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Biological soil crust and vascular plant communities in a sand savanna of northwestern Ohio[1]

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NEHER, D. A., T. L. WALTERS, E. TRAMER, T. R. WEICHT, R. M. VELUCI, K. SAIYA-CORK (Department of Earth, Ecological and Environmental Sciences, University of Toledo, Toledo, OH 43606) S. WILL-WOLF (Department of Botany, University of Wisconsin, 430 Lincoln Drive, Madison, WI 53706-1381), J. TOPPIN, J. TRAUB (Whitehouse, Ohio 43571-9803) AND JOHANSEN, J. R (Department of Biology, John Carroll University, University Heights, Ohio 44118). Biological soil crust and plant communities in a sand savanna of northwestern Ohio. J. Torrey Bot. Soc. 130:244–252. 2003.—A survey of biological crust components (bryophytes, lichens, chlorophyta, bacteria), soil fauna (nematodes, collembolans, mites) and vascular plants was conducted in a dry sand savanna in northwestern Ohio between 1995 and 2001. In soil, six free-living chlorophytes and seven cyanobacteria taxa were identified. Chlorophyta were more abundant than cyanobacteria with *Desmococcus olivaeus* and *Stichococcus bacillaris* being the most common species. For bryophytes, the most common species were *Polytrichum piliferum* and *Ceratodon purpureus*, and for lichens, *Cladonia* species. Notably, we found lichen species in the crusts have chlorophytes not cyanobacteria, as their photobionts. Twenty-seven families and 29 genera of nematodes, and four collembolan species were identified in crust and rhizosphere communities. Autotrophic denitrifying bacteria were not detectable with the method employed. The biological crust occurred among a vascular plant community with *Robinia pseudoacacia*, *Rubus flagellaris*, *Bromus inermis*, and *Vicia villosa* as the most abundant tree, shrub, graminoid, and non-grass herbaceous plants, respectively. To our knowledge, this is the first report of microbial crust community composition in xeric patches of northwestern Ohio. Moreover, our report includes a report of soil nematode or collembolan communities associated with soil biological crust communities.

Key words: Acari, biological soil crusts, bryophytes, collembolans, cyanobacteria, flora, lichens, mites, nematodes, Oak Openings, sand savanna.

Biological soil crusts are complex mixtures of lichens, mosses, liverworts, fungi, cyanobacteria, eukaryotic algae, and heterotrophic bacteria. They have been found on all seven continents and in all climatic regions (Belnap and Lange 2001). They persist in environments that do not support higher organisms and often are the first colonizers of new or disturbed habitats. For example, algae are the first organisms to recover after fires and can form distinct crusts within a few years (Johansen and Rayburn 1989). Many algal and bacterial components of biological crusts are diazotrophic and photosynthetic, making crusts a source of fixed N and C. In areas where soils are infertile, native plants and soil microflora that are critical to plant survival often rely on intact biological crusts to provide sufficient water and nutrient flow. Biodiversity and ecological roles of these crusts have been described extensively for arid and desert ecosystems (Evans and Johansen 1999) but not for hab-

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Table 1. Species of cyanobacteria, eukaryotic algae, mosses, and lichens identified at the Badger Barren microbiotic crust site.

CYANOBACTERIA
Cyanothece aeruginosa (Näg.) Komárek
Leptolyngbya spp.
Microcoleus vaginatus (Vauch.) Gom.
Oscillatoria ornata Kütz. ex Gom.
Oscillatoria subbrevis Schmidle
Symploca muscorum (Ag.) Gom.
Trichormus sp.
CHLOROPHYTA
Desmococcus olivaceus (Pers. ex Ach.) Laundon
Fottea pyrenoidosa Broady
Fottea stichococcoides Hindák
Stichococcus bacillaris Näg.
Ulothrix tenuissima Kütz.
Vaucheria sp.
BRYOPHYTA
Ceratodon purpureus (Hedw.) Brid.
Polytrichum commune Hedw.
Polytrichum juniperinum Hedw.
Polytrichum piliferum Hedw.
Steerecleus serrulatus (Hedw.) Robins
LICHENS
Cladina arbuscula (Wallr.) Hale & Culb.
Cladina rangiferina (L.) Nyl
Cladonia cervicornis subsp. *verticillata* (Hoffm.) Ahti
Cladonia cristatella Tuck.
Cladonia cf. *gracilis* (L.) Willd.
Cladonia grayi G. Merr. ex Sandst.
Cladonia piedmontensis G. Merr.
Cladonia pyxidata (L.) Hoffm.
Cladonia polycarpoides Nyl.
Cladonia rei Schaerer
Diploschistes muscorum (Scop.) R. Sant.
Trapeliopsis granulosa (Hoffm.) Lumbsch

