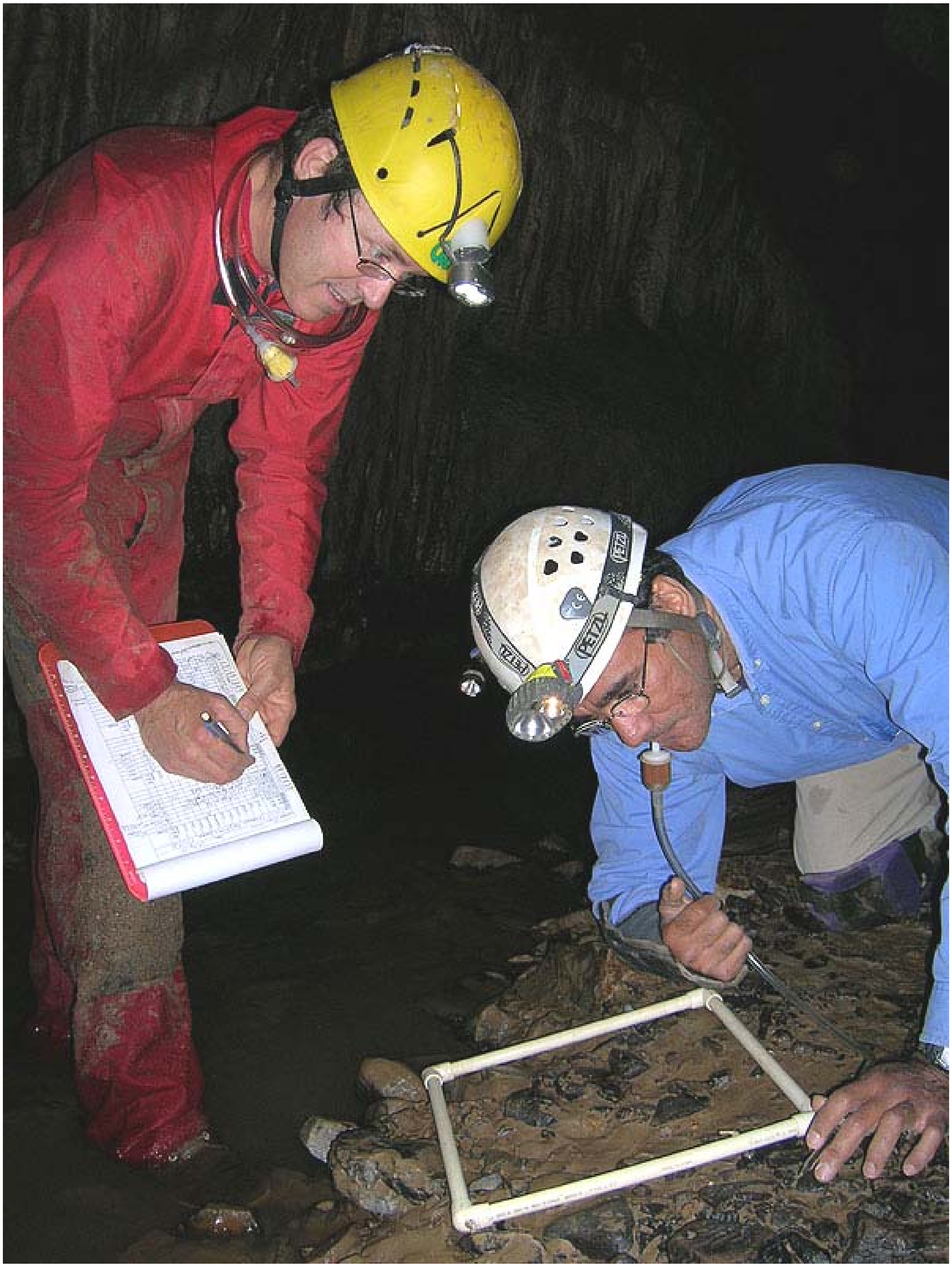

Figure 10. Censusing a quadrat in Illinois Caverns, Monroe County, Illinois, in 2009.

A.

B.

Figure 11. Examples of drip pools sampled in 2009 for springtails in A).Wanda's Waterfall Cave, Monroe County, Illinois; and B) Wizard Cave, St. Clair County, Illinois.

E. Cheese Smears: Especially in areas where it was impossible to place pitfall traps, we smeared a small amount of limburger cheese in localized areas of the substrate (typically bedrock), and returned 2 days later to collect any springtails aggregating in the vicinity of the cheese.

F. Hand samples: We made additional hand collections of springtails in various habitats. Habitats sampled included, clay, sand, silt, gravel, rock, bedrock, leaf litter, woody debris, small mammal (bats, raccoons, rodents, etc.) dung (Figure 13), and drip pools. For pitfall traps, we used a quadrat centered on the 5-trap arrays to estimate the substrate composition (e.g., 40% clay, 20% rocks, 30 % bedrock, 10 % litter). Quadrat searches substrate composition was estimated in the same manner. We recorded temperature, relative humidity (Figure 14), and light (Figure 15) as often as was feasible at semi-quantitative sample locations, and characterized substrate moisture (dry, ‘cave normal’ [feels damp to touch], wet [at least glistening]). Sampling

Figure 12. Sampling leaflitter in the dark zone of Bat Sump Cave, Monroe County, Illinois in 2009.

Figure 13. Fungal and bacterial growth on old raccoon dung in Wizard Cave, St. Clair County, Illinois, in 2009. Two springtails can bee seen on the dung, and two others are nearby on the substrate (arrows).

Figure 14. Recording relative humidity and soil temperature in Wizard Cave, St. Clair County, Illinois, in 2009.

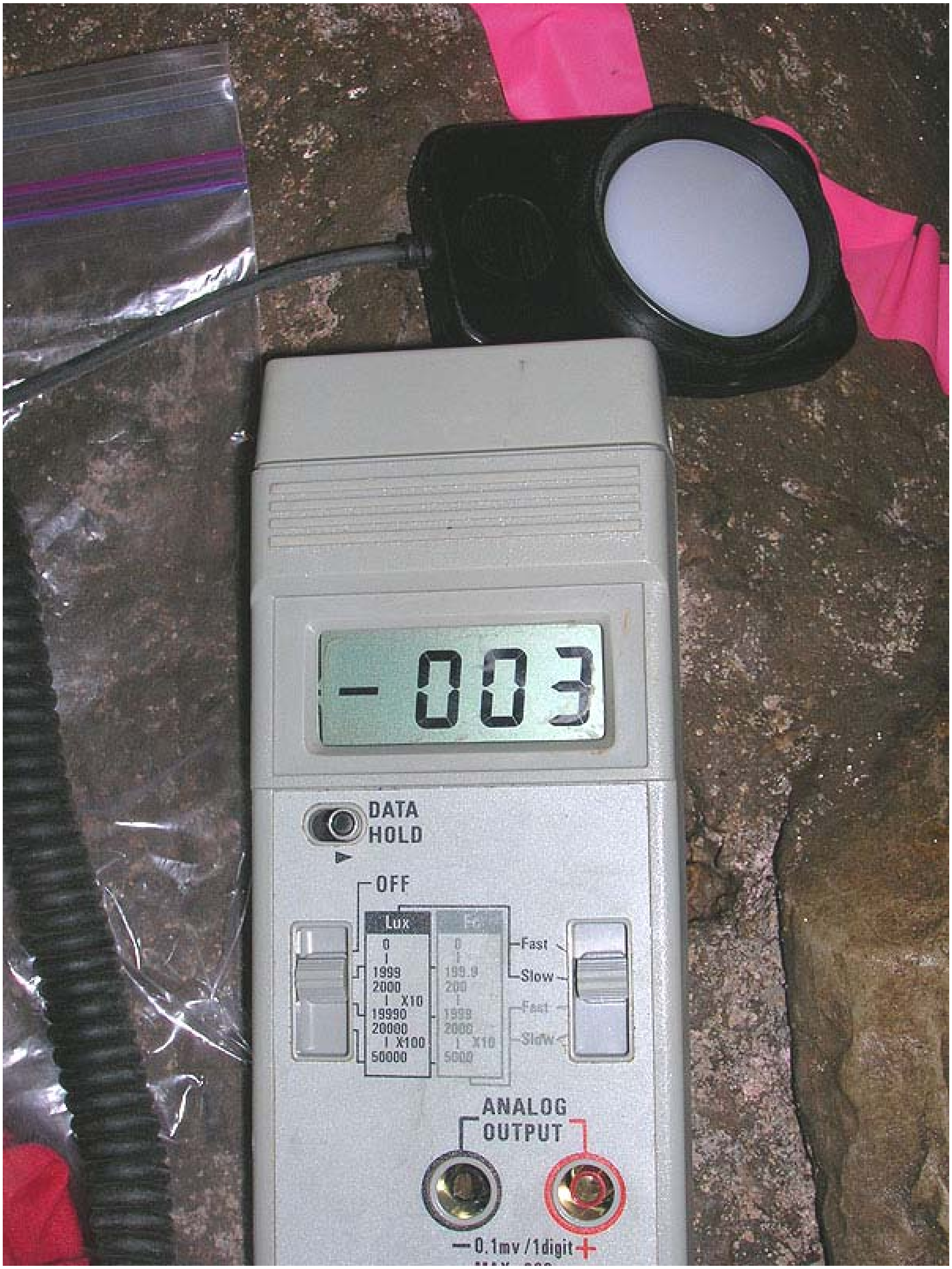

Figure 15. Light meter in use in Wizard Cave, St. Clair County, Illinois, in 2009.

primarily focused on the dark zone of caves. Where possible (when habitats were suitably abundant to allow replication), we collected ten replicate samples for pitfalls, quadrats, and drip pools in each cave.

Species Accounts

The ecological classification into troglobite (TB), troglophile (TP), trogloxene (TX) and accidental (AC) follows Lewis *et al*. (2003) and is based on definitions provided by Barr (1963, 1968). The rankings provide a measure of the extent of a species distribution at the state (S) and global (G) level. Rankings are circumscribed following Lewis *et al*. (2003) as species reported in 5 or fewer localities (1), 6-20 localities (2), 21-100 localities (3), widespread and common (5), and introduced from other biogeographic regions (SE). Rankings of the species listed below are based on Illinois and North American records obtained from either the Collembola of North America (Christiansen and Bellinger 1998) or from the database of North American Collembola records (Christiansen 2010). Additional sources of distributional information are listed under individual species accounts. New records for Illinois are identified after the species name.

Springtail species identifications were carried out by the lead PI using standard methods for Collembola and keys available in Christiansen & Bellinger (1998), supplemented by primary literature. Voucher specimens were deposited in the Illinois Natural History Survey Insect Collection.

Distribution, abundance, diversity, and microhabitats

We used EstimateS version 8.0.0 (Colwell 2006) to calculate metrics of species richness and species accumulation curves, using 1000 iterations and default settings, except that Chao 1 & Chao 2 were calculated without bias correction because the coefficient of variation was greater than 0.5. Cluster analysis of species presence absence was calculated using the UPGMA (Unweighted Pair Group Method with Arithmetic mean) clustering algorithm, average linkage cluster analysis (Sneath and Sokal 1973), in the statistical analysis software package SAS 9.1.3 (with Service Pack 4). Diversity and evenness indices (Krebs 1999, Magurran 2004, Pielou 1977) were calculated using the "Diversity Index Calculator," an add-in for MS-Excel obtained from the Statistical Services Centre, University of Reading (© 2010). We used Simpson's index (Simpson 1949) to measure diversity, following guidelines in Magurran (2004, p. 101), and dominance was measured using the Berger-Parker index (d). Relative percent abundance of Collembola taxa by cave were examined using a Whittaker plot, a type of rank/abundance pot (see Magurran 2004, p. 22).

Results

Bioinventory of eight caves (Figure 16) in Monroe and St. Clair counties, Illinois in 2009 yielded 1611 springtail specimens, 1605 of which were collected and identified to genus or, in most cases, to species. This material represents 49 distinct species, in 32 genera, 16 families, and four different orders (Table 2). Among the material are seven undescribed species, several of which are present in sufficient numbers to allow species description.

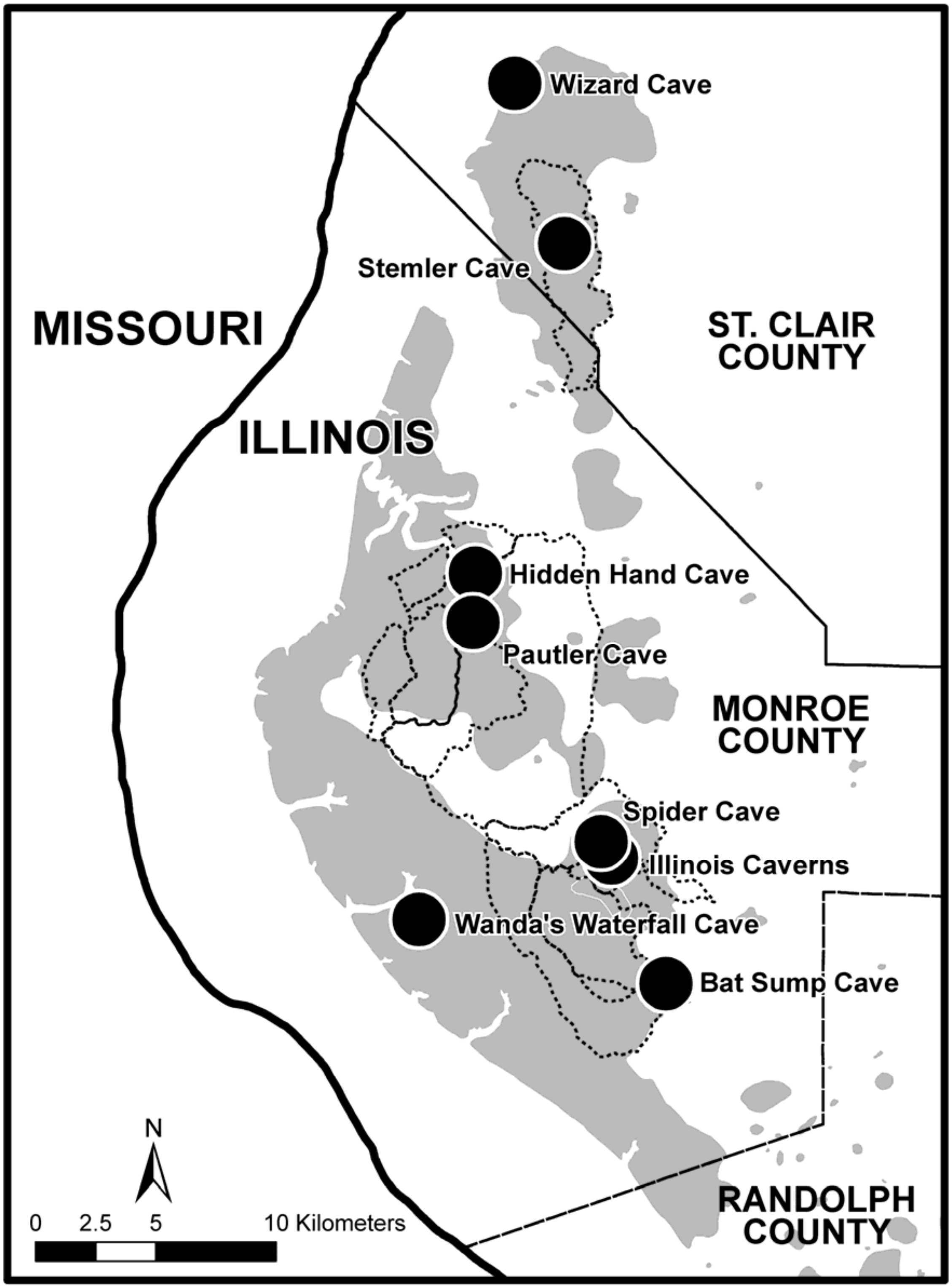

Figure 16. Distribution of eight caves where springtails were collected during 2009. Dotted lines indicate karst drainage basins defined by dye tracing (Ozark Underground Laboratory), gray shading indicates approximate boundaries of karst based on sinkhole mapping (Illinois State Geological Survey). Cave locations are approximate.

Table 2. Classification and checklist of Collembola collected from eight caves in Monroe and St. Clair counties, Illinois, in 2009, with total number of specimens collected. Higher classification follows Deharveng (2004) and Bellinger *et al*. (2010).

Taxon	Total Specimens
Class Collembola Lubbock, 1870	
Order Poduromorpha Börner, 1913	
Superfamily Neanuroidea Massoud, 1967	
Family Neanuridae Börner, 1901	
Subfamily Neanurinae Börner, 1901	
Tribe Paleonurini Cassagnau, 1989	
Vitronura Yosii, 1969	
Vitronura giselae (Gisin, 1950)	2
Subfamily Pseudachorutinae Börner, 1906	
Pseudachorutes Tullberg, 1871	
Pseudachorutes aureofasciatus (Mac Gillivray, 1893)	1
Pseudachorutes n. sp.	1
Family Odontellidae Massoud, 1967	
Superodontella Stach, 1949	
Superodontella cornifer (Mills, 1934)	1
Superodontella rossi (Christiansen & Bellinger, 1980)	1
Superodontella substriata (Wray, 1952)	2
Superodontella n. sp.	1
Superfamily Hypogastruroidea Salmon, 1964	
Family Hypogastruridae Börner, 1906	
Ceratophysella Börner, 1932	
Ceratophysella brevis (Christiansen & Bellinger, 1980)	617
Ceratophysella boletivora (Packard, 1873)	83
Ceratophysella denticulata (Bagnall, 1941)	2
Ceratophysella engadinensis/denticulata	8
Ceratophysella n. sp.	5
Hypogastrura Bourlet, 1839	
Hypogastrura pannosa (Macnamara, 1922)	8
Xenylla Tullberg, 1869	
Xenylla welchi Folsom, 1916	1
Superfamily Onychiuroidea D'Haese 2002	
Family Onychiuridae Lubbock, 1867	
Subfamily Onychiurinae Börner, 1901	
Tribe Onychiurini Börner, 1906	

(continued)

Table 2. Continued.

Taxon	Total Specimens
Onychiurus Gervais, 1841	
Onychiurus n. sp.	88
Tribe Thalassaphorurini Pomorski, 1998	
Thalassaphorura Bagnall, 1949	
Thalassaphorura encarpata (Denis, 1931)	1
Tribe Hymenaphorurini Pomorski, 1996	
Heteraphorura Bagnall, 1948	
Heteraphorura subtenuis (Folsom, 1917)	2
Family Tullbergiidae Bagnall, 1935	
Subfamily Stenaphorurinae Luciañez & Simón, 1992	
Mesaphorura Börner, 1901	
Mesaphorura silvicola (Folsom, 1932)	3
Order Entomobryomorpha Börner, 1913	
Superfamily Tomoceroidea Szeptycki, 1979	
Family Oncopoduridae Carl & Lebedinsky, 1905	
Oncopodura Carl & Lebedinsky, 1905	
Oncopodura iowae Christiansen, 1961	14
Family Tomoceridae Schäffer, 1896	
Subfamily Tomocerinae Schäffer, 1896	
Pogonognathellus Paclt, 1944	
Pogonognathellus flavescens (Tullberg, 1871)	275
Pogonognathellus nigritus (Maynard, 1951)	7
Lethemurus Yosii, 1970	
Lethemurus missus (Mills, 1949)	7
Superfamily Isotomoidea Szeptycki, 1979	
Family Isotomidae Schäffer, 1896	
Subfamily Anurophorinae Börner, 1901	
Hemisotoma Bagnall, 1949	
Hemisotoma thermophila (Axelson, 1900)	16
Subfamily Proisotominae Stach, 1947	
Folsomia Willem, 1902	
Folsomia bisetosa Gisin, 1953	1
Folsomia candida Willem, 1902	35
Folsomia prima Mills, 1931	2
Folsomia stella Christiansen & Tucker, 1977	2

(continued)

Table 2. Continued.

