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PROCEEDINGS OF THE INDIANA ACADEMY OF SCIENCE

The *PROCEEDINGS* OF THE INDIANA ACADEMY OF SCIENCE is a journal dedicated to promoting scientific research and the diffusion of scientific information, to encouraging communication and cooperation among scientists, and to improving education in the sciences.

THE INDIANA ACADEMY OF SCIENCE

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Cover: In 2017 a lichenologist from the New York Botanical Garden inventoried a 900 acre area of core forest in Brown and Monroe Counties, IN. The area was delimited by the Indiana Forest Alliance as the priority for an "ecoblitz" aimed at documenting *en toto* biodiversity in Indiana forests. The project resulted in the discovery of many lichen species that had not previously been reported from Indiana, and the recognition that most species in the study area were rare (i.e., present in small numbers at few locations). Left: Hickory (*Carya*) trunk with abundant cover of the crustose lichen *Lepraria normandinoides*. Right: Mature beech (*Fagus grandifolia*) with a mosaic of diverse crustose and foliose lichens including the common script lichen (*Graphis scripta*). For additional details on this project, see the article entitled "Lichens and Allied Fungi of the Indiana Forest Alliance Ecoblitz Area, Brown and Monroe Counties, Indiana Incorporated into a Revised Checklist for the State of Indiana" by James Lendemer in this issue. (Photographs by James Lendemer)

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(revised March 2015)

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Figures 1–4.—Right chelicerae of species of *Centruroides* from Timbuktu. 1. Dorsal view; 2. Prolateral view of moveable finger; 3. *Centruroides* holotype male; 4. *Centruroides* female. Scale = 1.0 mm.

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DR. JOHN O. WHITAKER, JR. DISTINGUISHED PROFESSOR OF ECOLOGY AND VERTEBRATE NATURAL HISTORY, AN OLD-TIME NATURALIST PAR EXCELLENCE

Marion T. Jackson[1]: Professor Emeritus of Ecology and Natural History, Indiana State University, Terre Haute, IN 47809 USA

Editor's Note: Periodically the *Proceedings of the IAS* publishes biographical articles honoring living members of the Indiana Academy of Science. These scientists have all served the Academy with great distinction and have made valuable contributions in their respective fields of scientific inquiry. Dr. John O. Whitaker, Jr., Professor Emeritus in the Department of Biology at Indiana State University has been chosen for this recognition and great honor.

INTRODUCTION

I am honored and exceedingly pleased to have been invited by Dr. Don Ruch of Ball State University to compile the next article in this series, which features the professional life and accomplishments of Dr. John O. Whitaker, Jr. – my career-long colleague, close friend, and confidant (Fig. 1). John's professional career of well more than 50 years, which continues unabated at this writing, features his continuing excellence in all three of the basic aspects of academic endeavor: namely *Teaching, Research*, and *Publication*. My daunting task is how to do justice to a career that has excelled as remarkably in all three areas of scientific activity for so many decades.

Without question, John Whitaker's forte has been research and publication, having produced more than 400 scientific articles, reviews, book chapters, and books in print since his 1957 article in *Entomological News*. Rare is the journal featuring vertebrate natural history or ecology that has not published at least one of his articles.

AN EARLY BEGINNING

John had the distinct advantage of beginning his career interest in natural history at a very young age. He was born in Oneonta, in upstate New York, in 1935 (Fig. 2). As a youth, he was a keen observer of nature and an inveterate collector of outdoorsy things, especially nature objects and organisms. When I first came to know him back in the 1960s, he told me of the museum he started as a child in his parents' basement for his outdoorsy treasures. He even charged his boyhood friends a penny to tour his collection. He told me, with his sly smile, that "he probably made a dime" from the admission fees!

John benefited greatly from his early acquaintance with Robert E. Goodwin, then a graduate student at Cornell, who took him on many field trips and taught him how to make mammal study skins when John was around 12 years old. In his catalog Bob had written REG as the processor, so John followed his example and did the same. A year or so later he realized those were Bob's initials and did not stand for "regular" as he had thought. From then on he used the designation JOW.