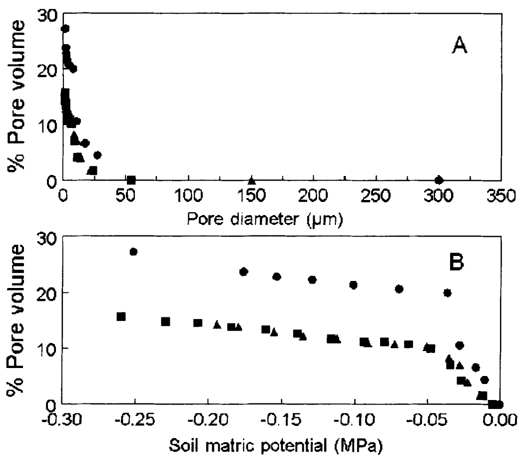

Fig. 1. Pore size distribution (A) and water release curves (B) for each of three core samples taken at Badger Barren. Soil water is represented by matric potential (MPa) with 0 for saturated soils and dry for progressively negative numbers and pore diameter represented by micrometers (μm). Note that solid circles have higher pore volume and, consequently, delayed water release compared with other two samples.

itats in regions where the prevailing climate is mesic and temperate. We report crust and vascular plant community composition in an oak savanna of northwestern Ohio. Preliminary reports of biological soil crust occurrence in our study area and the northeastern region of the United States have been published previously (Rosentreter and Belnap 2001; Will-Wolf and Stearns 1999).

Materials and Methods. STUDY AREA. We conducted a survey of species composition in the Badger Barren in Oak Openings Preserve Metropark (Swanton Township, Lucas County, 41°42′38″N, 83°41′8″W) in northwestern Ohio between 1997 and 2001. The site is classified as a dry sand savanna (sand barren) with acidic sandy soils, low available water holding capacity, and low inorganic nutrient availability (Will-Wolf and Stearns 1999). The habitat occurs on a belt of fine quartz sand that extends from Henry County in northwest Ohio to Monroe County in southeast Michigan. The sand belt near the Oak Openings Preserve Metropark (Oak Openings) is approximately 8 km wide. It consists of dunes that reach a maximum height of 10 m, and was deposited about 12,500 years ago by the postglacial lakes Arkoma, Warren and Lundy (Kelley and Farrand 1967). The soils are psamments, a suborder of Entisols, pH 4.0–5.4, and are comprised of 91–94% sand, 0 to 3.0 μg of ammonium per g of dry soil, and 3.2 to 12.2 μg nitrate per g of dry soil (D. Neher et al., *unpub. data*). Pore size distribution and water release curves (Fig. 1) are typical for sandy soils (Hillel 1982) and average bulk density is 1.51 Mg · m^{-3} for all samples. The bedrock is dolomite (limestone) with pH of 7–8, which is 15–24 m below the surface. Layered above the dolomite is glacial till with 50% nonexpandable (kaolinite) clay content, which lies 0–6 m below the surface. Similar habits cover 44,030 km^2 across seven states (OH, MI, IN, IL, IA, MN, and WI), plus portions of Canada (Will-Wolf and Stearns 1999).

According to records filed in the Lucas County Courthouse, land that included Badger Barren was first purchased by European settlers in 1838. It is likely that clearing of the primeval vegetation and farming of the area began soon thereafter. Subsequently, the land passed through a series of owners. Aerial photos of the area extending back to 1940 indicate the land was being farmed intensively. Finally, the Barren was included in a 24.7 ha land parcel purchased by the Toledo Area Metroparks in 1951 (J. Jaeger, *pers. comm.*). Subsequent aerial photos and park records indicate the Barren, then, was allowed to revert to natural vegetation.