Taxon	Total Specimens
Folsomia variabilis Fjellberg, 1984	3
Proisotoma Börner, 1901	
Proistoma sepulcralis (Folsom, 1902)	2
Subfamily Isotominae Schäffer, 1896	
Desoria Agassiz & Nicolet, 1841	
Desoria trispinata (Mac Gillivray, 1896)	252
Parisotoma Bagnall, 1940	
Parisotoma notabilis (Schäffer, 1896)	12
Isotomiella Bagnall, 1939	
Isotomiella minor (Schäffer, 1896)	1
Superfamily Entomobryoidea Womersley, 1934	
Family Entomobryidae Schäffer, 1896	
Subfamily Entomobryinae Schäffer, 1896	
Entomobrya Rondani, 1861	
Entomobrya sp.	1
Coecobrya Yosii, 1956	
Coecobrya tenebricosa (Folsom, 1902)	62
Homidia Börner, 1906	
Homidia socia Denis, 1929	2
Subfamily Lepidocyrtinae Wahlgren, 1906	
Pseudosinella Schäffer, 1897	
Pseudosinella argentea Folsom, 1902	14
Pseudosinella aera Christiansen & Bellinger, 1980	7
Order Neelipleona Massoud, 1971	
Family Neelidae Folsom, 1896	
Neelides Caroli, 1912	
Neelides minutus (Folsom, 1901)	1
Megalothorax Willem, 1900	
Megalothorax minimus Willem, 1900	3
Megalothorax tristani Denis, 1933	2
Order Symphypleona Börner, 1901	
Superfamily Sminthuridoidea Fjellberg, 1989	
Family Sminthurididae Börner, 1906	
Sminthurides Börner, 1900	

(continued)

Table 2. Concluded.

Taxon	Total Specimens
Sminthurides n. sp.	2
Sphaeridia Linnaniemi, 1912	
Sphaeridia serrata Folsom & Mills, 1938	2
Family Bourletiellidae Börner, 1912	
Subfamily Bourletiellinae Börner, 1912	
Bourletiella Banks, 1899,	
Bourletiella sp.	1
Superfamily Dicyrtomoidea Bretfeld, 1994	
Family Dicyrtomidae Börner, 1906	
Subfamily Ptenothricinae Richards, 1968	
Ptenothrix Börner, C, 1906	
Ptenothrix sp.	1
Superfamily Katiannoidea Bretfeld, 1994	
Family Katiannidae Börner, 1913	
Sminthurinus Börner, 1901	
Sminthurinus henshawi (Folsom, 1896)	9
Family Arrhopalitidae Stach, 1956	
Pygmarrhopalites Vargovitsh, 2009	
Pygmarrhopalites principalis (Stach, 1945)	11
Pygmarrhopalites sapo (Zeppelini & Christiansen, 2003)	3
Pygmarrhopalites n. sp. 1	4
Pygmarrhopalites n. sp. 2	24
Undetermiend (seen, not collected)	6

Species Accounts

Hypogastruridae

Hypogastrura pannosa (Macnamara), 1922 — AC S1/G5 — new state record

This species is widespread in North America but this is the first report from Illinois. There is one previous report from Kentucky caves, the species is most likely an accidental.

Hypogastrura pannosa is part of a complex that includes *H. essa*, *H. matura* and the Palearctic *H. assimilis* (Thibaud *et al*. 2004). The determination of the Illinois cave specimens as *H. pannosa* was based on the number of arms on PAO, mucronal shape and presence of s.s. p5 on Abd. 4.

Ceratophysella boletivora (Packard), 1873 — TX S2/G5

This species was previously reported from Cisco, Markham and Cook counties in Illinois. *Ceratophysella boletivora* has been reported from caves in Missouri, but this is the first report for the species in Illinois caves.

Ceratophysella brevis Christiansen and Bellinger, 1980 — TX S1/G5 — new state record

This is the first Illinois report for this species. *Ceratophysella brevis* was originally described from surface habitats in Wyoming, but now it is also known from Alaska (Fjellberg 1985) and from caves in Kentucky, California and Indiana. In addition to the North American records, the species has been reported from Siberia.

Ceratophysella denticulata (Bagnall), 1941 — TX S5/G5

This is a common species, widely distributed through out the Northern Hemisphere. In Illinois *C. denticulata* has been identified from at least seven caves in Calhoun, Johnson, Union and Monroe counties.

Ceratophysella engadinensis Gisin, 1949 — TX? S?/G5 — new state record

This is another common species widely distributed through out the temperate zone of the Northern Hemisphere. *Ceratophysella engadinensis* differs from *C. denticulata* in small details of the chaetotaxy that can be seen only using a compound microscope (Fjellberg 1998). Although the species has not been reported from Illinois before, it is likely that in the past it has been confused with, or included as part of, *C. denticulata*.

Ceratophysella n. sp. — TB S1/G1 — new state record

This is an undescribed specie closely related to the Indiana cave species *C. lucifuga* (Skarzynski 2007). This is a troglophile in the early stages of adaptation to caves. The species lacks pigment, but retains all eyes and there is little change in the relative length of antennae and claw, or in the development of sensory organs.

Xenylla welchi Folsom, 1916 — AC S5/G5

This is a cosmopolitan species known to occur throughout North America and Eurasia in surface leaf litter (Thibaud *et al*. 2004).

Odontellidae

Superodontella cornifer Mills, 1934 — AC S1/G5

This species is widely distributed throughout North America and was previously reported from Hardin Co., Illinois. However, this is the first record of the species from an Illinois cave.

Superodontella rossi Christiansen and Bellinger, 1980 — AC? S1/G2? — new state record

This is a new record for Illinois. This is a relatively rare species usually found in forest leaf litter. The species has been reported from Pennsylvania and Kansas. This is the first time *S. rossi* is reported in caves.

Superodontella substriata Wray, 1953 — AC? S2/G2

This is a forest leaf litter species originally described from Illinois. In Illinois, *S. substriata* has been reported from Champaign, Clark, Jackson, Logan and Pope counties. Additional records for the species include North Carolina, Connecticut and British Columbia.

This is the first record of this species from caves.

Superodontella n. sp. — AC? S1/G1? — new state record

The single individual collected in Wanda's Waterfall Cave appears to be a new species characterized by a very short furcula. The species is dark blue and does not show characters typically present in cave adapted species. Surface leaf litter sample will have to be examined to try gather more individuals for proper description

Neanuridae

Pseudachorutes aureofasciatus (Harvey), 1898 — AC S5/G5

This is a widespread species found in forest leaf litter from British Columbia and California in the west to Pennsylvania and Florida in the east. In Illinois the species has been reported from Calhoun, Johnson, and Union (Guthrie Cave) counties. In addition to Guthrie Cave, *P. aureofasciatus* was previously reported from Hunter's Cave, in Jackson Co., Iowa.

Pseudachorutes n. sp. — AC? S1/G1? — <u>new state record</u>

The single individual collected in Wanda's Waterfall Cave apparently represents an undescribed species. This is a black species, without morphological adaptations to subterranean life. This is likely a surface leaf litter form accidentally found inside the cave. As in the case of the new species of *Superodontella*, surface leaf litter sample will have to be examined to try gather more individuals for proper description.

Vitronura giselae Gisin, 1950 — AC SE

This is probably an introduced species now common in moist woodchip beds. The first published report of *V. giselae* from North America is as recent as 1998, although the species was known to be established in the continent before that (Richard Snider, Michigan State University, personal communication). In Illinois the species was previously known from Champaign Co. This is the second record of *V. giselae* from North American caves, the species was already reported from Swamp River Cave, Tennessee.

Although white when preserved in alcohol, and with a reduced number of eyes, this species is not really a troglophile. Living specimens are bright orange and the reduced number of eyes is characteristic of the lineage.

Onychiuridae

Onychiurus n. sp. — TB? S1?/G1? — <u>new state record</u>

The distribution of this species is unclear. This is a member of the *O. reluctus* species complex, which comprises a number of very closely related forms formally included in *O. reluctus*. A recent review of some populations originally identified as *O. reluctus* was found to include five species, four of which were new to science (Pomorski *et al*. 2009).

The populations from Bat Sump and Stemler Cave were previously sampled and identified as *O. reluctus* (Lewis *et al*. 2003). However, from the revision by Pomorski *et al*. (2009) it is now clear that the *Onychiurus* in these caves in fact represent a new species. Thus, it is possible that other records of *O. reluctus* in caves from western Illinois (e.g., Hidden Hand Cave) and eastern Missouri may represent this is species.

Heteraphorura encarpata (Denis), 1931 — TX S2/G5

This is common species widespread across North America. *Protaphorura encarpata* is know from Cumberland, Jackson, Johnson (Firestorm Cave), Piatt and Wayne counties in Illinois. This species is relatively common in subterranean habitats as it has been reported from caves in Missouri, Indiana, Texas and Hawaii, in addition to the cave record from Johnson county, Illinois.

Thalassophorura subtenuis (Folsom), 1917 — TX S2/G5

This is part of a complex that includes three other species (*T. bimus, T. casus* and *T. talus*). The actual distribution of *T. subtenuis* is unclear as old identifications might have conflated the identity of all four forms. Confirmed records indicate the species ranges from Alaska and British Columbia in the west and east to Maine in the north and North Carolina in the south, although it appears to be absent in the region between Iowa-Missouri-Arkansas and British Columbia. In Illinois the species has been reported from Alexander, Champaign, Coles, Jackson, La Salle, Union, Vermillion, Washington counties. *Thalassophorura subtenuis* has been previously reported from caves in Alaska, Illinois, Indiana, North Carolina, Texas and West Virginia.

Mesaphorura silvicola (Folsom), 1932 — AC S1/G5

Widespread in North America and common in surface leaf litter. In Illinois *M. silvicola* is known from Jackson, Monroe, Vermillion counties. The species was previously reported from a cave in Indiana.

Isotomidae

Hemisotoma thermophila (Axelson), 1900 — AC S1?/G5

This is a common surface species widely distributed across the temperate and tropical regions of the World (Potapov 2001, Mari Mutt and Bellinger 1990). Previously known from Champaign County in Illinois. This appears to be the first record for this species from caves.

Desoria trispinata (MacGillivray), 1896 — TX S5/G5

This is a common surface species widely distributed across temperate regions of the North Hemisphere (Potapov 2001). In North America, this is one of the most common species of springtails in surface leaf litter, second only to *Parisotoma notabilis*. *Desoria trispinata* is relatively common in cave leaf litter in North America. The individuals from Salem Plateau have only three labral papilla, a character shared with some populations found in Missouri caves, but different from other *D. trispinata* populations outside the Salem Plateau region. The labral character may define an isolated population restricted to the Salem Plateau region on both sides of the Mississippi River.

Folsomia bisetosa Gisin, 1953 — AC S1/G5 — new state record

The identification of this specimen as *F. bisetosa* is provisional. This individual agrees with the description of *F. bisetosa* provided by Fjellberg (2007) in all characters except in having long unilaterally serrate macrosetae on all segments (macrosetae are smooth in *F. bisetosa*). *Folsomia bisetosa* is distributed across the Old World arctic and subarctic regions and its presence in an Illinois cave seems unlikely. However, additional material is needed to confirm the identity of the species. Either as *F. bisetosa* or as a new species, this represents a new record for Illinois.

Folsomia candida Willem, 1902 — TP S5/G5

This is a common subsoil species often found in North American caves.

Folsomia prima Mills, 1931 — TX S2/G5

This is a common surface leaf litter species often found in caves. In Illinois the species has been reported from caves in Hardin Co. and from surface leaf litter in Champaign, Vermillion and Williamson counties.

Folsomia stella Christiansen and Tucker, 1977 — TX S5/G5

This is a common species distributed across temperate North America and Eurasia (Potapov 2001). In North America, this species is often found in caves. In Illinois, the species is previously known from Alexander, Champaign, Monroe and Vermillion counties.

Folsomia variabilis Fjellberg, 1984 — AC S1/G5 — <u>new state record</u>

This is the first record for this species from Illinois and from caves. The species was originally described from populations found in mosses at 11,000 feet of elevation in Colorado (Fjellberg 1984).

Isotomiella minor Schäffer, 1896 — TX S5/G5

This is a common species in surface and cave habitats throughout North America.

Parisotoma notabilis (Schäffer), 1896 — TX S5/G5

This is a common surface species widely distributed across temperate regions of the Northern Hemisphere, and probably the most common species of springtails in surface leaf litter in North America. The species is often found in caves.

Proisotoma sepulcralis Folsom, 1902 — AC S1/G1 — <u>new state record</u>

This is the first record from Illinois and from caves for this uncommon species. *Proisotoma sepulcralis* was previously known only from Washington D.C., Michigan and Pennsylvania.

Tomoceridae

Lethemurus missus Mills, 1949 — TB S2/G2 (Figure 17)

This troglobiont is widespread in caves in Salem Plateau. *Lethemurus missus* was originally described from Jersey Co. Illinois, but now is know to occur in Kentucky, Missouri, Alabama, Indiana, Virginia and Colorado.

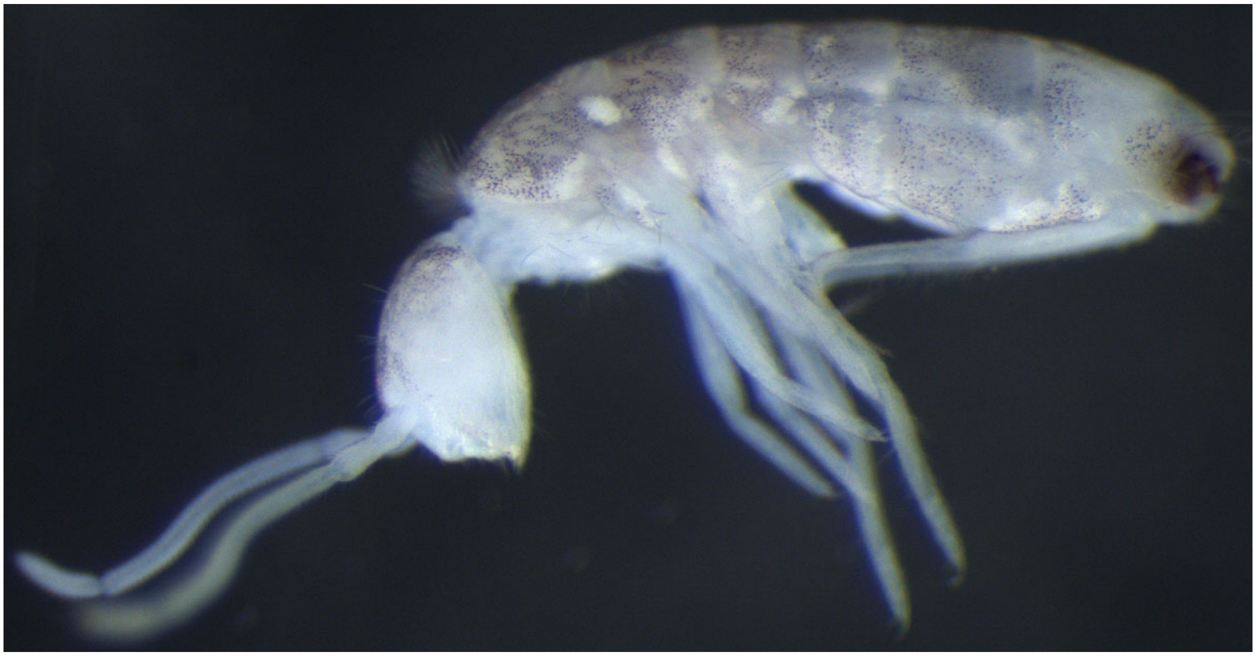

Figure 17. *Lethemurus missus* Mills, 1949 (Tomoceridae) from Pautler Cave, Monroe County, Illinois, 2009.

Pogonognathellus flavescens (Tullberg), 1871 — TX S5/G5 (Figures 18, 19)

This specie is the most common member of this family in surface leaf litter and in caves. *Pogonognathellus flavescens* appears to be widespread in North America and Europe, although the large amount of morphological variation reported from throughout its range suggests that it represents a complex of species.

Pogonognathellus nigritus (Maynard), 1951 — TX S5/G5? — new state record

This is a common surface leaf litter species in the Salem Plateau region. The actual distribution of the species in North America is not really known because in the past this species has been included as part of the variation of *P. flavescens,* hence the interrogation mark for global ranking. This is the first record for the species from caves.

Oncopoduridae

Oncopodura iowae Christiansen, 1961 — TB S2/G2 (Figure 20)

This is the most common species of *Oncopodura* found in Illinois caves. The species has been previously reported from Monroe Co. in Illinois and throughout Iowa, Missouri and South Dakota caves.

Figure 18. *Pogonognathellus flavescens* (Tullberg), 1871 (Tomoceridae) dorsal view of freshly molted individual with a full complement of body and antennal scales, showing coloration produced by scales. From Hidden Hand Cave, Monroe County, Illinois in 2009.

Figure 19. *Pogonognathellus flavescens* (Tullberg), 1871 (Tomoceridae) from Hidden Hand Cave, Monroe County, Illinois in 2009. This individual lost most of the scales and the light brown cuticular pigment dominates the color pattern.

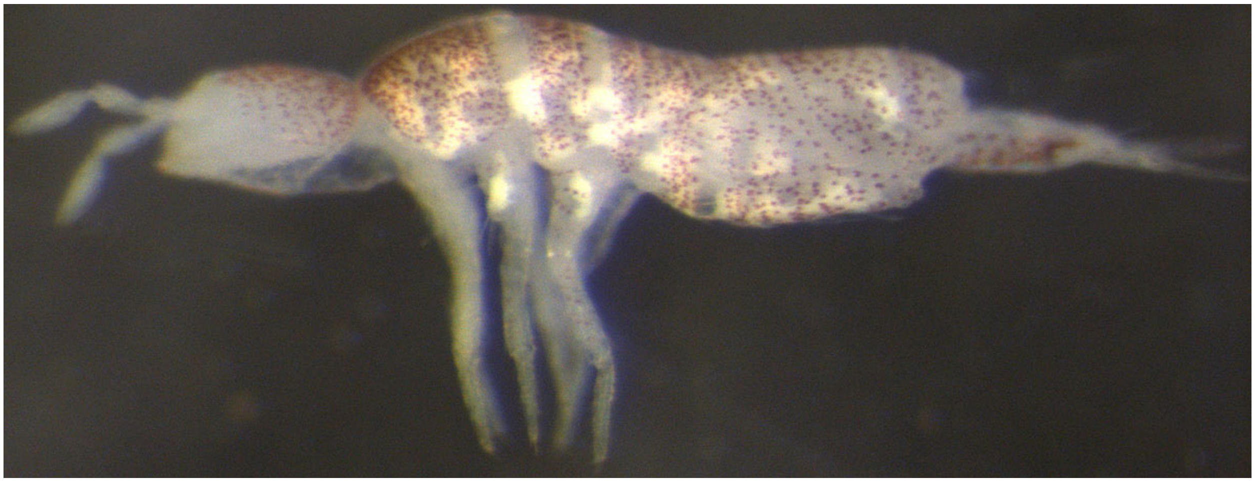

Figure 20. *Oncopodura iowae* Christiansen, 1961 (Oncopoduridae) from Stemler Cave, St. Claire County, Illinois in 2009.

Entomobryidae

Pseudosinella aera Christiansen and Bellinger, 1980 — TP S2/G5 (Figure 21)

In Illinois this species has been previously reported from caves in Gallatin and Johnson (Firestone Creek Cave) counties. This species appears to have a mostly southern distribution, the localities in Illinois are at or near the northernmost limit of the species.

Pseudosinella aera does not show strong adaptations to cave habitat, but there are very few records of surface populations. Almost all records of this species, from Mexico to Illinois are from caves.