When John was in the 8th grade he and his brother Bill traveled with Bob to South Carolina. John brought a copperhead back and promptly took the snake out into his backyard to photograph it. When the neighbor looked over and saw what he was doing she became very upset because she was afraid it was going to get loose and end up in her yard. John's mother, Ruth, was also very afraid of snakes, but never let her son know that.

Around this same time period, John picked up a road-killed skunk and brought it home to process. As might be imagined, it smelled terrible and he took it outside. He picked a good spot to work between his house and the next-door neighbor's garage but the smell remained too terrible to ignore; he threw it out in an old creek bed. John still considers Bob "one of [his] three fathers" (along with JOW, Sr., and his graduate advisor, William J. Hamilton, Jr.).

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Figure 1.—John O. Whitaker, Jr. in the field.

Ever ready for outdoor activity, John regularly accompanied the Ornithology class at Oneonta State Teachers College on their field trips, helping to find and identify birds. It also should be noted that John found time to become the New York high school tennis champion two years in a row, with two different partners (Fig. 3).

Figure 2.—John at home in upstate New York.

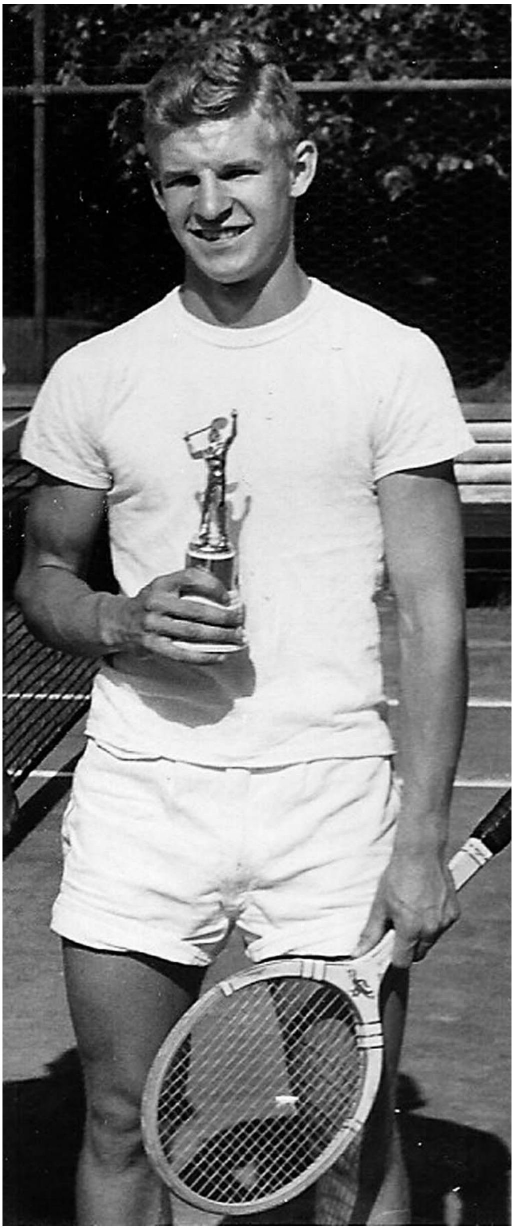

Figure 3.—John Whitaker, New York State high school tennis champion.

Since he was the eldest child in a family of three boys, it was assumed that he would follow in his father's successful dental practice in Oneonta, New York, as a career. His dad had served during World War II as a U.S. Army dentist and was the head of the dental unit at Bowling Field in

Washington, D.C. He had some military notables as patients during his tour of active duty, including Army General George Patton and F.D.R.'s son.

But John O. Whitaker, Jr., had a different objective in mind for his career. One day when he was in eighth grade, he was helping his mother clear the kitchen following a family meal, when she told him abruptly, "John, you know that you don't have to become a dentist if you don't want to." Whereupon he stated matter-of-factly, "Good, then I won't. I would rather go to Cornell University and study Vertebrate Natural History." At that young age, the die was cast for him to become a natural historian, a most fortunate choice, both for him and for that field of study. Although John has examined many teeth of other (non-human) mammalian species, neither John Jr. nor either of his two brothers was to follow their father into dentistry. John, along with his aunt Wanita Whitaker Lewis, his brother Bill, his son Bill, and his daughter Lynne Whitaker O'Brien, did take up John Sr.'s mantle in at least one regard, completing his book on the family genealogy in 1990.