Old records and debris suggest that a house once was located in the southern portion of Badger Barren, and there appear to be two small buildings present in the 1940 and 1957 aerial photos. This residential influence may account for the presence of several of the weedier plant species in the Barren. During fall 1994 and spring 1995, small plots were burned in the Barren as part of a study of the short-term effects of low intensity fire on the vegetation. The total area burned was only about 150 m^2. Otherwise, fire has been excluded from the Barren. Also, in 1995, Metroparks field crews removed some of the woody alien and invasive native species from the central portion of the Barren and many of the pines and aspens that were encroaching from the forested edges. This management led to the local extirpation or reduction of some species.

DATA COLLECTION. Biodiversity surveys of the area were conducted between 1995 and 2001; they included biological crust components (bryophytes, lichens, chlorophyta, bacteria), soil fauna (nematodes, collembolans, mites) and vascular plants. Crust components were collected with a small trowel in the upper 3 cm of the soil. Eukaryotic algae were identified to species according to Ettl and Gärtner (1995) and Prescott (1962), and cyanobacteria according to Geitler (1932) and Komárek and Anagnostidis (1999). Bryophytes were identified using keys in Crum and Anderson (1981), with nomenclature updated after Anderson et al. (1990). Lichens were identified by Will-Wolf following nomenclature of Esslinger and Egan (1995), with updates from the Esslinger (2002) web page, and voucher specimens are deposited in the Wisconsin State Herbarium (WIS) at University of Wisconsin-Madison.

To quantify populations, soil from the top 1 cm was dilution plated (10^{-3} dilution) onto 1.5% agar solidified Bold's Basal Medium (Bold and Wynne 1978), enhanced with 40 ml soil water and 30 mg sodium metasilicate. Plates were kept in an environmental chamber with a 12-hour photoperiod, temperatures of 12–22 C and fluorescence rate 43.2 W • m^{-2}. Algal colonies that grew were isolated into unialgal culture and transferred to fresh plates. Cyanobacteria were isolated on BG-11 medium (Bold and Wynne 1978) with 1% agar with a thin layer of diluted BG-11 liquid medium (half strength). Chlorophyta and cyanobacteria were directly enumerated in fresh soil samples using epifluorescence microscopy (Johansen and Rushforth 1985). Chlorophyll *a* was determined using a DMSO extraction method modified for soil crust studies (Johansen et al. 2001).

Soil fauna were extracted from intact soil cores (5 cm diameter, 7.5 cm deep) using Cobb's sieving and gravity for nematodes (Neher and Campbell 1994; Neher et al. 1995) and heptane flotation (Guers et al. 1991; Walter et al. 1987) for microarthropods. Soil nematodes were identified to taxonomic family according to Bongers (1987), Nickle (1991), Hunt (1993), Goodey (1963), Maggenti (1983; 1991), and Maggenti et

Table 2. Nematode families and their relative abundance of total individuals identified at Badger Barren.

Nematode	% (n = 345)[a]	Barren	Grass	Forest edge
Bacterivores				
Bunonematidae	2.0			x
Cephalobidae	36.2	x	x	x
Plectidae	9.9	x	x	x
Panagrolaimidae	1.7			x
Prismatolaimidae	5.2		x	x
Rhabditidae	4.9			x
Fungivores				
Anguinidae	0.9			x
Aphelenchidae	0.3	x		
Aphelenchoididae	4.3	x	x	x
Diptherophoridae	0.3			x
Leptonchidae	1.8	x		
Tylenchidae	6.7	x	x	x
Herbivores				
Belondiridae	0.3		x	x
Criconematidae	2.9	x	x	x
Dolichodoridae	1.2			x
Hoplolaimidae	0.9	x	x	x
Leptonchidae	1.7	x	x	x
Longidoridae	1.4	x	x	
Nordiidae	0.6	x		x
Pratylenchidae	8.4	x	x	x
Trichodoridae	1.2	x	x	
Tylodoridae	0.6			x
Omnivores				
Dorylaimidae	0.9		x	
Qudsianematidae	1.7	x	x	x
Thornenematidae	0.3			x
Predators				
Aporcelaimidae	2.9	x		x
Discolaimidae	0.3	x		
Nygolaimidae	0.3		x	

[a] Identity of 2.0% were not determined.

Table 3. Collembolan species at Badger Barren.