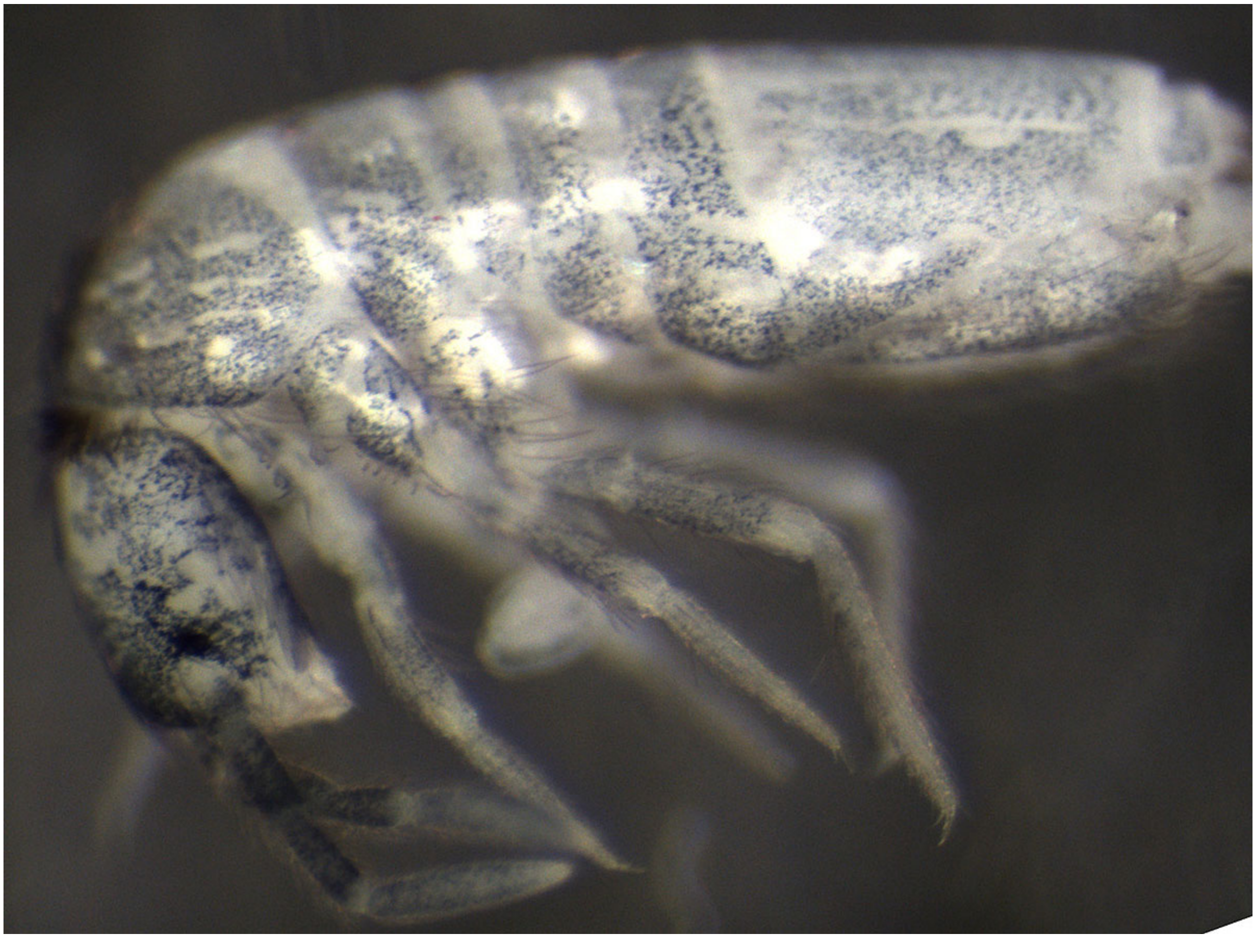

Figure 21. *Pseudosinella aera* Christiansen and Bellinger, 1980 (Entomobryidae) from Wanda's Waterfall Cave, Monroe County, Illinois in 2009.

Pseudosinella argentea Folsom, 1902 — TP S2/G5? (Figure 22)

This is a common cave species in Illinois. It has been previously reported from Caroll, Hardin (Brown's Hole Cave) and Monroe (Saltpeter, Fogelpole, Spider and Wanda's Waterfall caves) counties. Surface populations in Illinois have been reported from Champaign, Clark, Edgar, Johnson and Union counties.

The species also appears to be common in caves in Kentucky, Missouri, Arkansas, Indiana, Alabama Tennessee, Washington, Virginia, West Virginia, Pennsylvania and Connecticut.

The large amount of morphological variation reported throughout its distribution suggests this is a species complex (Christiansen and Bellinger 1998). The question mark after global ranking reflect the fact more than one species may be involved, some of which may have restricted distributions. The specimens from Illinois caves, however, do match the description of individuals identified as *P. argentea* collected in caves in West Virginia (Soto-Adames 2010).

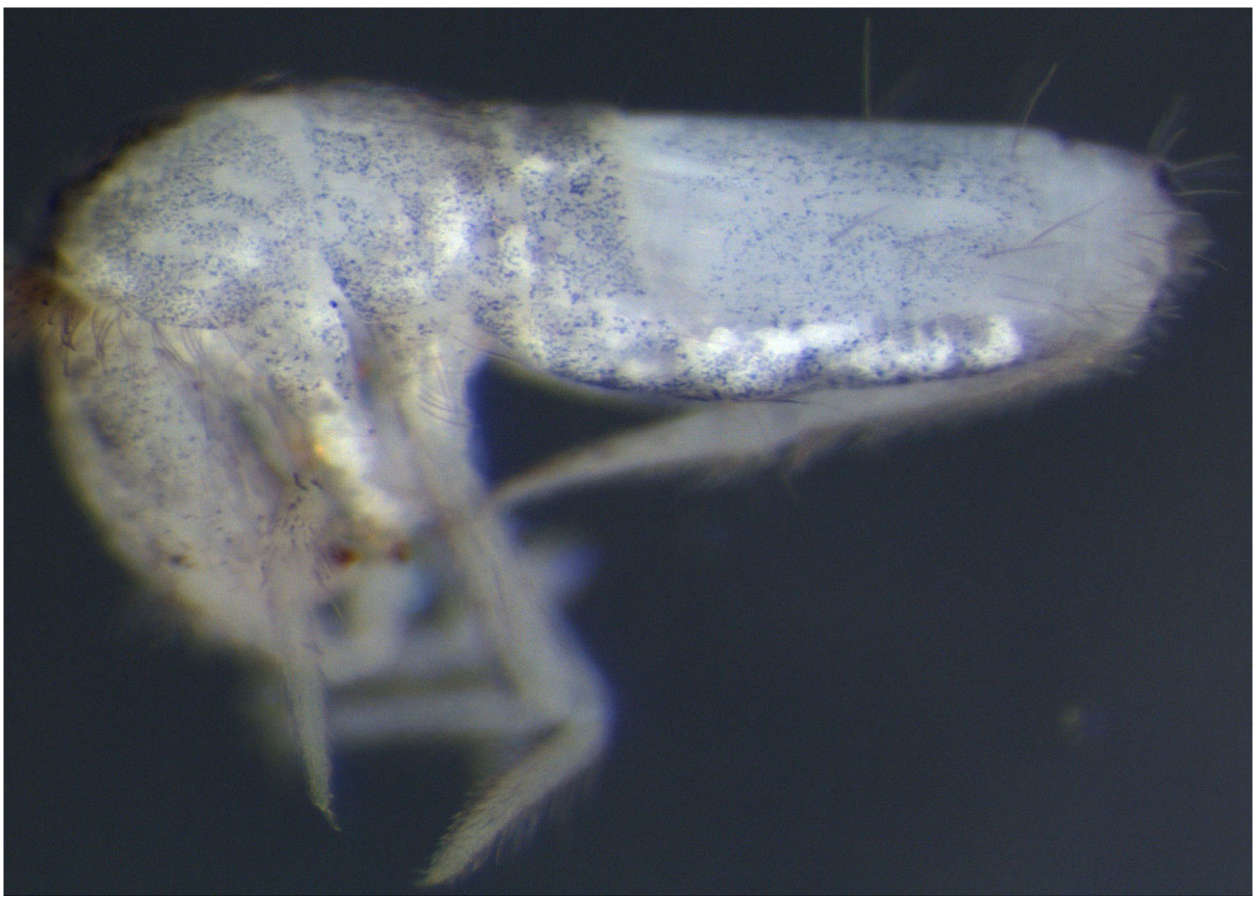

Figure 22. *Pseudosinella argentea* Folsom, 1902 (Entomobryidae) from Spider Cave, Monroe County, Illinois in 2009.

Coecobrya tenebricosa Folsom, 1902 — TP S5/G5 (SE?) (Figure 23)

This is a very common cave species in North America. Previous reports of this species from Illinois caves include Rose Hole and Pautler Cave, both in Monroe Co.

This species was originally described from the Washington D.C. area, but currently is found around the world in protected habitats such as greenhouses. The genus *Coecobrya* is almost exclusively East Asian in distribution (Chen and Christiansen 1997) and it is possible that *C. tenebricosa* represents an early introduction, during historic times, into North America.

Entomobrya sp.

This was a single early instar juvenile, not identifiable to species.

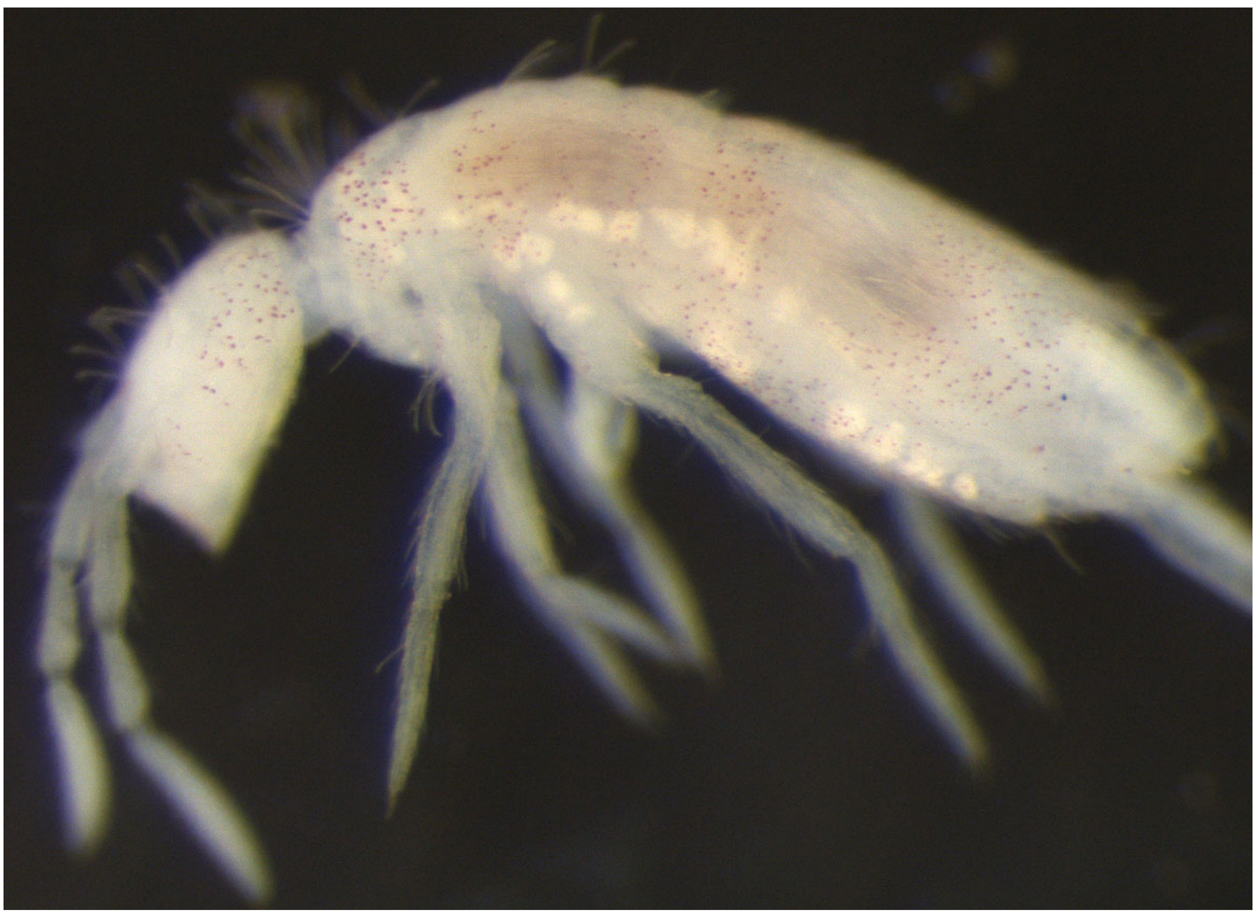

Figure 23. *Coecobrya tenebricosa* Folsom, 1902 (Entomobryidae) from Pautler Cave, Monroe County, Illinois in 2009.

Homidia socia Börner, 1909 — AC SE

This is an introduced species only noticed in Illinois in the last 25 or so years. This is the first record for this species in Illinois caves, although it has been previously collected in caves in Harrison and Crawford counties, Indiana.

It is interesting that the historical collection of springtails at the Illinois Natural History Survey, which goes back to the early 1900's, does not include a single individual of this species, despite the fact that now this is one of the most common species in grasses growing along country roads in Champaign County. The oldest record for the Midwest appears to be from 1984 from Jasper Co., Iowa.

Neelidae

Megalothorax minimus (Willem), 1900 — TX S5/G5

This is a common surface leaf litter species frequently found in caves. The species has been recorded from Grundy, Lawrence and Washington counties. This appears to be the first record for the species from Illinois caves.

Megalothorax tristani (Denis), 1933 — AC S1/G1

This is either a rare species, or it has been generally confused with the more widely distributed *M. incertus*. There is a single previous Illinois report for *M. tristani* dating back to 1948. This is the first Illinois cave record for this species.

Neelides minutus (Folsom), 1901 — TX S5/G5

This is a common surface leaf litter species often seen in cave samples. In Illinois the species has been previously reported from Calhoun, Cook, Gallatin, Jackson, Lake, La Salle, Lawrence and Wayne counties.

Sminthurdidae

Sphaeridia serrata (Folsom and Mills), 1938 — AC S1/G3

This is an uncommon species previously reported from Herod and Pope counties in Illinois. This is the first record of this species from caves.

Sminthurides n. sp. — AC S1/G1 — <u>new state record</u>

This species has a unique combination of characters not seen in other Nearctic species. This is not a cave adapted form. Only one male and one female were seen and formal description of the species must await the study of further material.

Arrhopalitidae

Pygmarrhopalites principalis (Stach), 1947 — TX S1/G5 — <u>new state record</u>

This identification is provisional, until specimens of *A. principalis* can be studied. This is the first record for *A. principalis* from North America, where individuals similar to *P. principalis* have usually have been assigned to *P. benitus*. The species is common in Europe in moss, leaf litter and other surface habitats.

Pygmarrhopalites sapo (Zeppelini and Christiansen), 2003 — TB S1/G1 (Figure 24)

This species is endemic to Monroe Co., and it was previously reported from Frog, Pautler, Jacobs and Rose Hole caves (Zeppelini and Christiansen 2003).

Pygmarrhopalites n. sp. 1 — TB? S1/G1 — <u>new state record</u>

This species is very similar to *P. principalis*, but differs in color pattern and other morphological details.

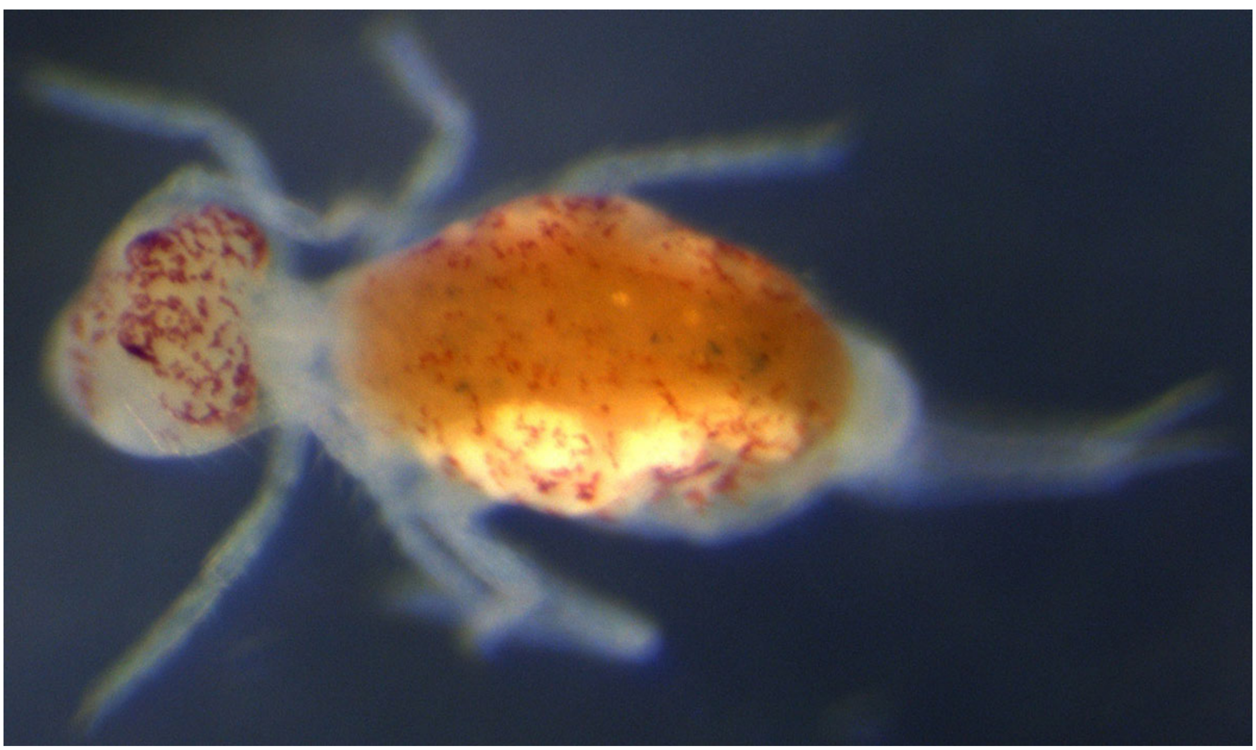

Figure 24. *Pygmarrhopalite s sapo* (Zeppelini and Christiansen), 2003 (Arrhopalitidae), male from Pautler Cave, Monroe County, Illinois in 2009.

Pygmarrhopalites n. sp. 2 — TB S1/G1 — new state record (Figure 25)

This species is very similar to the recently described *P. leonardwoodensis* (Zeppelini *et al*. 2009), but there are sufficient morphological differences (in addition to the fact that their ranges are separated by the Mississippi River) to justify the creation of a new taxon. This species is part of a complex of closely related forms which appear to be endemic to Salem Plateau region.

Katiannidae

Sminthurinus henshawi (Folsom), 1896 — TX S5/G5

This is a common surface species widespread across North America. In Illinois, the species has been previously reported from Jackson, Champaign, Coles, Cook, DuPage, Kane, Lake, Randolph, Richland and Woodford counties. *Sminthurinus henshawi* is common in caves, but this is the first record from this habitat in Illinois.