When he was a senior in high school, he met his high school sweetheart, Royce L. Bagg, an education major of Oneonta State Teachers College in New York. They have been married for almost 60 years and are the parents of three successful children, sons John S. and William H. (for Hamilton), both graduate engineers, and daughter Lynne, in communication and education, along with eleven grandchildren, two adopted.

On John's first day at Cornell, he was out looking for birds when he ran into another birdwatcher. That young man, Bob Budliger, turned out to be in John's classes, and later they shared a room. On another occasion he and a different classmate, Jay Eisenhart, went to Pennsylvania to observe a Peregrine Falcon nest near the top of a 300 foot cliff. Jay had brought a rope which they used to descend from the top, and John took pictures of the young birds. It turned out that this was the last nest in the eastern U.S. After they returned to their car, Jay realized he had left his binoculars at the top of the cliff. It was too late to go back to get them, and they had to stay the night. Jay had a sleeping bag, but John ended up with just a burlap bag. Since it was too cold for him to sleep after about 3 a.m., John took the opportunity to jot down the calls of all the birds he heard.

Following his undergraduate study in vertebrate zoology and mammalogy in the Conservation Department at Cornell, John entered graduate work for a PhD at Cornell, under the mentorship of Dr. W.J. Hamilton, Jr., a well-known vertebrate zoologist. John's humor may come in part from his experiences with Hamilton, who was widely known as "Wild Bill," for good reason. John recounts an episode at one of the mammal meetings in springtime where Wild Bill did a little too much imbibing. He was later seen near a pond, trying to croak with the frogs. Even without imbibing, Wild Bill frequently played practical jokes. John recounts stories of Wild Bill, on field trips with the Vertebrate Taxonomy and Natural History classes, finding a salamander, facing sideways to the class, and appearing to throw the creature down his throat and eating it. Of course, he was just throwing it past the side of his head.

John's graduate committee included Dr. R.T. Clausen, plant taxonomist, and Dr. J.G. Franclemont, insect taxonomist – fortunate graduate committee choices indeed, as he already had a great love for studies of food habits. While a student at Cornell, John obtained solid field experience with the New York State Museum and New York Conservation Department. He worked for Paul Connor of the NYSM, and remembers the day that he and Paul encountered some narrow passages in a cave. Paul had an artificial leg, which he removed in order to get through the cave!

As a graduate student John gained teaching experience in a wide array of undergraduate and graduate courses in the natural sciences. His dissertation was on the life history and ectoparasites of the meadow jumping mouse. While Hamilton had advised him to avoid studying ectoparasites, which are difficult to identify, John naturally took this as a challenge and ultimately made it a focus of his life's work.

A PRODUCTIVE CAREER

Following receipt of his doctoral degree in 1962, John had offers from two "Indiana State Colleges" – one in Indiana, Pennsylvania (now Indiana University of Pennsylvania) and one in Terre Haute, now known as Indiana State University (ISU). John accepted the offer from Terre Haute because he thought it had more research potential.

John's first action upon deciding to move to Indiana was to obtain the 12 quadrangle maps of

Vigo County, divide them into 25 × 25 m plots, and then select 500 plots at random. Upon arriving he began trapping mammals in the plots. He also collected fish throughout the county to learn the distribution of the various species. Each Thursday after class he set traps, to be checked on Friday and Saturday and picked up on Sunday. During the process, he wore out "one car – a brand new car," he says with a smile. This intensive study proved useful in both research and teaching; as the reigning expert on distribution of vertebrate species in Vigo County, he passed this knowledge to generations of ISU students at both undergraduate and graduate levels. To this day, he continues to participate in "bioblitzes" around the Midwest.

While at ISU, John's research has covered a wide range of topics. He has published extensively on ectoparasites, food habits, and bats – well over 100 papers on each of these topics – and has authored or co-authored four major books on mammals: *Mammals of Indiana* (two editions, 1982 and 2009), *Mammals of Indiana: A Field Guide* (2010), *The Audubon Field Guide to North American Mammals* (1996), and *Mammals of the Eastern United States* (2nd and 3rd editions, 1979 and 1998). He also served as co-editor of *Habitats and Ecological Communities of Indiana: Presettlement to Present* (2012).