Family	Species
Sminthuridae	*Sminthurus butcheri* Snider 1969
Isotomidae	*Folsomina onychiurina* Denis 1931
	Isotoma (Pseudisotoma) *monochaeta* Kos 1942
Tullbergiidae	*Tullbergia silvicola* Folsom 1932

al. (1987) and taxonomic families assigned to a trophic group according to Yeates et al. (1993). Taxonomy of collembolans followed Christiansen and Bellinger (1998). Other orders of microarthropods were identified according to Dindal (1990) and Kranz (1978).

Numbers of bacteria were measured using soil dilution plating on soil extract agar media. Numbers of fungi and actinomycetes were counted using rose bengal-starch-casein-nitrate and colloidal chitin mineral salt agar media, respectively. A most probable number (MPN) method using diphenylamine as a color indicator was employed to enumerate denitrifying bacteria, which produce enzymes for conversion of nitrate to nitrite and nitrite to ammonia in soil. Numbers of protozoa were estimated also using a MPN method, with soil extract as the diluent and each dilution was replicated six times. Standardized methods were used for enumerating soil microbes and protozoa (Alef and Nannipieri 1995; Weaver et al. 1994).

Vascular plants were collected using bi-weekly meander surveys from 1995 to 1997 and monthly meander surveys until 2002. All records were vouchered with the specimens deposited in the herbarium at the Cleveland Museum of Natural History (CLM). Nomenclature followed Cooperrider et al. (2001).

Results. There were six free-living Chlorophyta and seven cyanobacteria taxa identified. Of these, chlorophytes were clearly dominant, particularly the coccoid taxa *Desmococcus olivaceus* and *Stichococcus bacillaris*. Cyanobacteria were present only in small numbers, and consisted mostly of nonheterocystous filaments. Notably absent were any *Nostoc*, *Scytonema*, or *Tolypothrix* species, which are common elements of desert crusts in the western United States (Belnap and Lange 2001). Bryophytes included one species of *Ceratodon*, three species of *Polytrichum*, and one species of *Steerecleus*. Of 12 lichen species, eight were *Cladonia* species and two were *Cladina* (Table 1). For bryophytes, the most common species were *Polytrichum piliferum* Hedw. and *Ceratodon purpureus*, and for lichens, *Cladonia* species.

Mean abundances of soil microflora per gram of dry soil were as follows: 2.1×10^5 cyanobacteria, 6.8×10^5 chlorophyta, 4.2×10^4 to 6.4×10^5 fungi, 5.8×10^5 to 2.8×10^6 actinomycetes, and 4.0×10^6 to 3.6×10^7 bacteria. Autotrophic denitrifying bacteria were not detectable with the method employed. Other eukaryotic algae, such as diatoms, tribophytes, eustigmatophytes, and euglenids, were not observed in the enrichment cultures. Mean abundances of soil microfauna per gram of dry soil were: < 1.0 springtails, < 1.0 mites, 175 nematodes, and 3.1×10^3 protozoans, Twenty-seven families and 29 genera of nematodes (Table 2), and four collembolan species (Table 3) were identified in crust and rhizosphere communities.

On a macro-vegetational scale, the biotic community is an eastern sand savanna with a mixture of isolated trees, forbs, grasses, shrubs and saplings. Specifically 20 tree, 9 shrub, 34 graminoids, and 49 species of non-grass herbaceous plants were identified (Table 4). The most abundant tree, shrub, graminoid, and non-grass herbaceous plants were *Robinia pseudoacacia*, *Rubus flagellaris*, *Bromus inermis*, and *Vicia villosa*, respectively.

Discussion. To our knowledge, this is the first report of microbial crust community composition in xeric patches of northwestern Ohio. At our site, mosses cover more surface area than do lichens or cyanobacteria (Veluci 2002). This contrasts with the composition of crusts in both Florida shrublands where algae and cyanobacteria dominate rather than mosses or lichens (Hawkes and Flechtner 2002) and arid land ecosystems where lichens or cyanobacteria are usually dominant (Rosentreter and Belnap 2001). The predominant moss species is *Polytrichum piliferum*, forming a continuous cover in some undisturbed areas (e.g., beneath shrubs), but generally occurring as fragmented crust. *Polytrichum* is a moss present in Ohio crust communities but is not found in other crust com-

Table 4. List of vascular plant species along with annotations on nativeness (*: alien species follows Cooperrider et al. 2001), relative dominance (A: abundant, C: common, F; frequent, O: occasional, S: scarce, L: local, X: extirpated; adapted from Voss, 1972), and rarity (SE: state endangered, ST: state threatened, SPT: state potentially-threatened, according to ODNR-DNAP, 2002).