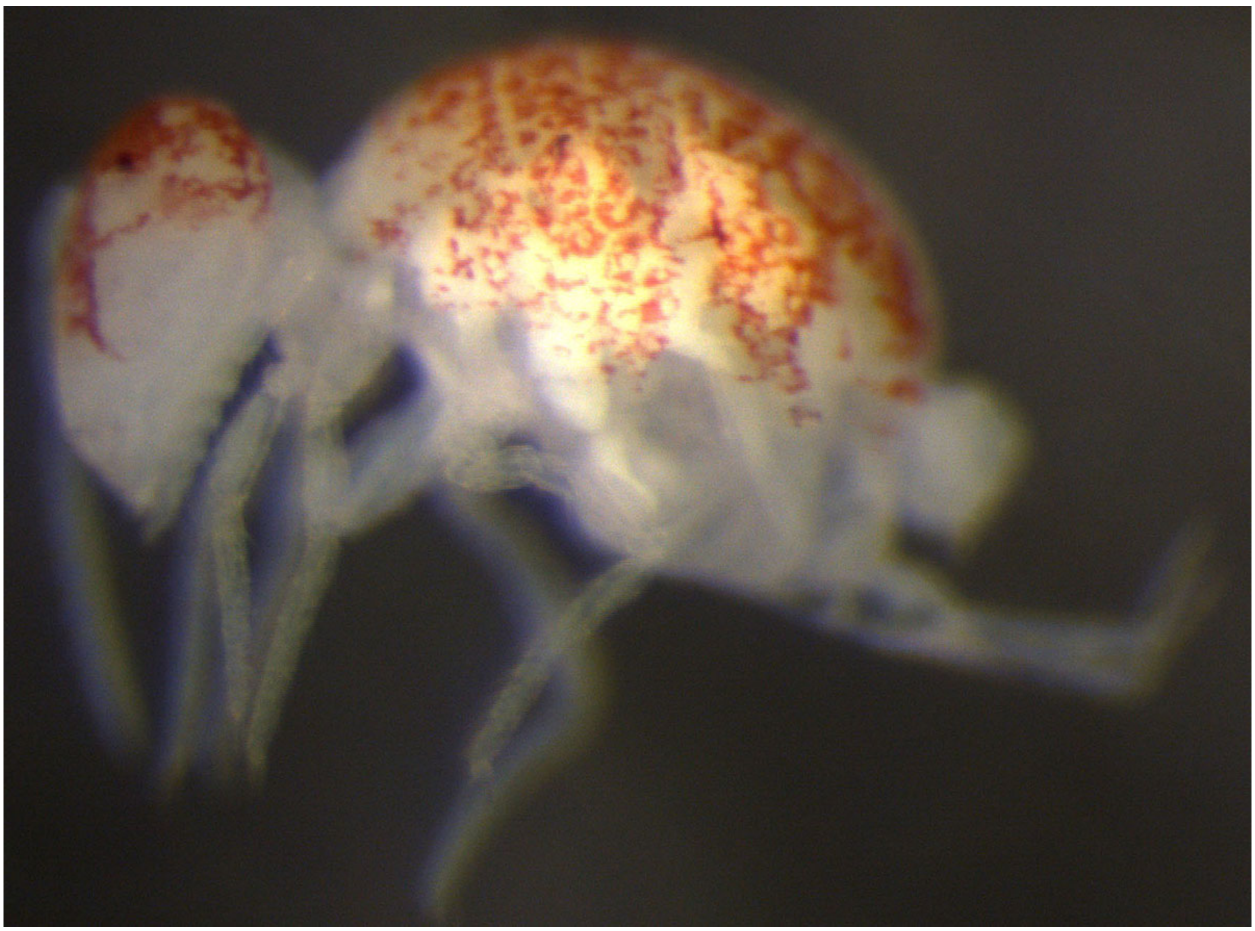

Figure 25. *Pygmarrhopalites* n. sp. 2 (Arrhopalitidae) from Stemler Cave, St. Clair County, Illinois in 2009.

Bourletiellidae

Bourletiella sp. — AC?

This is an early instar individual not identifiable to species. Members of this genus are not commonly found in caves. This is likely a accidental.

Dicyrtomidae

Ptenothrix sp.

This is a juvenile, not identifiable to species. Several species of *Ptenotrhix* frequent caves, including *P. atra, P. marmorata* and *P. maculosa*. In Illinois, *P. atra* is the species most often found in caves.

Distribution, abundance, diversity, and microhabitats

The greatest numbers of springtails were collected by pitfall trapping (29.5%), hand collections (28.1 %), and Berlese extraction of 1 gallon leaf litter samples (27.7%), and these three methods accounted for 1,376 (more than 85%) of the specimens recorded (Figure 26A). Relatively few specimens were recorded by quadrat census (2.1%) or by examination of drip pools (2.0%) (Figure 26A). Leaf litter, hand collections, and pitfall sampling methods produced similar numbers of species, a proportionally greater number of taxa than the remaining sampling methods (Figure 26C), with all three methods accounting for nearly 45% of the species collected during the study. Drip pool examination produced a high number of taxa – 30.6% of the species recorded during the study - relative to the number of specimens collected by this sampling method (Figure 26C).

The number of springtails collected varied considerably among caves, with 47.2% of the specimens being recorded from Bat Sump Cave, 22.5% from Illinois Caverns, down to only 1.1% from Pautler Cave (Figure 26B). The high numbers from Illinois Caverns come mostly from a leaf litter sample at the base of the entrance stairs. For Bat Sump Cave, the high number of individuals is attributable to a single species, *Ceratophysella brevis* (Christiansen & Bellinger, 1980), for which 598 specimens (37.3% of all springtail specimens collected during this study) were collected from this site by various methods. Site level taxa richness was not proportional to numbers of specimens collected, and two caves with relatively few specimens collected proved to be the most speciose – of the 49 species recorded in this study, we recorded 46.9% from Wanda's Waterfall Cave and 30.6% from Stemler Cave (Figure 26D). The lowest numbers of species were from Pautler and Hidden Hand caves, each with 8.2% of the species recorded in this study (Figure 26D).

Several species were present in high numbers, and 24 (49.0%) of the 49 species were represented by only one or two specimens (Figure 27). The most abundant species, *Ceratophysella brevis*, occurred in only two caves, and 598 (96.9%) of the 617 specimens of this species were collected in Bat Sump Cave (Table 3). The next two most abundant species were *Pogonognathellus flavescens* (Tullberg, 1871), with 275 specimens (17.1% of all Collembola

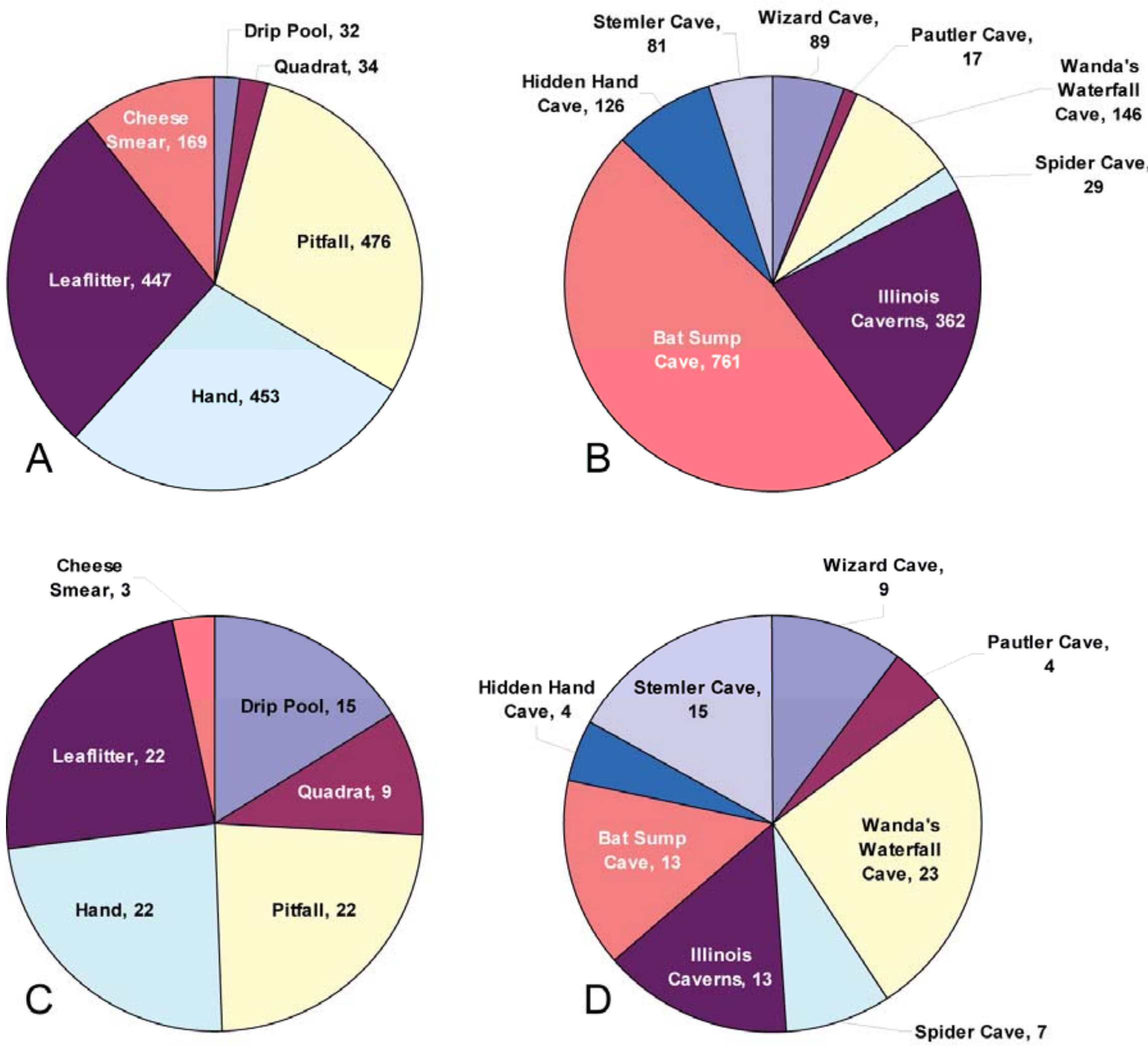

Figure 26. Total number of springtail specimens recorded (A, B) and number of springtail taxa recorded (C, D) for six sampling methods (A, C) and eight caves (B, D) in Monroe and St. Clair counties, Illinois, in 2009.

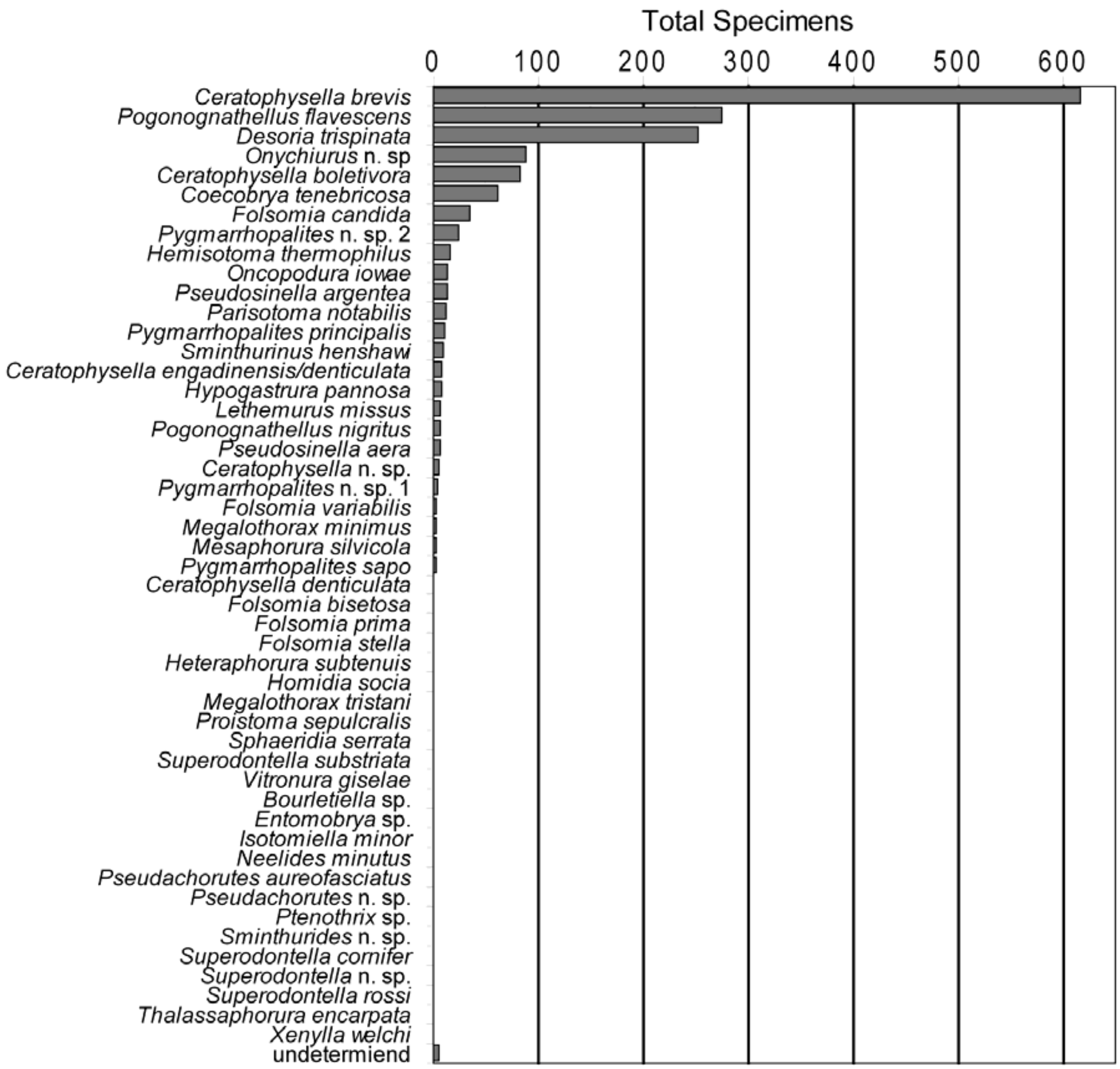

Figure 27. Abundance of 49 species of springtails collected from eight caves in Monroe and St. Clair counties, Illinois, in 2009. The "undetermined" material is six specimens seen but not collected.

Table 3. Summary of number of specimens per species by cave for Collembola collected from eight caves in Monroe and St. Clair counties, Illinois, in 2009. Higher classification follows Deharveng (2004) and Bellinger *et al*. (2010).

Order	**Family**	***Taxon***	**Wizard Cave**	**Pautler Cave**	**Wanda's Waterfall Cave**	**Spider Cave**	**Illinois Caverns**	**Bat Sump Cave**	**Hidden Hand Cave**	**Stemler Cave**
Poduromorpha	Neanuridae	*Vitronura giselae*	0	0	2	0	0	0	0	0
		Pseudachorutes aureofasciatus	0	0	0	0	0	0	0	1
		Pseudachorutes n. sp.	0	0	1	0	0	0	0	0
	Odontellidae	*Superodontella cornifer*	0	0	0	0	0	1	0	0
		Superodontella rossi	0	0	1	0	0	0	0	0
		Superodontella substriata	0	0	1	0	1	0	0	0
		Superodontella n. sp.	0	0	1	0	0	0	0	0
	Hypogastruridae	*Ceratophysella brevis*	0	0	19	0	0	598	0	0
		Ceratophysella boletivora	0	0	5	0	62	16	0	0
		Ceratophysella denticulata	0	0	0	0	0	0	0	2
		Ceratophysella engadinensis/denticulata	0	0	0	0	8	0	0	0
		Ceratophysella n. sp.	0	0	5	0	0	0	0	0
		Hypogastrura pannosa	0	0	7	0	0	0	0	1
		Xenylla welchi	0	0	0	0	0	0	0	1
	Onychiuridae	*Onychiurus* n. sp	0	0	0	0	0	79	0	9
		Thalassaphorura encarpata	0	0	1	0	0	0	0	0
		Heteraphorura subtenuis	0	0	0	0	0	1	0	1
	Tullbergiidae	*Mesaphorura silvicola*	0	0	1	0	0	2	0	0
Entomobryomorpha	Oncopoduridae	*Oncopodura iowae*	1	0	2	0	2	0	1	8
	Tomoceridae	*Pogonognathellus flavescens*	47	4	23	20	21	48	107	5

(continued)

Table 3. Continued.

Order	Family	*Taxon*	Wizard Cave	Pautler Cave	Wanda's Waterfall Cave	Spider Cave	Illinois Caverns	Bat Sump Cave	Hidden Hand Cave	Stemler Cave
Entomobryomorpha	Tomoceridae	*Pogonognathellus nigritus*	0	0	0	1	5	1	0	0
		Lethemurus missus	0	7	0	0	0	0	0	0
	Isotomidae	*Hemisotoma thermophila*	0	0	1	0	0	0	0	15
		Folsomia bisetosa	0	0	0	0	0	0	0	1
		Folsomia candida	0	0	7	0	1	1	0	26
		Folsomia prima	0	0	0	0	1	1	0	0
		Folsomia stella	0	0	0	0	0	1	0	1
		Folsomia variabilis	0	0	1	0	0	0	0	2
		Proistoma sepulcralis	0	0	0	0	0	0	0	2
		Desoria trispinata	0	0	56	0	196	0	0	0
		Parisotoma notabilis	0	0	1	0	6	0	5	0
		Isotomiella minor	1	0	0	0	0	0	0	0
	Entomobryidae	*Entomobrya* sp.	1	0	0	0	0	0	0	0
		Coecobrya tenebricosa	15	3	1	0	43	0	0	0
		Homidia socia	0	0	0	2	0	0	0	0
		Pseudosinella aera	7	0	0	0	0	0	0	0
		Pseudosinella argentea	0	0	0	3	11	0	0	0
Neelipleona	Neelidae	*Neelides minutus*	0	0	1	0	0	0	0	0
		Megalothorax minimus	0	0	3	0	0	0	0	0
		Megalothorax tristani	2	0	0	0	0	0	0	0
Symphypleona	Sminthurididae	*Sminthurides* n. sp.	0	0	0	0	0	1	0	0
		Sphaeridia serrata	0	0	2	0	0	0	0	0

(continued)

Table 3. Concluded.

Order	Family	Taxon	Wizard Cave	Pautler Cave	Wanda's Waterfall Cave	Spider Cave	Illinois Caverns	Bat Sump Cave	Hidden Hand Cave	Stemler Cave
Symphypleona	Bourletiellidae	*Bourletiella* sp.	0	0	0	1	0	0	0	0
	Dicyrtomidae	*Ptenothrix* sp.	0	0	0	1	0	0	0	0
	Katiannidae	*Sminthurinus henshawi*	0	0	0	0	0	9	0	0
	Arrhopalitidae	*Pygmarrhopalites principalis*	11	0	0	0	0	0	0	0
		Pygmarrhopalites sapo	0	3	0	0	0	0	0	0
		Pygmarrhopalites n. sp. 1	4	0	0	0	0	0	0	0
		Pygmarrhopalites n. sp. 2	0	0	4	1	4	0	10	5
undetermiend			0	0	0	0	1	2	3	0
		Total Springtails	**89**	**17**	**146**	**29**	**362**	**761**	**126**	**80**
		Species Richness	**9**	**4**	**23**	**7**	**13**	**13**	**4**	**15**

collected), and *Desoria trispinata* (Mac Gillivray, 1896), with 252 specimens (15.7% of all Collembola collected) (Table 3). *Desoria trispinata* was recorded almost exclusively from leaflitter samples (99.6% of *D. trispinata* specimens) and was only recorded from two caves (Illinois Caverns, Wanda's Waterfall Cave). In contrast, *P. flavescens* occurred in numbers in all eight caves, where on average accounted for 33.0% of the specimens collected, ranging from 5.8% to 84.8% per cave. The next two most abundance species, *Onychiurus* n. sp. (88 specimens) and *Ceratophysella boletivora* (Packard, 1873) (83 specimens) were recorded from only two (Bat Sump Cave, Stemler Cave) and three (Bat Sump Cave, Illinois Caverns, Wanda's Waterfall Cave) caves, respectively, with *C. boletivora* being recorded primarily (91.6% of specimens) from leaflitter samples.