John's work was not restricted to mammals; he published many papers on fish, reptiles, amphibians, and birds, particularly on their food habits and distribution (Figs. 4–7). And his publications are not all about Indiana – or even North America – but cover the world, from Alaska to Indonesia to Zambia to Brazil, as scientists send their collected food samples and parasites to John for analysis. Over 150 ectoparasitic mites were discovered or described by John himself, and at least seven mites actually bear his name!

In 2005, he founded ISU's Center for North American Bat Research and Conservation (now Center for Bat Research, Outreach, and Conservation), whose annual bat festival continues to attract thousands of visitors. Many of his students went on to become college professors themselves, while others work for state agencies, consulting firms, and museums throughout the country. One even became the Chief Ecologist for the country of Uganda.

John has earned many awards during his career. He became a fellow in the American Association for the Advancement of Science in 1968 and in the Indiana Academy of Science in 1976; received the Research and Creativity award from ISU and the H.H.T. Jackson Award from the American Society of Mammalogists, both in 1991; was named a Distinguished Professor at ISU in 1999, and was conferred the Indiana Academy of Science Distinguished Scholar Award in 2011.

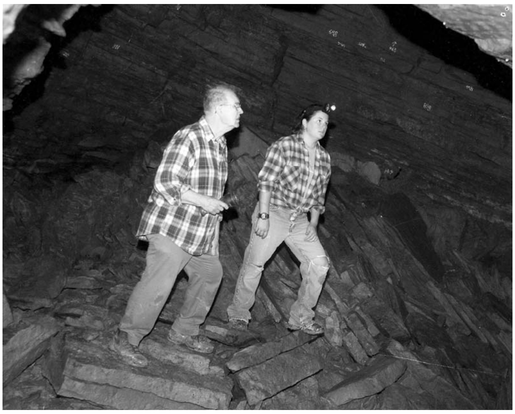

Figure 4.—Surveying for bats in a mine.

In addition to John's incredible performance level in scientific research, publication, and teaching, he is also a popular speaker – on campus, within the community, statewide, and nationally, as he presents his vast knowledge of mammals in general, and bats in particular, to audiences from kindergarten through seniors (Fig. 8). He has given numerous talks to the American Society of Mammalogists and the Indiana Academy of Science. He is a most effective communicator in helping citizens understand the importance of science in our lives.

At least two other important organizations in Terre Haute owe a great deal to John Whitaker. For 20 years he served as president of Terre Haute Recyclers of Waste. During his tenure the objective was to build the operation until it could be sold to a private company. At the time of the sale THROW had about $200,000 in the bank, which was donated to help the ISU recycling center get started. John currently serves on the board of Ouabache Land Conservancy, a land trust.

But it was not all work and no play. For about 20 years there was volleyball at the Whitaker house whatever the season. Unless it was raining at the scheduled starting time, the game was played Saturday and Sunday all year long, and Wednesdays during the summer. At times they had to shovel snow off the court. There were

Figures 5 & 6.—John at work! Figure 5 (top): Seining for fish. Figure 6 (bottom): Collecting snakes.

usually 4–10 people consisting of graduate students, faculty, wives, neighbors; anyone was welcome. The games allowed students and faculty to know each other as individuals and not just as student or faculty member. And as Dave Rubin, John's first graduate student, says, "Most acquaintances don't know John's humorous side unless they get to know him well. On the outside, to most people, he seems very serious all the time. Under the right circumstances, he can joke and kid with the best."

John's most impressive scientific productivity over several decades is a product, in part, of his enormous capacity for sustained work during long hours, as well as his goal for completing all tasks as efficiently and quickly as possible. John's zeal for efficiency required several techniques to increase his work output, some innate, some learned.

Figure 7.—John working in the field with a bat detector.

Likely his greatest increase in work output stemmed from his lack of need to sleep in amounts typical for most adults. He frequently related that he usually did not go to bed on most nights until 11:00 PM or midnight, but then he typically would wake up sometime between 5:00 and 6:00 AM, whereupon he would arrive at his ISU office by 6:30, thereby increasing his usual work day by 2–4 hours daily. By such a schedule, and needing only 4–5 hours' sleep daily, he accomplished 1½–2 days more work per week than most university faculty members.