TREES

Acer negundo L. [S]
Acer rubrum L. [LO]
Amelanchier arborea (F. Michx.) Fern. [X]
Betula populifolia Marshall [S]
Gleditsia triacanthos L. [X]
Juniperus virginiana L. [S]
Malus pumila Mill [*X]
Nyssa sylvatica Marshall [X]
Pinus strobus L. [O]
Pinus sylvestris L. [*S]
Populus deltoides W. Bartr. ex Marshall [LO]
Populus tremuloides Michx. [LO]
Prunus americana Marshall [X]
Prunus serotina Ehrh. [S]
Quercus velutina Lam. [O]
Rhus copallina L. var. *latifolia* Engl. [O-LC]
Rhus glabra L. [LO]
Rhus typhina L. [LO]
Robinia pseudoacacia L. [*F]
Sassafras albidum (Nutt.) Nees [LC]

NON-GRAMINOID HERBS

Achillea millefolium L. [O]
Alliaria petiolata (M. Bieb.) Cavara & Grande [*S]
Ambrosia artemisiifolia L. [O]
Apocynum cannabinum L. [LO]
Arabidopsis thaliana (L.) Heynh. [*S]
Asclepias amplexicaulis Sm. [S; SPT]
Asclepias tuberosa L. [S]
Asparagus officinalis L. [LO]
Botrychium dissectum Spreng. [O]
Botrychium matricariifolium (Doll) A. Braun ex W.D.J. Koch [LO]
Calystegia sepium (L.) R. Br. *sensu lato* [O-F]
Cardamine hirsuta L. [*S]
Chenopodium album L. [*O]
Cirsium discolor (Muhl. ex Willd.) Spreng. [S]
Conyza canadensis (L.) Cronq. [O-F]
Coreopsis tripteris L. [O]
Desmodium canadense (L.) DC. [O]
Desmodium paniculatum var. *dillenii* (Darl.) Isely [S]
Desmodium sessilifolium (Torr.) Torr. & A. Gray [LO; SE]
Dianthus armeria L. [*C]

SHRUBS

Comptonia peregrina (L.) J. M. Coulter [LO: ST]
Cornus drummondii C. A. Mey. [LO]
Eleagnus umbellata Thunb. [*O]
Rosa multiflora Thunb. ex Murray [*LS]
Rubus flagellaris Willd. *sensu lato* [A]
Smilax glauca Walter [LC]
Spiraea alba DuRoi [LS]
Spiraea tomentosa L. [LO]
Toxicodendron radicans (L.) Kuntze [LO]

GRAMINOIDS

Agrostis hyemalis (Walt.) BSP. [O-F]
Agrostis perennans (Walt.) Tuck. [LO]
Andropogon virginicus L. [O]
Aristida purpurascens Poir. [LC; SPT]
Bromus inermis Leysser. [*LA]
Bromus japonicus Thunb. ex Murray [*LF]
Bromus tectorum L. [*F]
Carex muhlenbergii Shkuhr. ex Willd. [C]
Carex pensylvanica Lam. [LS]
Carex rugosperma Mack. [C]
Carex swanii (Fern.) Mack. [F]
Cenchurus longispinus (Hackel) Fern. [O]
Cyperus esculentus L. [LF]
Cyperus lupulinus ssp. *macilentus* (Spreng.) Marcks [C]
Cyperus strigosus L. [O]
Danthonia spicata (L.) F. Beauv. ex Roem. & Schultes [O-F]
Digitaria ischaemum (Schreb.) Muhl. [*O]
Digitaria cognata (Schultes) Pilg [F]
Elymus repens (L.) Gould [LC]
Eragrostis cilianensis (All.) Vognolo ex Janch. [*O]

Table 4. Continued.