Pogonognathellus flavescens was the only species to be recorded from all eight caves, most other species (29 species, 59.2%) were recovered from only a single cave, and many more (12 species, 24.5%) were recovered from only two caves (Figure 28). Other more widespread species included *Oncopodura iowae* Christiansen, 1961, which was recorded from five caves, in spite of being represented by only 14 specimens, *Pygmarrhopalites* n. sp. 2, which was recorded from five caves (24 specimens), *Coecobrya tenebricosa* (Folsom, 1902), which was recorded from four caves (62 specimens), and *Folsomia candida* Willem, 1902, which was recorded from four caves (35 specimens) (Figure 28).

Using several estimators of species richness, we calculated species accumulation curves with the eight caves treated as samples (Figure 29). This analysis suggests that our sampling is incomplete. First, the species accumulation curve is far from asymptotic, indicating additional springtail species should be recovered with additional sampling. Second, the predictors final estimates of the true number of springtail species present in the caves of Illinois' sinkhole plain ranged from 60.2 (bootstrap) to 105.4 (ICE) (Figure 29). Therefore, our overall estimate is that from 11 to 56 springtail species may yet be detected in caves of Illinois' Salem Plateau (Monroe and St. Clair counties). Indeed, we did not find several additional species already recorded in earlier studies (see discussion). Therefore we know that the actual species richness is higher than indicated by our collections.

The cluster analysis of sites (Figure 30) shows that caves with the least taxa present (Figure 26D) – Spider, Pautler, and Hidden Hand caves – were the most similar on the basis of taxon presence/absence. Sites with more taxa present tended to have more unique species, and thus the sites with the greatest number of species, Wanda's Waterfall Cave and Stemler Cave, show up in the tree as least similar to other sites (Figure 30), even though neither of these two caves were among those with the largest number of specimens collected (Figure 26B). By clustering species based on their presence or absence at the eight sites (Figure 31), similar patterns emerge. Wanda's Waterfall and Wizard caves each produced a number of species unique to the particular cave, but these suites of species were relatively dissimilar (Figure 31). In addition, several of the species were relatively widespread, being found in 4 up to all 8 of the caves examined (Figure 31).

Similarly, cluster analysis of sampling methods (Figure 32) shows that those methods that yielded the least taxa (Figure 26C) – Cheese Smears and Quadrat Samples – were the most

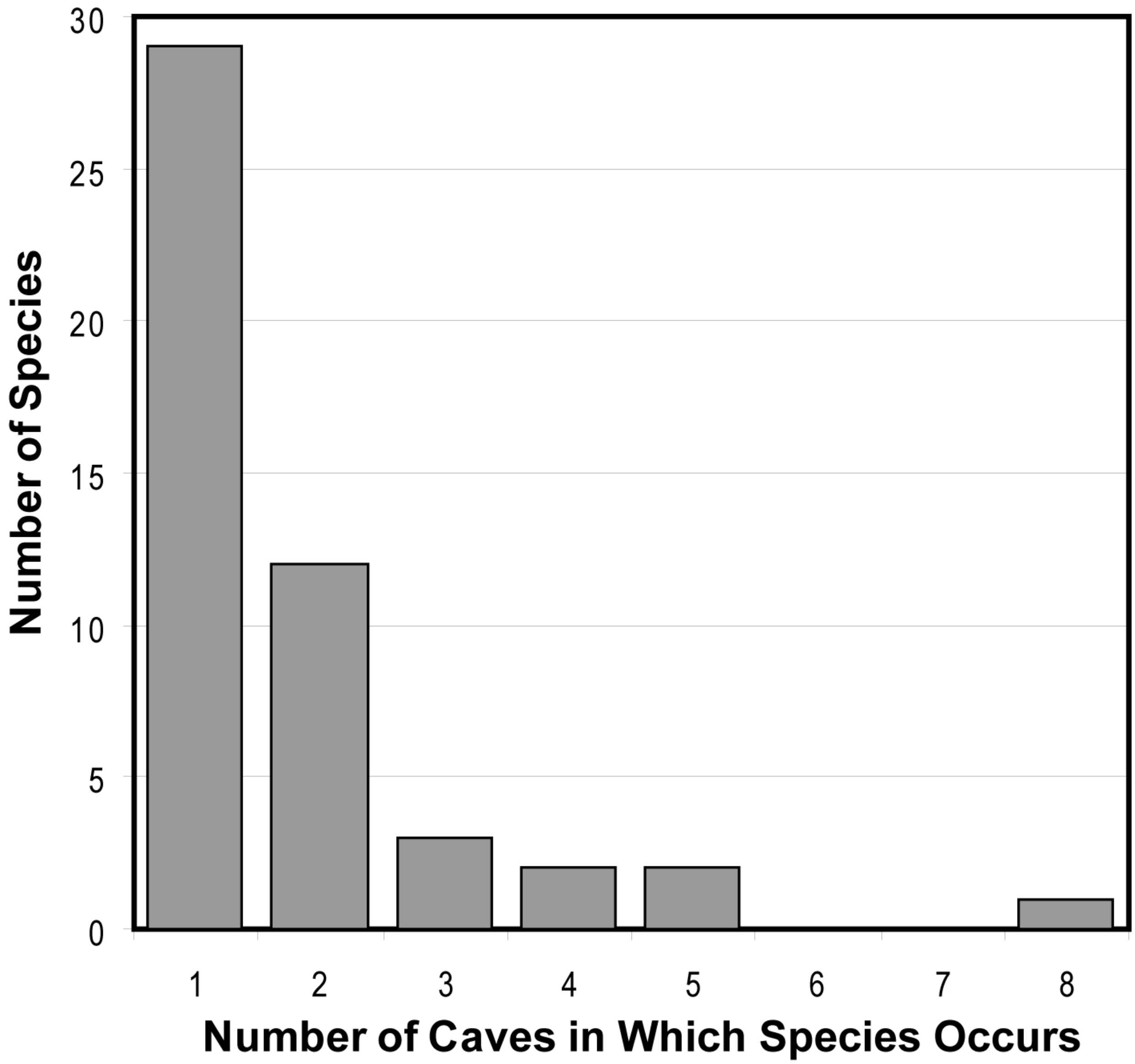

Figure 28. Occurrence of 49 species of Collembola in eight caves in Monroe and St. Clair counties, Illinois, based on 2009 collections.

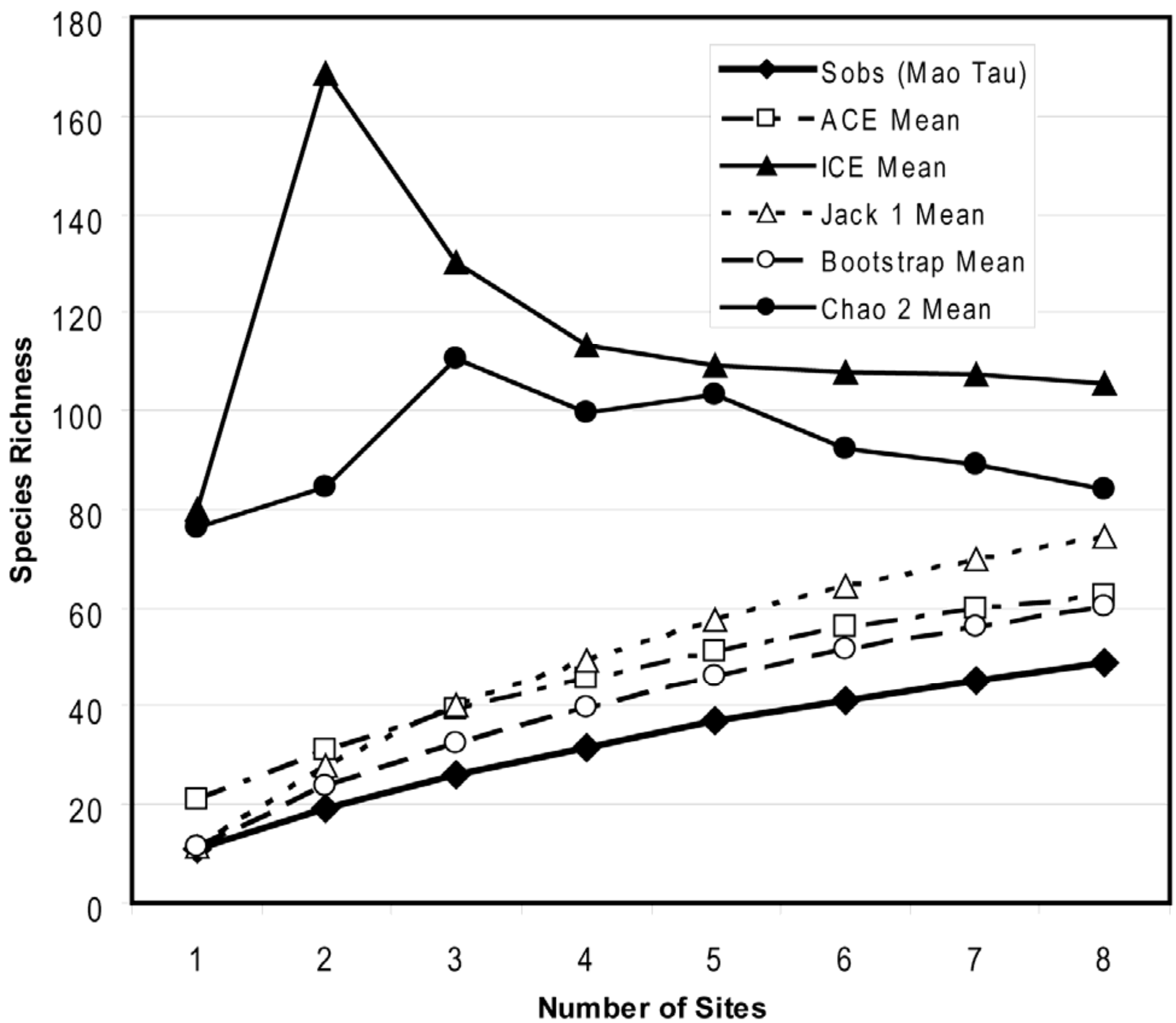

Figure 29. Species accumulation curves for the observed species (Sobs) and several estimators of species richness (Colwell 2006), using individual caves as “samples”. Based on collections of 49 species of Collembola from eight caves in Monroe and St. Clair counties, Illinois, in 2009.

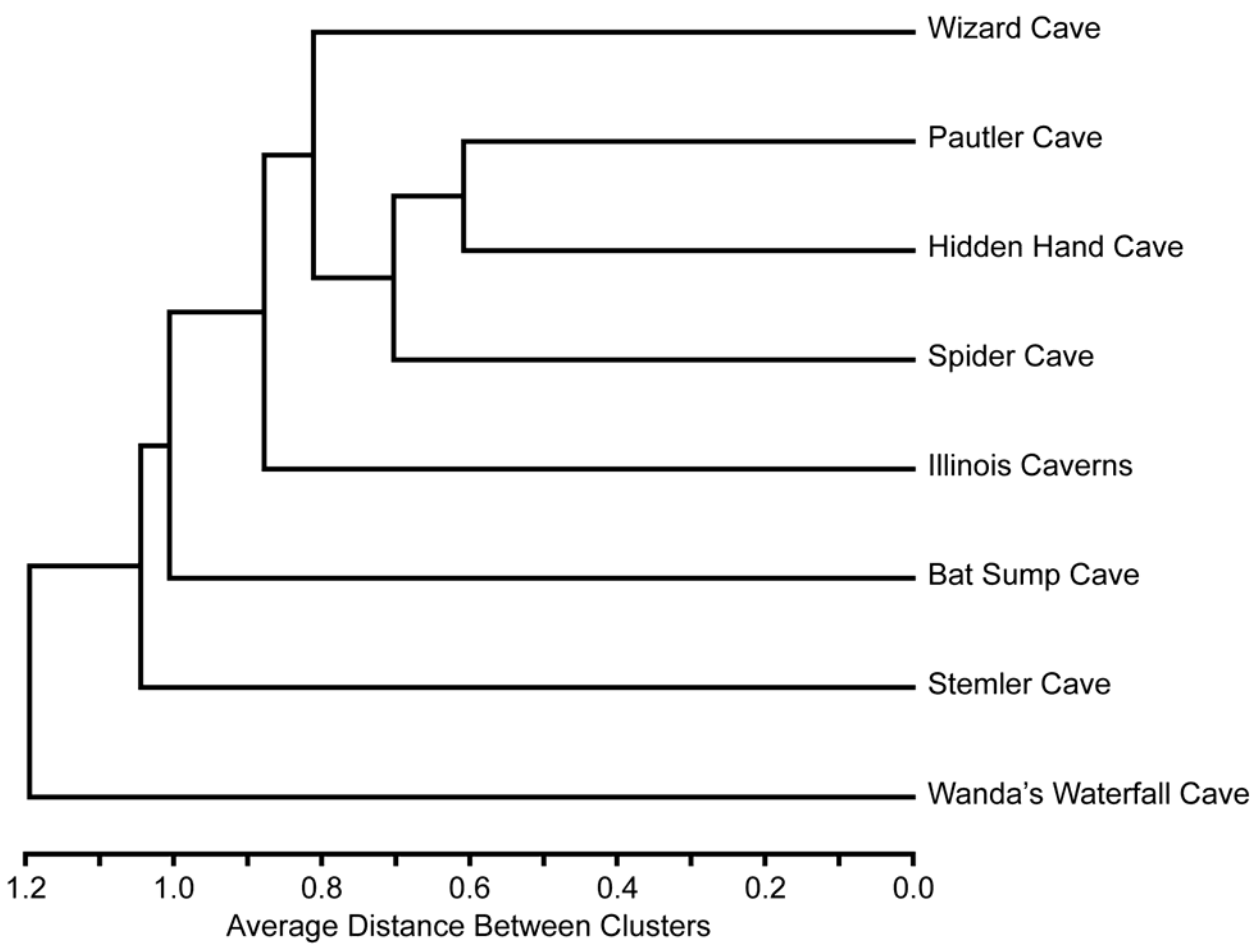

Figure 30. Cluster analysis of similarity among eight caves in Monroe and St. Clair counties, Illinois, based on presence/absence data for 49 species of Collembola collected in 2009.

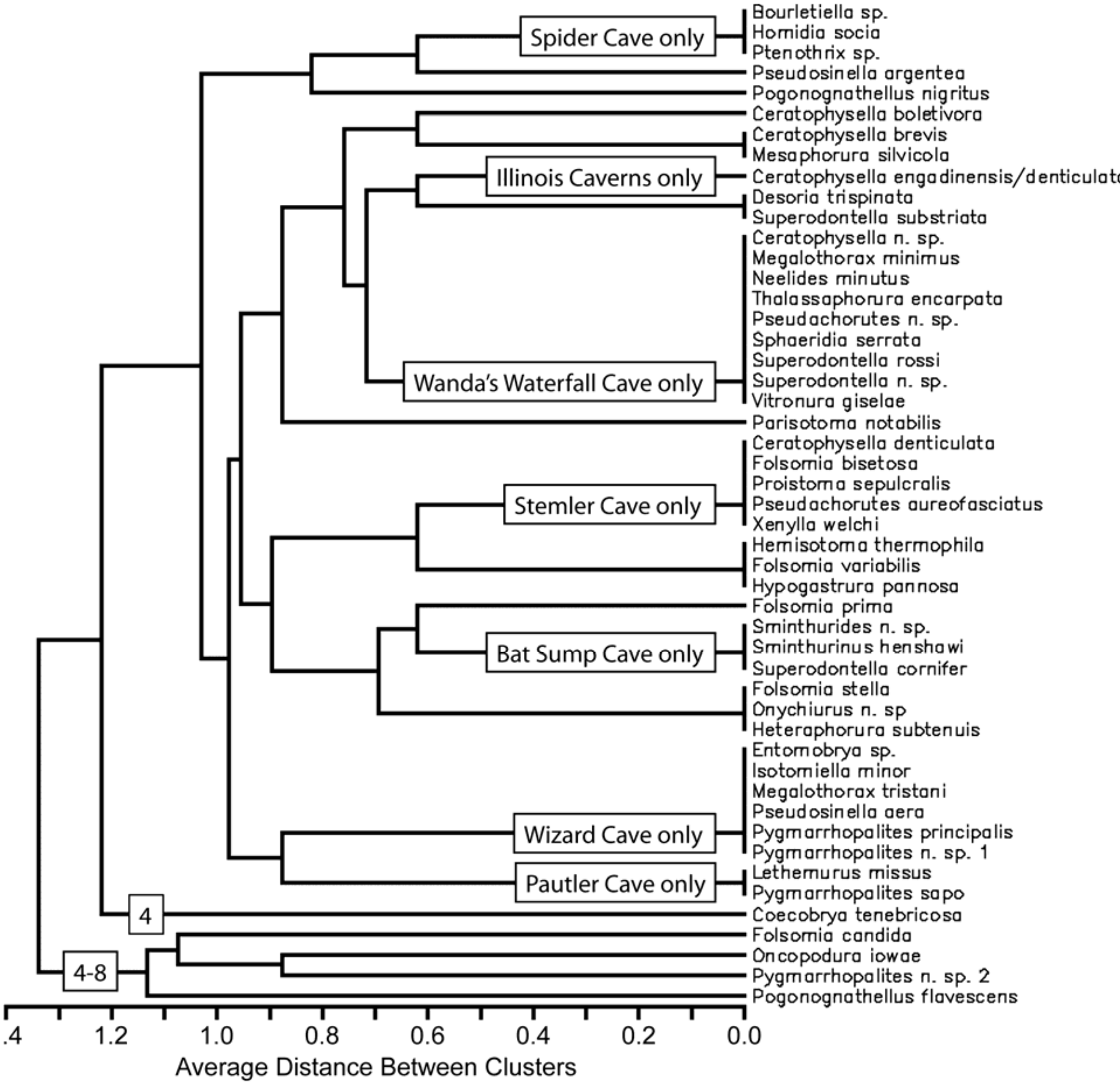

Figure 31. Cluster analysis of similarity among 49 species of Collembola based on their presence/absence in six types of samples taken in eight caves in Monroe and St. Clair counties, Illinois, based on data collected in 2009. The box with "4" indicates a species that was collected at four caves, the box with "4-8" indicates a group of species collected at 4 to 8 of the caves.