Another habit that John perfected was to speed walk, with lengthy strides for a relatively short person, to decrease transit time. He also rarely wastes steps by walking a longer distance than is necessary to get where he is going. One day, when we were both new faculty at ISU, we were going to the Life Science departmental office to get our mail. I started to go around the corridor one way when John said, "Let's go around the rectangle the other way, it's shorter." When I looked at him quizzically, he said, "When I came here, I stepped off the distances both ways and it is three steps shorter this way." That little experiment saved him six steps per round trip to the mailbox, and likely saved him a few thousand miles of walking in his 50 years at ISU! Thus, I began to understand how he accomplished so much each year.

He was equally conscious about saving time, as saving distance. He always travelled light on field trips, placing only one change of clothes in a grocery bag for himself, thereby saving time packing and unpacking. Likewise he often signed his name as JOW, instead of John O. Whitaker,

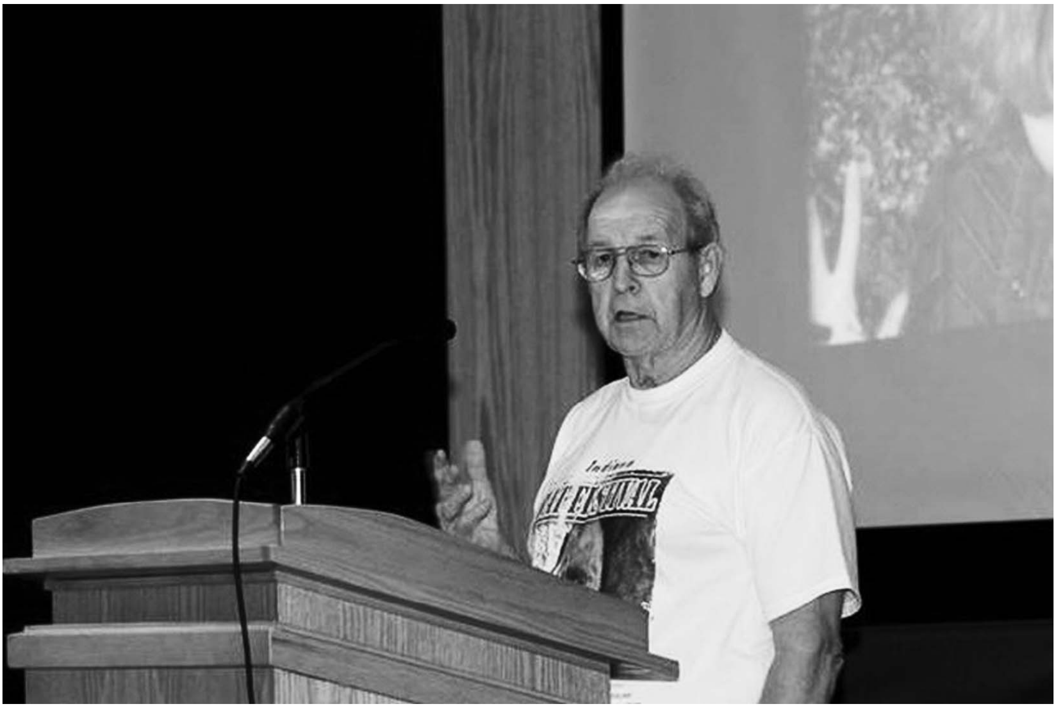

Figure 8.—John lecturing at the Bat Festival.

Jr., so much more time and space efficient! Never in my career have I encountered another person having JOW for initials. We all joked on field trips that someone shouting "JOW!" would put the fear of death into all surrounding small mammals in his vicinity, thereby increasing his efficiency at trapping!

In spring 1965, Dave Rubin, Earl Zimmerman, and John were headed out to collect salamanders in the mountains of North Carolina. About the time they left Murphy, John realized that they had no food with them except for a half a can of orange drink and one cookie. John suggested they go back and get supplies, as they were going to be in the mountains for two days. Dave and Earl looked at the map, found that there were a couple of hunting lodges along the way, and concluded that food would be available there. John said they could continue if they insisted, but if there was no food on the way he was going to proceed with the original plan to be gone for two days. When they arrived at their destination, nothing was open anywhere around. The three subsisted on their meager supplies.