Equisetum arvense L. [O]	*Eragrostis spectabilis* (Pursh) Steudel [F]
Equisetum hyemale L. var. *affine* (Engelm.) A. A. Eaton [S]	*Festuca ovina* L. [*O]
Equisetum laevigatum A. Braun [O]	*Juncus tenuis* Willd. [O]
Erigeron strigosus Muhl. ex Willd. [O]	*Panicum acuminatum* var. *fasciculatum* (Torr.) Lelong [F]
Euphorbia corollata L. [O]	*Panicum clandestinum* L. [LO]
Fragaria virginiana Duchesne [F]	*Panicum columbianum* Scribn. [O]
Galium aparine L. [LS]	*Panicum depauperatum* Muhl. [O]
Hedeoma hispida Pursh [F-C; ST]	*Panicum oligosanthes* var. *scribnerianum* (Nash) Fern. [C]
Helianthemum canadense (L.) Michx. [LC; ST]	*Paspalum setaceum* var. *ciliatifolium* (Michx.) Vasey [C]
Krigia virginica (L.) Willd. [C; ST]	*Phleum prateuse* L. [*O-LC]
Lechea villosa Elliot. [S; SPT]	*Poa compressa* L. [*O]
Lepidium campestre (L.) R. Br. [*O]	*Poa pratensis* L. [*LF]
Lepidium virginicum L. [C]	*Setaria viridis* (L.) P. Beauv. [*O]
Lespedeza capitata Michx. [F]	*Sporobolus cryptandrus* (Torr.) A. Gray [LC]
Malva neglecta Wallr. [*LO]	*Tridens flavus* (L.) A. Hitchc. [LS]
Mirabilis nyctaginea (Michx.) MacM. [*O]	*Triplasis purpurea* (Walt.) Chapman [LS; SPT]
Mollugo verticillata L. [*F]	*Vulpia octoflora* (Walt.) Rydb. var. *glauca* (Nutt.) Fern. [F]
Monarda fistulosa L [S]	
Oenothera laciniata Hill [O-F]	
Oxalis dillenii Jacq. [F]	
Physalis heterophylla Nees [S]	
Plantago aristata Michx. [*F]	
Polygala polygama Walter [S; ST]	
Potentilla recta L. [*LF]	
Potentilla simplex Michx. [O-F]	
Pycnanthemum virginianum (L.) T. Durand & B. D. Jacks. ex B. L. Rob. & Fernald [F]	
Rudbeckia hirta L. var. *pulcherrima* Farw. [O]	
Rumex acetosella L. [*C]	
Silene antirrhina L. [LS]	
Solanum carolinense L. [O]	
Solidago canadensis var. *hargeri* Fern. [O]	
Taraxacum officinale Weber ex F. H. Wigg. [S]	
Tragopogon dubius Scop. [*O]	
Trichostema dichotomum L. [LO]	
Triodanis perfoliata (L.) Nieuwl. [LO]	
Verbascum thapsus L. [*F]	
Veronica arvensis L. [*LS]	
Vicia villosa Roth [*A]	
Viola sagittata Aiton [S]	

munities in North America. *Ceratodon purpureus* is the next most common moss, occurring widely at the site, and also common in many arid crust communities in western North America. In a few places, *P. piliferum* grows as single plants scattered within clumps of *C. purpureus*, but the two species otherwise occur as separate homogeneous patches. Several dense areas of *P. commune* occur in shallow depressions. The other reported moss species are sparsely distributed at the site. *Pleurozium schreberi* (Brid.) Mitt., a species associated with biological soil crusts on the pine barrens in New Jersey (Rosentreter and Belnap 2001), forms extensive cover at nearby sites within the Oak Openings region.

Although green algae dominate the crust, several cyanobacteria species were present. In contrast to our site, soil crusts on the surface of sandy barrens in New Jersey and Michigan are dominated by cyanobacteria, including both *Nostoc* sp. and *Microcoleus vaginatus* (Rosentreter and Belnap 2001). Green-algae typically dominate the algal communities of moss-dominated crusts (Johansen et al. 1993), and soils of the eastern United States are dominated by green algae even in the absence of crust formation (Grondin and Johansen 1995). Relatively abundant mosses and chlorophytes are likely the primary contributors to soil chlorophyll *a,* which is more abundant than reported for the Mojave, Chihuahuan, and Great Basin Deserts (Johansen 2001, Johansen et al. 2001). Chlorophyll *a* in Oak Openings surface soils ranged from 2,400 to 18,600 ng chlorophyll $a \cdot g^{-1}$, and was inversely proportional to soil pH ($P = 0.02$). Hawkes and Flechtner (2002) suggest a positive correlation between chlorophyll *a* content and soil moisture.