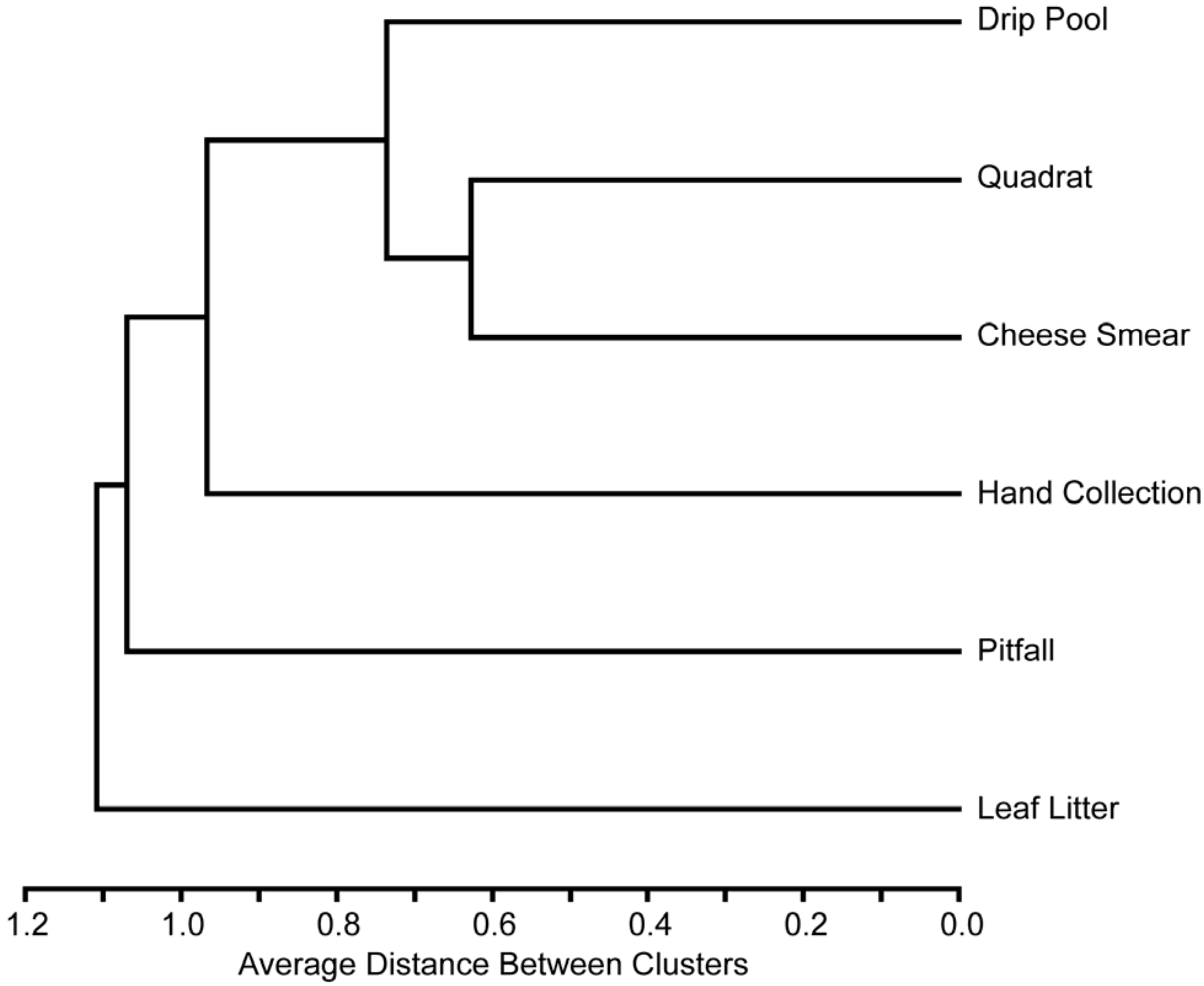

Figure 32. Cluster analysis of similarity among six types of samples taken in eight caves in Monroe and St. Clair counties, Illinois, based on presence/absence data for 49 species of Collembola collected in 2009.

similar on the basis of taxon presence/absence. Sampling methods which produced more taxa tended also to have more unique species, and thus the methods yielding the greatest number of species, Leaf litter, Hand Collections, and Pitfall Trapping, show up in the tree as least similar to other sites (Figure 32). The different sampling methods also showed differing rates of species accrual – or sampling completeness. Using data from all samples (across all caves) we produced several different estimators of actual species richness for each of the four most common sampling methods (pitfall trapping, hand collections, drip pools, and quadrat sampling) (Figure 33). These estimators could not be meaningfully applied to litter sampling and cheese smears due to inadequate sample size. This analysis showed that the rate of species accrual had not begun to plateau for any of the four sampling methods, and only for hand sampling did the various estimators of true species richness begin to converge towards a narrowed ranged of estimates (Figure 33). Comparing the observed rate of species accrul among these for methods, there are clear differences among methods. Hand collections were the most effective method for obtaining the larges number of taxa with the least number of samples, followed by pitfall trapping and then drip pools, and quadrat sampling was by far the least effective method (Figure 34).

Of the 49 taxa recorded in this study, just over half were obtained by a single sampling method, and more than 80% by only one or two sampling methods (Table 4). Neither quadrat sampling nor cheese smears yielded taxa not recovered by other sampling methods (Table 4). Leaf litter sampling produced the greatest number of taxa unique to a single sampling method, but some of these are likely not cave-obligate species (Table 4). Clustering of species based on their detection by each of the six sampling methods shows a similar pattern (Figure 35). The fauna recovered by pitfall trapping and hand collections was more similar than other methods, and shared a number of species in common, but Drip Pools and Leaf litter also produced unique assemblages of species (Figure 35). Pitfall trapping and examination of drip pools produced a large portion of the species richness attributable to a single method (Table 4), and these two approaches, along with hand collections, appear to be sufficient to capture the majority of the species detected by methods other than litter sampling.

Diversity and dominance metrics were calculated for each site and method, pooled by site, and pooled by method (Table 5). In general, the highest diversity was found at Wanda's Waterfall Cave and Stemler Cave, low diversity sites included Bat Sump Cave and Hidden Hand Cave. Drip pools and hand collection yielded the highest diversity of any of the sampling methods, and cheese smears produced the lowest diversity. Dominance (Berger-Parker index) was greatest at Bat Sump Cave and Hidden Hand Cave (Table 5). Steeper slopes on Whittaker plots (Figure 36) indicate greater dominance, while shallower slopes indicate more evenness (Magurran 2004). In the overall Whittaker plots of springtails at the eight caves (Figure 36), Hidden Hand and Bat Sump caves have the steepest slopes, thus higher dominance, while Stemler and Wanda's Waterfall caves have the shallowest slopes, thus higher evenness.

It is possible to rank caves in order of the number of additional species recorded by adding each cave, using a "simple greedy" algorithm (Cuista *et al*. 1997). This approach has recently been applied by Schneider & Culver (2004), and is applicable here as an exercise which might highlight caves for which cave protection might provide the greatest impact for the investment. When the eight caves are ranked by the "simple greedy" algorithm (Cuista *et al*. 1997) based on

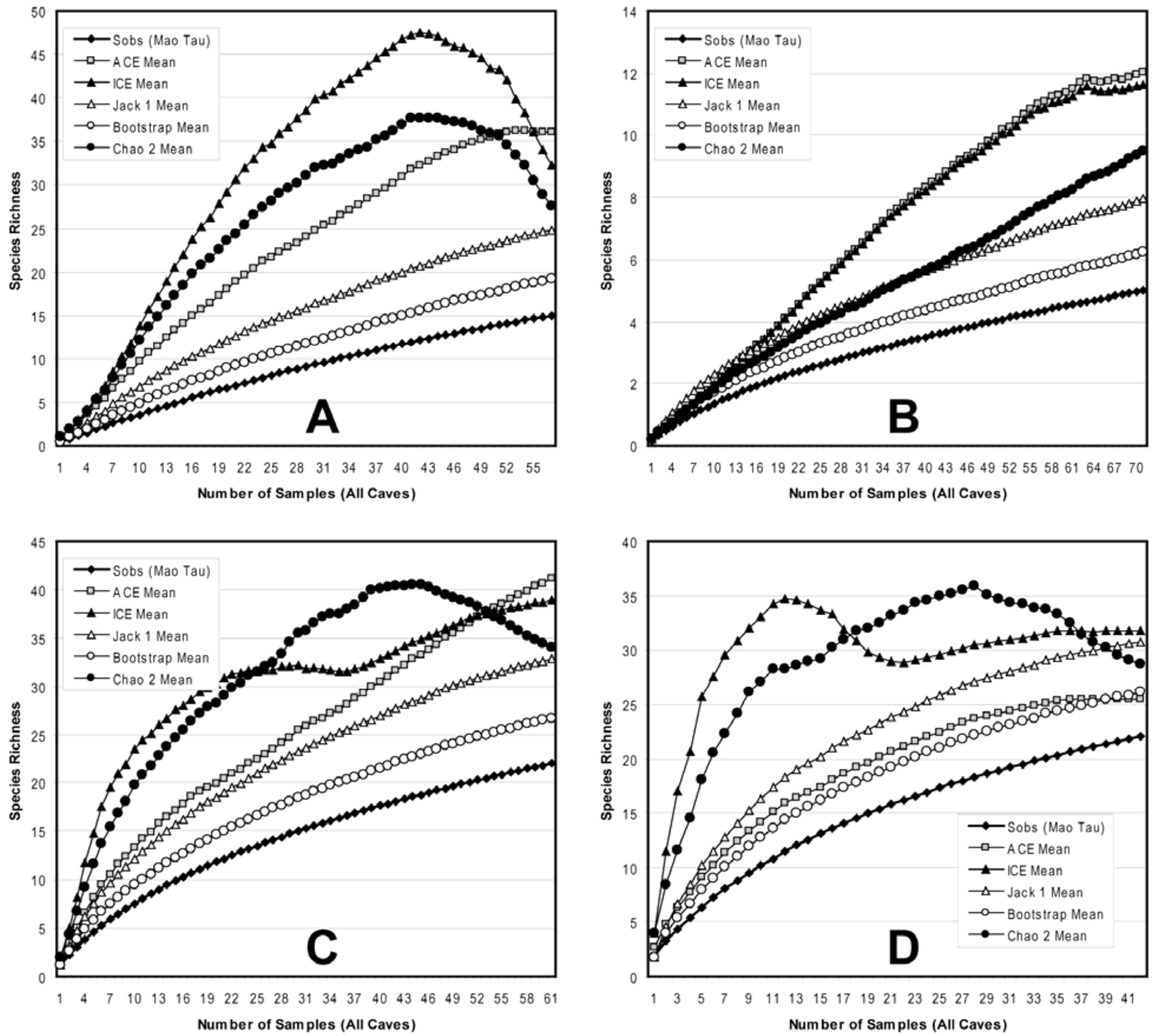

Figure 33. Species accumulation curves for the observed species (Sobs) and several estimators of species richness (Colwell 2006), using all samples across all caves for A) drip pools (15 species, 57 samples, estimated richness: 19.2-36.1); B) quadrat samples (5 species, 71 samples, estimated richness: 6.2-12.0); C) pitfall trap arrays (22 species, 61 samples [5 pitfall traps per sample], estimated richness: 26.7-41.2); and D) hand collections (22 species, 42 samples, estimated richness: 25.4-31.8). Based on collections of 49 species of Collembola from eight caves in Monroe and St. Clair counties, Illinois, in 2009.

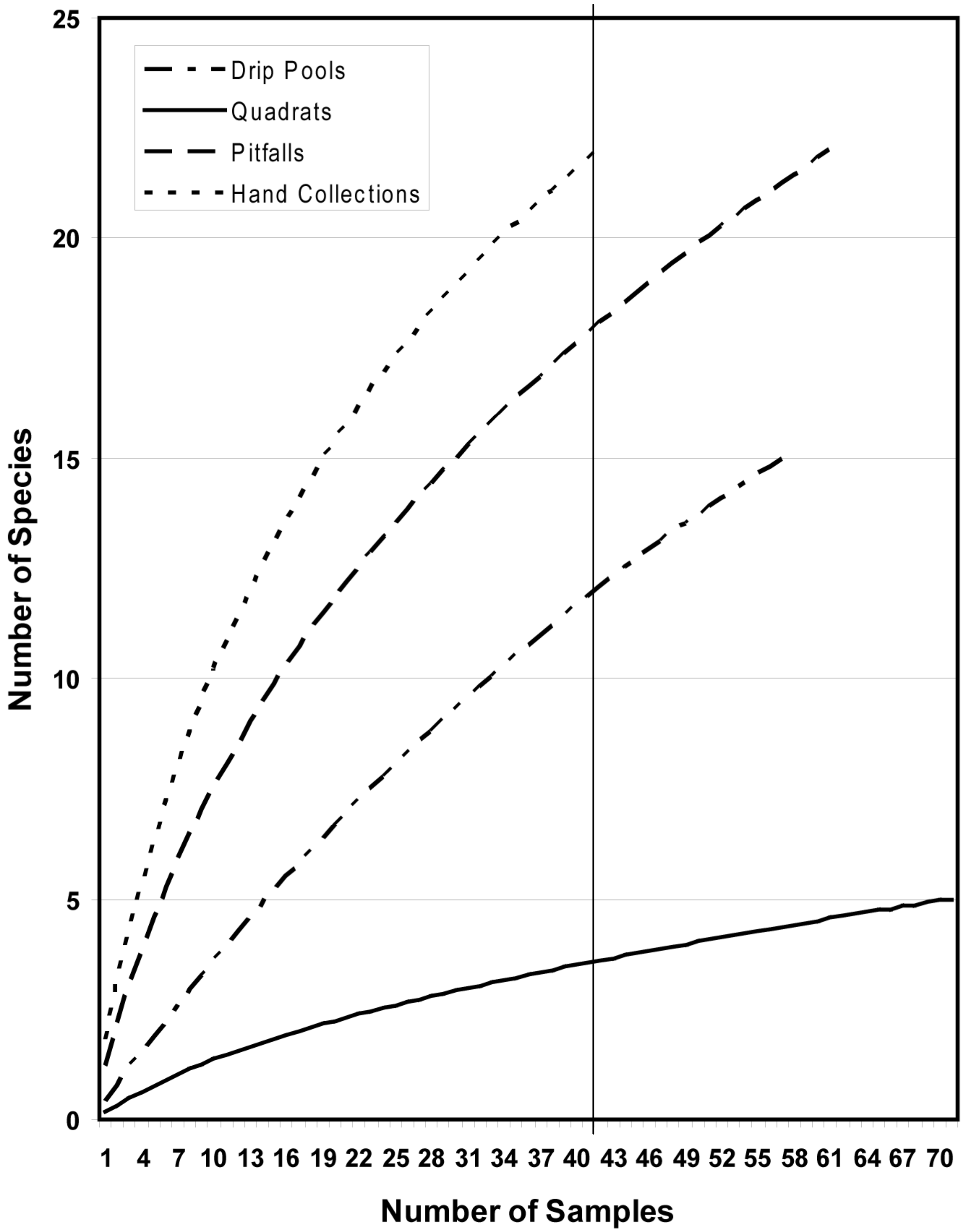

Figure 34. Species accumulation curves for the observed species (Sobs) (Colwell 2006) for each of the most commonly used sampling methods, using all samples across all caves. See Figure 33 for sample sizes. Based on collections of 49 species of Collembola from eight caves in Monroe and St. Clair counties, Illinois, in 2009. Vertical line allows comparison among sampling methods with 41 samples: Hand, 22 species; Pitfalls 17.9 species; Drip Pools, 11.9; Quadrats, 3.6 species.

Table 4. Summary of springtail taxa collected only by one or two of the six sampling methods. Based on collections at eight caves in Monroe and St. Clair counties, Illinois, in 2009.

	Drip Pool	Quadrat	Pitfall	Hand	Leaflitter	Cheese Smear	One method	Two methods
Total unique taxa collected by this method	4	0	7	4	10	0	25	40
Percents of total species which are unique to this method	8.2%	0.0%	14.3%	8.2%	20.4%	0.0%	51.0%	81.6%
Percent of species collected by this method which are unique to this Method	26.7%	0.0%	31.8%	18.2%	45.5%	0.0%		

Table 5. Summary of collembolan diversity and dominance by sample type and site for eight caves in Monroe and St. Clair counties, Illinois, sampled in 2009.

Sample type	**Simpson's index**	**Berger-Parker index**	**Site**
Cheese Smear	0.22	0.88	Bat Sump Cave
Cheese Smear	0	1	Hidden Hand Cave
Cheese Smear			Illinois Caverns
Cheese Smear			Pautler Cave
Cheese Smear			Spider Cave
Cheese Smear	0.5	0.75	Stemler Cave
Cheese Smear	0	1	Wanda's Waterfall Cave
Cheese Smear			Wizard Cave
Drip Pools			Bat Sump Cave
Drip Pools	0	1	Hidden Hand Cave
Drip Pools			Illinois Caverns
Drip Pools			Pautler Cave
Drip Pools			Spider Cave
Drip Pools	0.68	0.56	Stemler Cave
Drip Pools	0.9	0.29	Wanda's Waterfall Cave
Drip Pools			Wizard Cave
Hand	0.56	0.55	Bat Sump Cave
Hand	0.07	0.96	Hidden Hand Cave
Hand	0.6	0.59	Illinois Caverns
Hand	0.69	0.46	Pautler Cave
Hand	0.44	0.75	Spider Cave
Hand	0.9	0.23	Stemler Cave
Hand	0.69	0.53	Wanda's Waterfall Cave
Hand	0.56	0.63	Wizard Cave

(continued)

Table 5. Continued.

Sample type	Simpson's index	Berger-Parker index	Site
Leaflitter	0.54	0.63	Bat Sump Cave
Leaflitter			Hidden Hand Cave
Leaflitter	0.47	0.7	Illinois Caverns
Leaflitter			Pautler Cave
Leaflitter			Spider Cave
Leaflitter	0.68	0.5	Stemler Cave
Leaflitter	0.67	0.56	Wanda's Waterfall Cave
Leaflitter			Wizard Cave
Pitfalls	0.14	0.93	Bat Sump Cave
Pitfalls	0.41	0.75	Hidden Hand Cave
Pitfalls	0.81	0.38	Illinois Caverns
Pitfalls	0	1	Pautler Cave
Pitfalls	0.79	0.5	Spider Cave
Pitfalls	1	0.5	Stemler Cave
Pitfalls	0.92	0.22	Wanda's Waterfall Cave
Pitfalls	0.77	0.41	Wizard Cave
Quadrats	0.67	0.5	Bat Sump Cave
Quadrats			Hidden Hand Cave
Quadrats			Illinois Caverns
Quadrats	0	1	Pautler Cave
Quadrats	0.4	0.8	Spider Cave
Quadrats	0.68	0.56	Stemler Cave
Quadrats	0.67	0.67	Wanda's Waterfall Cave
Quadrats			Wizard Cave
All Methods	0.79	0.38	All Caves
Cheese Smear	0.45	0.67	All Caves
Drip Pool	0.9	0.29	All Caves
Hand	0.81	0.27	All Caves
Leaflitter	0.64	0.56	All Caves
Pitfall	0.48	0.71	All Caves
Quadrat	0.83	0.31	All Caves

(continued)

Table 5. Concluded.