Dave recalls that John's sense of humor was as untiring as his physical and mental capabilities. Returning at the end of the trip, in spring 1965, they drove the ISU VW microbus (later known as the "JOW-mobile") all night in driving rain to get back to Terre Haute. It was raining so hard that they were even finding cave salamanders (*Eurycea lucifuga*) among the herps on the road as they drove through Tennessee and Kentucky. They were so tired that all, including John, got "slap happy" and basically laughed the whole way home. Dave further notes that the trip was made because he and Earl were taking a Special Topics class from John in which they reviewed Richard Highton's 1962 "Revision of North American salamanders of the genus *Plethodon*." That class and that field trip led to his working, with John as advisor, on the *Plethodon jordani* complex for the first PhD out of the Life Sciences Department at ISU.

Stories like this helped establish that when on field trips, especially with his graduate students, John would not stop any more than absolutely necessary. That would enable more time for field observation, or collecting organisms, data, etc., hence greater field trip efficiency. One of the students, having heard this, always brought along plenty of snacks. Subsequently, they really didn't need to stop much.

Besides trips associated with classes, as John describes in his teaching philosophy (below), his graduate students often went out in the field with him outside of classes. Those experiences contributed much to their development as biologists and as future educators. Dave Rubin remembers many such experiences in addition to the North Carolina trip described above. Graduate students, would often go out with John and Dale Wallace in the mid-1960s as they conducted their survey of the fishes of Vigo County. On one of those trips, they were seining in one of the sloughs in the southern part of the county and were in the water almost up to their armpits, way above the top of their hip boots, trying to drag the net forward. They were a funny sight and the humor of it was not lost on them.

John, Earl (an undergraduate student at the time), and Dave went on several small mammal collecting trips together. Their first job every morning, before breakfast, was to check traps and then, while still fresh, to put up skins for anything that they caught overnight. One such trip was to Willow Slough in the sand prairie area of northwestern Indiana. On another such trip, to southwestern Indiana, they took a rowboat out on Hovey Lake in Posey County, where they came across a huge snapping turtle swimming in the shallow water. Dave jumped out of the boat, grabbed the turtle by the tail, and managed to lift it up to the boat as John tried to keep the boat steady. Upon getting it into the boat, they simultaneously asked each other, "OK, now what are we going to do with it?" The snapper very quickly got released back into the lake. At no time were all three men in the boat with the snapper!

John often wanted to trap small mammals on private land, which of course required permission from the owners. Not everyone understands the importance of scientific research, and a few refused to give access to their lands. One farmer told him that there was a bull in his field, even though it was a soybean field and clearly held no livestock. Another refused him access because the federal government wanted to put a wildlife refuge in the vicinity, and she planned to "be on the front lines with [her] Pappy" if the bulldozers came. She even complained to the department chair, saying that Whitaker was "misrepresenting the department" because "any fool knew that cats would immediately remove any mice from traps set outdoors." Others just thought the idea of trapping mice was funny. One, sitting on his porch, simply bent his chair back, put his feet on the railing, and laughed and laughed, while John stood there. And a policeman, seeing John and

Dale Wallace approaching a stream to seine for fish on a rainy day, told them that was one of the funniest things he had seen – second only to the time he saw another fellow in a cornfield setting mouse traps, also on a rainy day. Of course, that "other fellow" was John Whitaker!

One of John's early plots was located on a 1200 acre farm in northern Vigo County. John had permission from the owner to come and go as he pleased, as long as he let him know in advance. One Sunday morning, when John was on the property picking up his traps, he looked up and saw a tractor coming across the end of the corn field. John waved and noted that the driver did not wave back. As soon as he got to the corner of the field he immediately turned and came towards John. He jumped off the tractor before it was stopped, handed John a pencil and paper, and said, "No talk, I just want your name and address." John tried to explain, but the driver cut him off and reiterated that he was not discussing it, he just wanted John's name. He thought John was stealing corn left in the field. When John finally mentioned something about his brother giving permission, he calmed down and said next time John should ask *him*.