The lichen species in the crusts have chlorophyta, not cyanobacteria, as their photobionts. Schulten (1985) found a similar predominance of lichens with chlorophyte phycobionts in an Iowa sand prairie crust community, even finding many of the same lichen species. This contrasts with crust communities in New Jersey and Michigan, where cyanolichens, *Collema* spp., are of major importance (Rosentreter and Belnap 2001). *Cladina* and *Cladonia* species with growth forms equivalent to our species were also found in New Jersey crust communities. Studies of eastern USA soil crust communities are so few and limited that interpretation of these differences is difficult. Taylor (1967, 1968) reported nine of the 12 lichen species we found, with four in northwestern Ohio, and noted that barrens-like vegetation is a good place to hunt for soil lichens, without recognizing the soil crust community as a distinct entity. Likely, there are more lichen species to be found in soil crust communities of northwest Ohio savannas (Will-Wolf, *pers. comm.*), and quantitative surveys await the future. In well-studied soil crust communities in arid western USA, more disturbed and early successional soil crust communities have fewer species and are dominated by cyanobacteria and cyanolichens, while less disturbed and later successional communities have more species and strong representation of lichen species having chlorophyte photobionts (Rosentreter and Belnap 2001; Rosentreter and Eldridge 2002). Some of the algal and cyanobacteria species reported for the Oak Openings also occur in western deserts, notably *Microcoleus vaginatus*, *Desmococcus olivaceus*, and *Stichococcus bacillaris.*

Moreover, our report includes a report of soil nematode or collembolan communities associated with soil biological crust communities (Neher 1999). Mite communities in crusts have been characterized in arid landscapes (Belnap 2001). Nematodes, Collembola and mites (oribatid, prostigmatid and astigmatid) are known to consume lichens as food (Lawrey 1987; Seyd and Seaward 1984). This is one of the first reports of collembolan species in the state of Ohio. The closest report is for collembolan species in Great Lakes region in Wisconsin (Rebek et al. 1999). Purrington et al. (1991) have studied collembolans taxonomically in Ohio but not conducted a formal ecological survey.

The history of Badger Barren and the surrounding area exerts the greatest influence on the present floral diversity. Prior to the cessation of farming of the Barren, second-growth forest had almost completely surrounded the Barren. This may have effectively isolated the developing Barren from recolonization by many sand barren species. Portions of the Barren with the greatest percent vegetative cover are dominated by alien C_3 grasses or a combination of *Rubus flagellaris*, *Vicia villosa* and *Fragaria virginiana*. It is unknown whether this area was planted for pasture or soil stabilization after abandonment, but the presence of these species suggests this may have been the case. The more open sandy areas within the sand barren have a vascular flora dominated by *Aristida purpurascens*, *A. longispica*, *Helianthemum canadense*, *Rumex acetosella* and *Carex rugosperma*. The woody component is dominated by *Rhus copallina* var.

latifolia and saplings *Sassafras albidum* and *Robinia pseudacacia*. Several open-grown *Quercus velutina* are the only large trees more than 50 cm DBH at a density of 1.5 per ha.

In comparison to typical eastern sand savanna of Will-Wolf and Sterns (1999) and other area barrens or 'balds', the shrub component of Badger Barren lacks ericoid shrubs and *Ceanothus americanus* L. Notably absent from this barren are the bluestem grasses and associated taxa, *Pteridium aquilinum* (L.) Kuhn, *Lupinus perennis* L., *Comandra umbellata* (L.) Nutt. and *Euphorbia corollata* L Not only are they normally present in eastern sand savannas, these are typical species throughout the dry regions of the Oak Openings. The absence of these species is caused possibly by the isolation of the Barren during revegetation and the exclusion of fire during most of this period. Other typical Eastern barrens species such as *Asclepias amplexicaulis*, *Lespedeza capitata*, *Helianthemum canadense* and *Carex pensylvanica* were present in expected densities.

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