Sample type	**Simpson's index**	**Berger-Parker index**	**Site**
All Methods	0.36	0.79	Bat Sump Cave
All Methods	0.24	0.87	Hidden Hand Cave
All Methods	0.66	0.54	Illinois Caverns
All Methods	0.76	0.41	Pautler Cave
All Methods	0.52	0.69	Spider Cave
All Methods	0.84	0.32	Stemler Cave
All Methods	0.81	0.38	Wanda's Waterfall Cave
All Methods	0.68	0.53	Wizard Cave

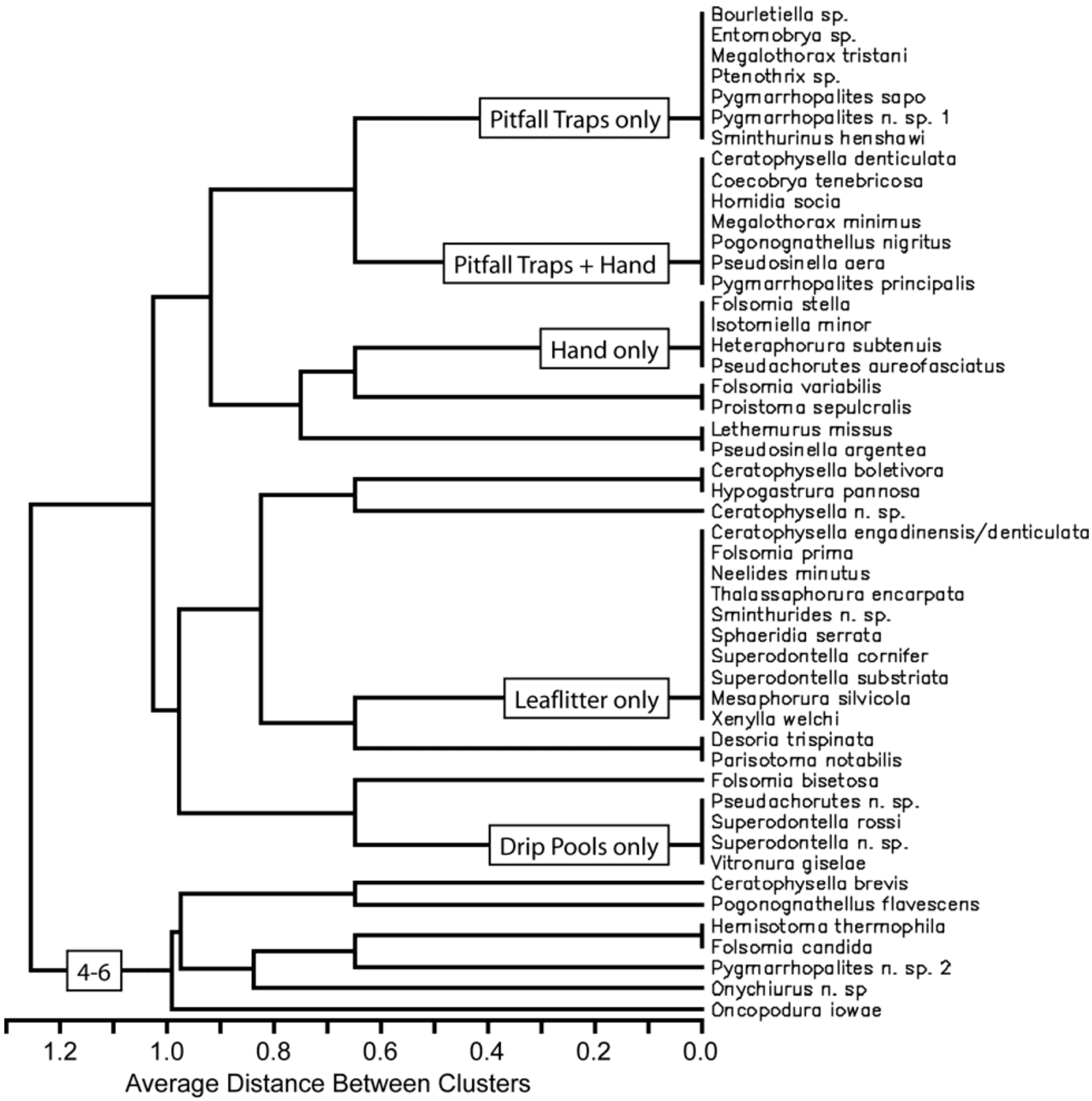

Figure 35. Cluster analysis of similarity among 49 species of Collembola based on their presence/absence in six types of samples taken in eight caves in Monroe and St. Clair counties, Illinois, based on data collected in 2009. The box with “4-6” indicates a group of species collected by 4 to 6 of the sampling methods.

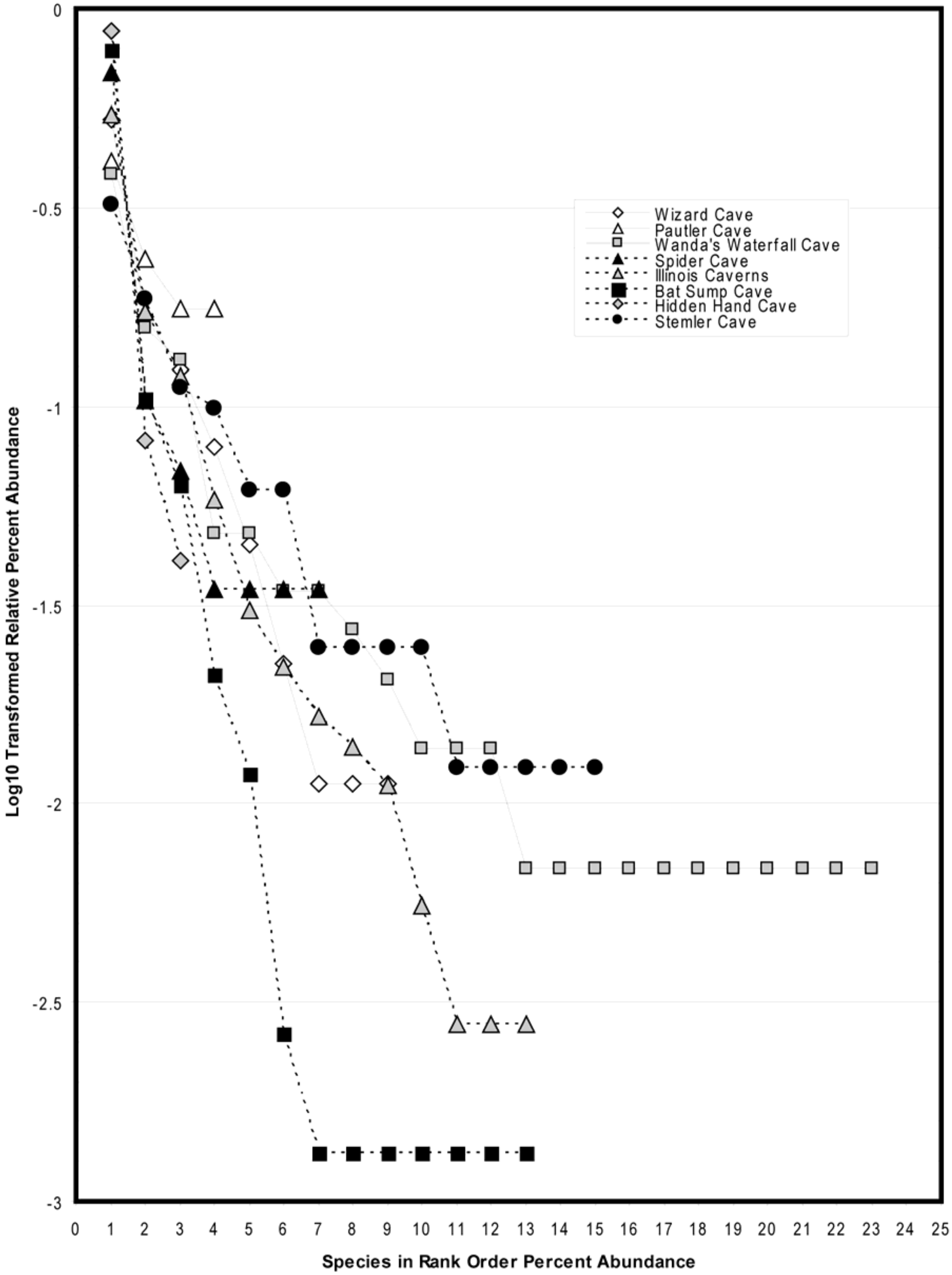

Figure 36. Whittaker plot of rank order relative percent abundance of Collembola collected in eight caves in Monroe and St. Clair counties, Illinois, in 2009.

springtail species (Table 6), six of the eight caves need protection to protect 95% of the species. However, protecting only three of the caves – Wanda's Waterfall Cave, Stemler Cave, and Wizard Cave – would achieve protection for 75% of the species (Table 6). The two caves with the least conservation value in the sense of this particular analysis are the two caves which regularly experience the heaviest visitation – Illinois Caverns and Hidden Hand Cave. Ironically, these two are among the caves for which the land managers are in the best position to properly manage the caves. Because the Salem Plateau contains more than 100 caves and we sampled only eight, the "simple greedy" algorithm analysis presented here should be considered only as an example of the principles which could guide better management of Illinois' caves to best protect the fauna in the face of limited resources.

We can compare the eight caves by evaluating the rate of species accrual on the basis all samples, regardless of sampling method. Although different caves produced differing numbers of species, most of the caves showed very similar rates of species accrual (Figure 37), with Pautler and Hidden Hand caves accruing species at a lower rate, and Wanda's Waterfall Cave accruing species at a markedly higher rate than the other caves. With the possible exception of Pautler Cave, none of the caves' rates of accrual appear to be asymptotic, thus sampling of the caves appears incomplete. The Pautler Cave species accrual curve only represents a relatively small part of the cave, and clearly more species should be found in the more varied parts of the cave we did not sample, in spite of Figure 37.

<u>Habitat and Environmental Parameters</u>

In-cave air tempertures during our study ranged from 10.5 to 20.4 °C (50.9-68.7 °F), averaging 15.2 °C (59.3 °F, n=28). Two centimeter soil temperatures ranged from 13.1 to 18.6 °C (55.5-65.4 °F), averaging 15.4 C (59.7 °F, n=23). Relative humidity was measured as ranging from 73.2 to 90.6 %, averaging 85.9 % (n=23).

Thought data on many species were based on too few specimens to accurately describe typical habitats of the species, there appeared to be some differences between species (Figure 38). Silt, Clay, and Sand were among the most frequent substrates from which springtails were recorded for those methods with quadrat-based substrate characterization (Pitfalls, Quadrats; Figure 38).

Specific data on temperature, humidity, light, and microhabitats for all species collected by all methods are summarized below.

Poduromorpha

Neanuridae

Vitronura giselae

This species was found in drip pools in Wanda's Waterfall cave at and air temperature of 16.7 °C, and soil temperature of 15.8 °C (n=2).

Pseudachorutes aureofasciatus

A single specimen was taken in a drip pool on bedrock in the dark zone of Stemler Cave.

Table 6. Maximum number of additional Collembola taxa added by including another cave, using the Csuti *et al.* (1997) "simple greedy" algorithm. Data based on specimens collected from eight caves in Monroe and St. Clair counties, Illinois, in 2009.

Site	Total Additional Taxa	Cummulative Total Taxa	Cumulative Percent of Taxa
Wanda's Waterfall Cave	23	23	46.9
Stemler Cave	8	31	63.3
Wizard Cave	6	37	75.5
Bat Sump Cave[1]	5	42	85.7
Spider Cave[1]	4	46	93.9
Pautler Cave	2	48	98.0
Illinois Caverns	1	49	100.0
Hidden Hand Cave	0	49	100.0

[1]These two caves were tied for fourth place, and whichever is ranked fourth would add 5 species, with the other, ranked fifth, adding 4 more species – none of the other caves' counts of additional springtail taxa are affected.

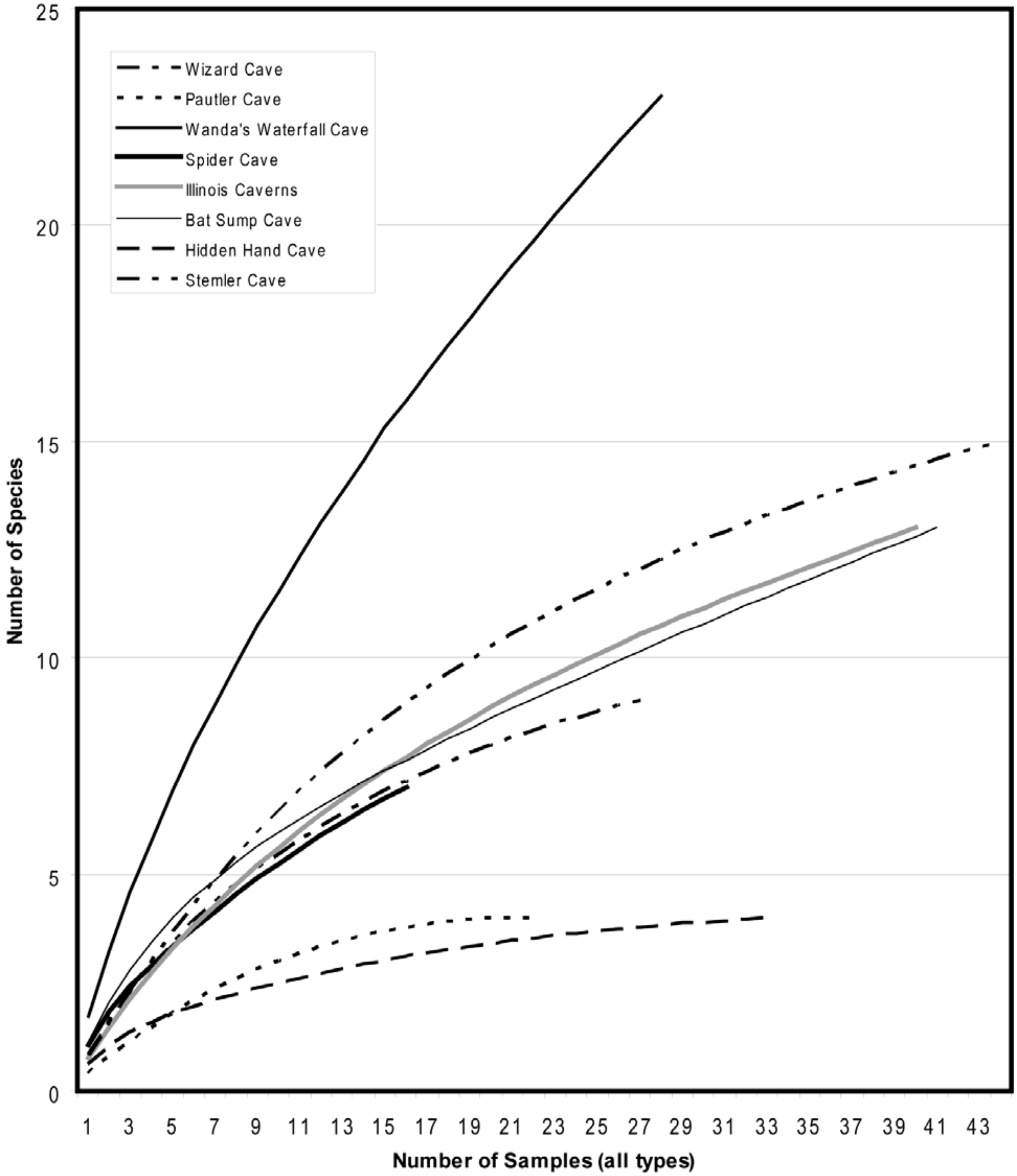

Figure 37. Species accumulation curves for the observed species (Sobs) (Colwell 2006) for each of cave, using all samples across all sample types. Based on collections of 49 species of Collembola from eight caves in Monroe and St. Clair counties, Illinois, in 2009.

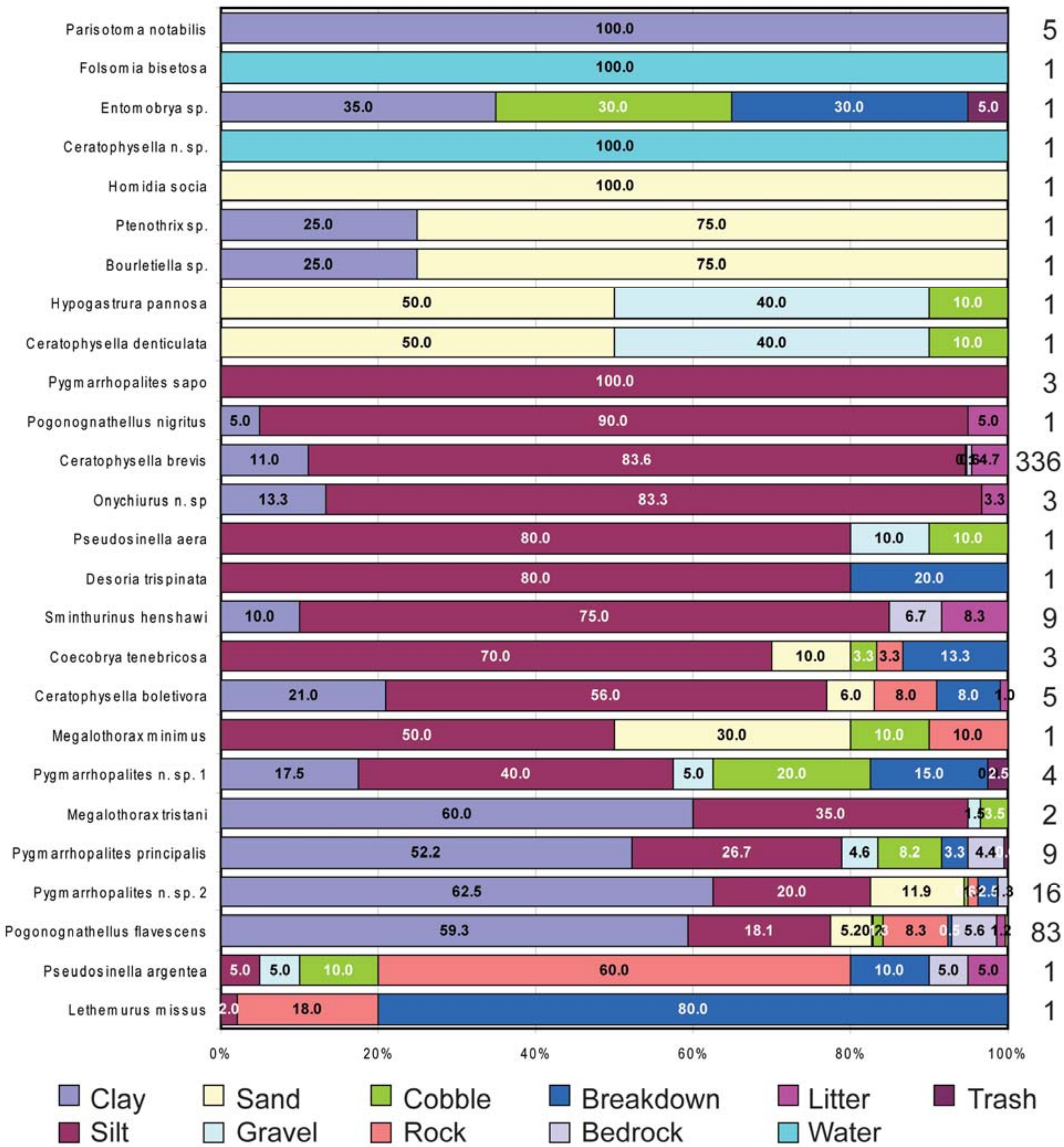

Figure 38. Quadrat based substrate characterization for all pitfall- and quadrat-collected springtails. Values represent average for all individuals (not all samples) of each species. Numbers on right hand side of figure are sample size. Based on samples taken in eight caves in Monroe and St. Clair counties, Illinois, in 2009.

Pseudachorutes n. sp.

A single specimen was taken in a drip pool in the dark zone of Wanda's Waterfall Cave at and air temperature of 16.7 °C, and soil temperature of 15.8 °C.

Odontellidae

Superodontella cornifer

A single specimen was taken from a dark zone litter sample from a silt covered floor in Bat Sump Cave.

Superodontella rossi

A single specimen was taken from a drip pool in the dark zone of Wanda's Waterfall Cave at an air temperature of 16.7 °C, and soil temperature of 15.8 °C.

Superodontella substriata

Two specimens were collected, each from a litter sample in the twilight zone, but in two caves (Wanda's Waterfall Cave and Illinois Caverns).

Superodontella n. sp.

A single specimen was collected from a dark zone drip pool in Wanda's Waterfall Cave at an air temperature of 16.7 °C, and soil temperature of 15.8 °C.

Hypogastruridae

Ceratophysella brevis

This species was very common in collections (n=617), occurring in Drip Pool (n=2), Pitfall (n=336), Hand (n=120), Litter (n=46) and Cheese Smear (n=113) collections (Figure ZB). It was recorded in conditions averaging 12.4 °C air temperature (range 10.5-16.7 °C, n=340), 15.8 °C soil temperature (n=3), at relative humidities averaging 87.5 % (range 83.3-88.5 %, n=334), primarily (98.3% of 345 specimens) in the dark zone, under typically normal moisture conditions (normal: n=312; wet: n=24). In spite of the high numbers of specimens, this species was only found in Wanda's Waterfall Cave (n=19) and Bat Sump Cave (n=598).

Ceratophysella boletivora

This species was common (n=83) and was recorded from the dark and twilight zones under normal to wet conditions in Drip Pool (n=2), Pitfall (n=5) and Litter (n=76) samples at air temperatures averaging 15.2 °C (range 11.0-16.7 °C, n=6), soil temperatures averaging 15.6 °C (range 15.3-15.8 °C, n=5) and at relative humidities averaging 83.7 % (range 73.2-87.3 %, n=4). It was recorded from Illinois Caverns (n=62), Bat Sump Cave (n=16) and Wanda's Waterfall Cave (n=5).

Ceratophysella denticulata

Two specimens of this species were recorded from Stemler Cave. It occurred in the dark zone in normal moisture conditions at an air temperature of 15.7 °C, a soil temperature of 15.4 °C and a relative humidity of 85.9%. It was taken both by hand and pitfall trapping.

Ceratophysella engadinensis/*denticulata*

This species was taken in a litter sample from the twilight zone in Illinois Caverns (n=8).

Ceratophysella n. sp.

This undescribed species was collected only at Wand's Waterfall Cave, where it was collected at 16.7 °C air temperature and 15.8 °C soil temperature (n=1), in the dark and twilight zones, primarily in a twilight zone litter sample but also in a drip pool.

Hypogastrura pannosa

Several specimens (n=5) were collected from drip pools (n=4), litter (n=3) and pitfall samples (n=1) in the dark zones of Wanda's Waterfall and Stemler caves. Average air temperatures were 16.5 °C (range 15.7-16.7 °C, n=5), soil temperatures 15.7 °C (range 15.4-15.8 °C, n=5) and at a relative humidity of 85.9 % (n=1).

Xenylla welchi

A single specimen was taken in Stemler Cave in a litter sample on wet silt, clay floor in the dark zone.

Onychiuridae

Onychiurus n. sp.

This species was common in Bat Sump Cave (n=79) and also was recorded from Stemler Cave (n=9). It occurred in the dark zone (n=73) and twilight (n=1) at an average air temperature of 12.4 °C (range 10.5-15.8 °C, n=74), a soil temperature of 15.5 °C and at relative humidities averaging 86.7 % (range 83.3-90.1 %, n=74). This new species was recorded from Drip Pool (n=1), Quadrat (n=2), Pitfall (n=1) and Hand (n=83) collections.

Thalassaphorura encarpata

A single specimen was taken from litter in the twilight zone of Wanda's Waterfall Cave in litter among breakdown.

Heteraphorura subtenuis

This species was recorded from Bat Sump and Stemler caves on the basis of two specimens taken in hand collections. It occurred on wet silt and clay on breakdown (n=1) and at a temperature of 12.3 °C (n=1) and 86.7 % relative humidity (n=1).

Tullbergiidae

Mesaphorura silvicola

Three specimens of this species were recorded from litter samples in the dark and twilight zones of Wanda's Waterfall (n=1) and Bat Sump (n=2) caves.

Entomobryomorpha

Oncopoduridae

Oncopodura iowae

This species occurred in low numbers in the dark and twilight zones in Wizard Cave (n=1), Wanda's Waterfall Cave (n=2), Hidden Hand Cave (n=1), Stemler Cave (n=8) and Illinois Caverns (n=2). It was taken mostly in hand collections (n=11) but also in Drip Pool and Cheese Smear collections. It was recorded at an average air temperature of 16.6 °C (range 14.1-19.9 °C), an average soil temperature of 15.8 °C (range 13.9-17.9 °C) and an average relative humidity of 88.3 % (range 84.3-90.6 %). Some specimens were associated with old, dry raccoon scat or with an old rotting sandwich.

Tomoceridae

Pogonognathellus flavescens

This was one of the most commonly collected species (n=275) and occurred at all eight caves (Wizard Cave, n=47; Pautler Cave, n=4; Wanda's Waterfall Cave, n=23; Spider Cave, n=20; Illinois Caverns, n=21; Bat Sump Cave, n=48; Hidden Hand Cave, n=107; and Stemler Cave, n=5). Average conditions under which it was recorded were an air temperature of 15.6 °C (range 10.5-19.9 °C, n=170), a soil temperature of 15.5 °C (range 13.1-17.9 °C, n=153) and a relative humidity of 87.4 %

(range 73.2-90.6 %, n=141). It was collected more commonly in the dark zone (n=106) than in the twilight zone (n=69), and under normal moisture conditions more commonly (n=89) than under wet conditions (n=26). This species was collected using all sampling methods, and was obtained most commonly in Hand collections (n=123) but also in Drip Pool (n=1), Quadrat (n=8), Pitfall (n=74), Litter (n=14) and Cheese Smear (n=55) collections.

Pogonognathellus nigritus

This speices was recorded from three caves (Stemler Cave, n=1; Illinois Caverns, n=5; and Bat Sump Cave n=1) where it was recorded from the twilight and dark zones in a Pitfall Trap (n=1) and by Hand Collections (n=6). it was recorded at an air temperature averaging 15.5 °C (range 11.0-18.0 °C, n=2), a soil temperature of 16.9 °C (n=1) and a relative humidity of 86.9 % (n=1). Most specimens were taken by hand from soil and litter in the twilight zone.

Lethemurus missus

This species was recorded only from the twilight zone of Pautler Cave (n=7) where most specimens (n=6) were recorded from Hand Collections on and under rocks and on decaying wood. It also was taken in a Pitfall Trap (n=1), where the air temperature was 13.5 °C and soil temperature was 13.1 °C.

Isotomidae

Hemisotoma thermophila

This species was recorded from Stemler Cave (n=15) and Wanda's Waterfall Cave (n=1). It wask taken in Drip Pool (n=3), Hand (n=3) and Litter (n=7) samples, primarily in the dark zone, where it was associated with an air temperature of 15.8 °C, soil temperature of 15.5 °C and relative humidity of 90.1%.

Folsomia bisetosa

Only two specimens of this species were recorded, from Stemler Cave. It was taken in Drip Pools in the dark zone at 15.8 °C air temperature, 15.5 °C soil temperature and 90.1 % relative humidity.

Folsomia candida

This species was taken at Wanda's Waterfall Cave (n=7), Illinois Caverns (n=1), Bat Sump Cave (n=1) and Stemler Cave (n=26). It was associated with an air temperature of 15.8 °C, soil temperature of 15.5 °C and relative humidity of 90.1%, and was taken in Drip Pool (n=13) and Litter (n=13) samples in the dark zone.

Folsomia prima

Two specimens of this species were taken in litter in Illinois Caverns (n=1) and Bat Sump Cave (n=1). It occurred in the dark and twilight zones.

Folsomia stella

Two specimens of this species were Hand collected from Bat Sump (n=1) and Stemler (n=1) caves in wet conditions in the dark zone. The species was associated with an air temperature of 12.3 °C and relative humidity of 86.7%.

Folsomia variabilis

This species was taken at Wanda's Waterfall Cave (n=1) and Stemler Cave (n=2) in hand and litter collections.

Proistoma sepulcralis

This species was only recorded from Stemler Cave (n=2) where it occurred in a Litter collection on wet silt/clay floor and in a drip pool.

Desoria trispinata

This species was abundant in Wanda's Waterfall Cave (n=56) and Illinois Caverns (n=196) where it occurred primarily in litter samples (n=251) in the twilight zone, but also in one pitfall sample (n=1) in the dark zone, where air temperature was 15.6 °C and soil temperature was 15.5 °C, and relative humidity was 87.3 %.

Parisotoma notabilis

This species was recorded from Wanda's Waterfall Cave (n=1), Illinois Caverns (n=6) and Hidden Hand Cave (n=5). It occurred in Pitfall (n=5) and Litter (n=7) samples, at an air temperature of 14.1 °C (n=5), a soil temperature of 13.9 °C (n=5) and a relative humidity of 90.6 %. It was present in both the dark (n=5) and twilight (n=7) zones.

Isotomiella minor

A single specimen of this species was Hand Collected from Wizard Cave on old dry raccoon scat on a normal moisture clay and rook floor in the twilight zone at an air temperature of 19.9 °C, a soil temperature of 17.9 °C and a relative humidity of 84.3 %.

Entomobryidae

Entomobrya sp.

A single specimen of this species was recorded from a Pitfall Trap in Wizard Cave at an air temperature of 19.9 °C, a soil temperature of 17.9 °C and a relative humidity of 84.3 %.

Coecobrya tenebricosa

This species was recorded from Wizard Cave (n=15), Pautler Cave (n=3), Wanda's Waterfall Cave (n=1) and Illinois Caverns (n=43). It was recorded at an average air temperature of 18.5 °C (range 14.2-19.9 °C, n=21), an average soil temperature of 17.0 °C (range (13.7-17.9 °C) and an average relative humidity of 84.7% (range 84.3-87.3 %, n=17). Most collections where by Hand (n=59) but it was also recorded from pitfall traps (n=3). Most specimens were from the twilight zone (n=15), but some were from the dark zone (n=6). It was recorded from normal moisture habitats (n=59).

Homidia socia

Two specimens were taken in Spider Cave at an air temperature of 17.8 °C, a soil temperature of 16.4 °C, at normal moisture levels in the twilight zone. It was collected both by pitfall trapping and hand collection.

Pseudosinella aera

This species was taken only in the twilight zone of Wizard Cave (n=7) under noarmal moisture conditions at an air temperature of 19.9 °C, soil temperature of 17.9 °C, and relative humidity of 84.3 %. Most (n=6) were taken by hand in association with old, dray raccoon scat on clay and rock floor, but one specimen was taken by pitfall trapping in the same area.

Pseudosinella argentea

This species was collected at Spider Cave (n=3) and Illinois Caverns (n=13) under normal moisture conditions. It was associated (n=3) with an air temperature of 18.0 °C, a soil temperature of 16.9 °C and complete darkness. Most material was taken in the dark zone near limburger cheese baited pitfall traps on clay and breakdown floor or, more commonly (n=9) in association with a rotting sandwich on clay covered breakdown. Most material was hand collected (n=13), with one specimen recovered from a pitfall trap.

Neelipleona

Neelidae

Neelides minutus

A single specimen of this species was taken in a litter sample taken among breakdown below the entrance in the twilight zone of Wanda's Waterfall Cave.

Megalothorax minimus

This species was taken only in Wanda's Waterfall Cave (n=3) in a pitfall trap (n=1) and by hand collections on a silt/sand wall ledge (n=2). All collections were in the dark zone under normal moisture conditions, associated with an air temperature of 16.7 °C and soil temperature of 15.8 °C.

Megalothorax tristani

Two specimens were taken in a pitfall trap in normal moisture conditions in the twilight zone of Wizard Cave at an air temperature of 19.9 °C, a soil temperature of 17.9 °C and at a relative humidity of 84.3 %.

Symphypleona

Sminthurididae

Sminthurides n. sp.

A single specimen was taken in Bat Sump Cave from leaflitter taken in the dark zone off silt substrate.

Sphaeridia serrata

Two specimens were collected in a litter sample taken in the twilight zone of Wanda's Waterfall Cave.

Bourletiellidae

Bourletiella sp.

This family is represented by a single specimen collected in the dark zone of Spider Cave in a pitfall trap on normal moisture substrate at 18.0 °C air temperature, 16.9 °C soil temperature.

Dicyrtomidae

Ptenothrix sp.

This family is represented by a single specimen collected in the dark zone of Spider Cave in a pitfall trap on normal moisture substrate at 18.0 °C air temperature, 16.9 °C soil temperature.

Katiannidae

Sminthurinus henshawi

Nine specimens of this species were taken in pifall traps in the entrance and twilight zones of Bat Sump Cave, under wet (n=8) and normal (n=1) substrate conditions, at an air temperature averaging 11.3 °C (range: 10.5-12.3 °C, n=9) and a relative humidity averaging 86.0 % (range: 83.3-88.5 %, n=9).

Arrhopalitidae

Pygmarrhopalites principalis

This species was recorded from Wizard Cave (n=11) were it was taken in pitfall traps (n=9) and by hand collection (n=2) in the twilight zone (n=11). It was recorded from normal moisture conditions and an air temperature of 19.9 °C, a soil temperature of 17.9 °C, and a relative humidity of 83.4 %.

Pygmarrhopalites sapo

This species was recorded in the twilight zone of Pautler Cave (n=3), where it was taken in pitfall traps (n=3) at 13.5 °C air temperature (n=2) and 13.1 °C soil temperature (n=2).

Pygmarrhopalites n. sp. 1

Four specimens of this new species were taken in Wizard Cave in normal moisture conditions in the twilight zone by pitfall trapping. It was associated with an air temperature of 19.9 °C, a soil temperature of 17.9 °C and a relative humidity of 84.3 %.

Pygmarrhopalites n. sp. 2

This new species was recorded from Wanda's Waterfall Cave (n=4), Spider Cave (n=1), Illinois Caverns (n=4), Hidden Hand Cave (n=10) and Stemler Cave (n=5). it was taken primarily in the dark zone (n=16) but also in the twilight zone (n=2) by various collecting methods (drip pools, n=1; quadrat, n=1; pitfall, n=15; hand, n=4; and litter, n=2). Air temperature for collections averaged 15.7 °C (range 12.8-18.0 °C, n=15), soil temperature 15.5 °C (range 13.5-16.9 °C, n=15) and relative humidity 89.9 % (range 86.2-90.6 %, n=13).

Discussion

<u>Species Accounts</u>

Of the 49 species reported here, 15 represent new records for Illinois and 18 represent new cave records for the species. Ten of the 49 species have morphological characters that suggest some level of adaptation to caves and are classified as either troglobionts or troglophiles. Seven of these ten species are currently known only from caves, although *O. iowae, L. missus* and maybe *Onychiurus* n. sp. are widely distributed across unconnected cave systems, suggesting surface migration. The other three species (all of them members of the family Entomobryidae) are widely distributed across North America, and surface populations are not rare.

Only 14 of the 49 species were ranked as widespread. More than half (29) of the species reported are ranked as rare at the state level (i.e., S1-S2). Seven of the species ranked rare for the state are common globally and the S1-S2 ranking is probably an artifact of the relatively poor knowledge of the fauna of Illinois. Some of the other species ranked as rare are probably really rare in the state, even if they are widespread elsewhere on the continent, because they represent the limit of the distributional range of the species (e. g., *Pseudosinella aera*, *Folsomia bisetosa*?). Some appear rare as result of unresolved taxonomic issues (e. g., *Onychiurus* n. sp.). Others, such as the *Pygmarrhopalites* species, are probably truly rare and endemic to the region.

Previous reports of cave Collembola from the Salem Plateau list 18 species (Peck and Lewis 1978, Lewis et al 2003). We did not find eleven of the species previously reported, but nine of those species were collected from caves we did not visit. Of the eight caves we surveyed, seven were previously sampled by Peck and Lewis (1978) and Lewis *et al*. (2003). In all instances each cave sampled in the present survey yielded more species than those previously reported (Table 7). In most cases, the species reported by Lewis *et al*. (2003) were collected again during the present survey. Of the 13 collection events listed by Lewis *et al*. (2003), only in five

Table 7. Comparison in the number of springtail species recorded in an earlier study (Lewis *et al*. 2003) to the numbers from the same caves in the present study.

Cave	**Lewis *et al*. (2003)**	**Present study**	**Species in common**	**Lewis *et al*. species not found in present study**
Pautler Cave	2	4	2	-
Wanda's Waterfall Cave	1	22	0	*Pseudosinella* sp. nr. *argentea*
Spider Cave	1	7	1	-
Stemler Cave	1	15	1	-
Illinois Caverns	3	13	2	*Lethemurus missus*[1]
Hidden Hand Cave	3	4	1	*Pygmarrhopalites carolynae* *Onychiurus* "*reluctus*"
Bat Sump Cave	2	12	1	*Sensilanura illina*[2]
Total Occurrences	13	77	8	5

[1]This species was recorded in another cave during the present study
[2]We collected specimens of this species in surface leaf litter near the entrance of this cave.

instances we did not repeat the species they reported (Table7). The lack of collections of *Pseudosinella* from Wanda's Waterfall, of *Pygmarrhopalites carolynae* and *Onychiurus* "*reluctus*" from Hidden Hand, and of *Sensillanura illina* from Bat Sump during the present survey is curious given that these were the shortest cave included in this study and we expected to have sampled their length. In addition, Wanda's Waterfall Cave yielded the largest number of species (Table 6). It is worth mentioning that although *S. illina* was not collected inside Bat Sump Cave this time, we do have examples of this species in collections of surface leaf litter made within 30 meters of the cave entrance on the same day the cave sampling was completed. On the other hand, we are not surprised we did not collected *L. missus* again in Illinois Caverns. Illinois Caverns is a large, complex system we barely managed to explore due to the limited amount of time we were allowed to spend underground. The time limitation gave us access only to the proximal part of the cave, precisely the section most impacted by the large number of visitors that tour this system every year (Figure 39).

The greater success of the present survey in comparison with the surveys of Peck and Lewis (1978), Webb *et al*. (1994) and Lewis *et al*. (2003) in collecting and identifying cave springtails has little to do with the general proficiency of the individual collectors. Previous studies have attempted to survey all invertebrate groups in the caves and their efforts have been, in a sense, diluted by the need to maximize catch diversity as a function of time spent in the cave. We attribute large part our success to the narrow focus of our collecting effort on one particular group of organisms and the use of a diverse array of collecting techniques. This focused attention on one group allowed us to collect material ideally preserved, such that species level identification were viable. Many general biodiversity surveys of caves use harsh preservatives that damage the cuticle of springtails and digest the specimens in this order. Damaged individuals are often impossible to identify and thus have a negative effect on the resolution of many general studies.

It is telling about the general state of our knowledge of the springtail fauna of Illinois that leaf litter samples collected inside caves, at the entrance, have yielded three new species and six new state records of what are clearly surface leaf litter species. Although the richness of the collembolan fauna in Illinois appears to be among the most complete for any of the continental states, it is clear from our narrowly focused survey that much additional work is needed to truly understand the springtail fauna of Illinois. For example, 20 species were ranked S1 (i.e., the species has been reported from five or fewer localities in Illinois), while at the other extreme five of species were ranked as G5 because they are widespread across North America or beyond. This suggests that past studies have failed to report even some very common species. Using the numbers of common species between the present study and the studies of Peck and Lewis (1978) and Lewis *et al*. (2003) we can safely speculate that the total number of species occurring in caves of the Salem Plateau could be more than twice what we have recorded in the present study (Figure 29), and we are certain to find many more species when caves of other Illinois karst regions are closely examined, using methods designed to secure springtails. Such additional surveys also seem very likely to discover additional species new to science.

Finally, it is also of some concern that the only member of the *Sinella-Coecobrya* complex, a complex of typically troglophile or troglobiont species, is an invasive species. It is not clear what the role of introduced species might be in fragile ecosystems such as cave. Caves in the

A.

B.

Figure 39. Heavy visitation at Illinois Caverns, Monroe County, Illinois on 24 September 2009. A. Part of a large school group preparing to enter the cave – at least 33 people are visible in this picture. B. Part of a larger group moving through Illinois Caverns – at least 29 people are visible in this picture.

Shawnee Hills, just south of the Salem Plateau region, harbor three native species of troglophiles/troglobionts in the genus *Sinella* (Christiansen and Bellinger 1998). It is always possible that the introduced form could move south, invade caves with native species and displace them to extinction.

Distribution, abundance, diversity, and microhabitats

The nature, extent and accessibility of the eight caves varied considerably. Spider Cave and Stemler Cave frequently flood to the ceiling, and such "pipe full" conditions may contribute to the depauperate fauna we encountered. Illinois Caverns and Hidden Hand Cave receive heavy visitation, and trampling by visitors (Figure 39) may have a negative impact on the fauna of these caves. Pautler Cave was likely under sampled due to difficulties we experienced in accessing portions of the cave which may have provided better habitat. In general, however, we have demonstrated that a remarkable diverse assemblage of Collembola occur in caves of Illinois' Salem Plateau, and we collected many springtail species which have not previously been recorded from Illinois caves, including eight species that appear to be new to science.

The single site endemic springtail *Pygmarrhopalites madonnensis* (Zeppelini & Christiansen, 2003), was not recovered from any of the caves we sampled (none of which were the type locality for the species), further validating its recent listing as state endangered in Illinois.

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