Another time John and several other Indiana mammalogists went to a cave in central Indiana where a couple of long-eared bats had been observed years earlier. Their five cars were parked one behind the other in a lane off the main road. The owner was away, but they had been in touch with a fellow who indicated he had gotten permission for them. What they didn't know was that he had not been able to contact the owners, nor the person who watched the property while they were away. They visited the cave without finding the bats. As they came back over the hill they saw a very large man standing in front of the cars. It turned out that he was the person who took care of things while the owners were out of town. He said that three police cars would be arriving shortly to take them to jail. Luckily, Jim Cope, a faculty member from Earlham College, was a very good talker and averted this course of action. They wondered afterwards how interesting it might have been for all the mammalogists in Indiana to have been arrested and taken to jail.

And one final note on personal efficiency. Rarely, if ever, do you note John Whitaker shooting the breeze with students or colleagues. If John is talking with others, during working hours especially, he is talking science, and not engaged in superfluous gossip. I suspect all of us field biologists could have accomplished far more during our careers had we adopted John's efficient ways of conducting our work days during the last half century. For many years John has said that he hoped to continue his work until age 100. He is currently continuing to work on *Mammals of New York* and some 50 other projects.

MY TEACHING PHILOSOPHY

by John O. Whitaker, Jr.

My teaching philosophy is to have the students learn firsthand, in the field as much as possible, through observation, joint classes, small groups, and individual research projects, whereby students learn how to answer questions for themselves. Sometimes these projects have taken place with different classes over several years, e.g., on western chorus frogs (*Pseudacris triseriata*) and narrow-mouthed salamander (*Ambystoma texanum*). In Vertebrate Zoology, which I have taught for many years, we always took several field trips. In Mammalogy, we took a preliminary day-long session in which we learned how to trap and how to examine specimens and how to prepare skins and skulls. The second field trip was for four days for practice in the field of Mammalogy – i.e., we prepared skins, took notes, and studied reproduction, food, and parasites. In Herpetology, the emphasis of the entire course was on research, culminating in a five-day field trip to North Carolina, essentially the capital of the world distribution for salamanders. I taught many summer classes entirely in the field – 10 years at a field campus in southern Pennsylvania, 10 years at the ISU field campus in Brazil, Indiana, and 10 years at Kieweg Woods, the biological field campus at West Terre Haute. For many years I took a group mostly of graduate students to the annual meeting of the American Society of Mammalogists. Most years this was combined with extra days to learn about the mammals of these areas.

As for classroom teaching, my main method was to ask questions and then to help the students to come up with the answers themselves by providing data. Many of these sessions were on taxonomy and nomenclature, evolution including isolating mechanisms, subspeciation, speciation, and a number of ecological topics.

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Dave Rubin adds, "John's own description of his teaching philosophy is spot on. He challenged students with questions, and then helped them answer the questions for themselves. He made them think. He was selfless in the time and effort he gave to helping his students, yet never claimed any credit for the work of his students even when he had contributed significantly. Perhaps the most important thing John did for me, starting early in my time as a graduate student at ISU (1963–69), was to ask me to go over papers he had written before he submitted them. And he gave me credit in print for doing so. He also asked me to help with the herp keys as he was writing his *Keys to the Vertebrates of the Eastern U.S.* His trust in me gave me confidence, and the opportunity to review his submissions honed my skills at writing and editing, skills which served me very well in my future careers."

A professor named Whitaker, John O.
Does research by collecting bat guano.
Rare bats are his quest
He's proved that not one is a pest
Without doubt, John O. is pro bono.
—A whimsical limerick by Marion T. Jackson

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LICHENS AND ALLIED FUNGI OF THE INDIANA FOREST ALLIANCE ECOBLITZ AREA, BROWN AND MONROE COUNTIES, INDIANA INCORPORATED INTO A REVISED CHECKLIST FOR THE STATE OF INDIANA

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ABSTRACT. Based upon voucher collections, 108 lichen species are reported from the Indiana Forest Alliance Ecoblitz area, a 900 acre unit in Morgan-Monroe and Yellowwood State Forests, Brown and Monroe Counties, Indiana. The lichen biota of the study area was characterized as: i) dominated by species with green coccoid photobionts (80% of taxa); ii) comprised of 49% species that reproduce primarily with lichenized diaspores vs. 44% that reproduce primarily through sexual ascospores; iii) comprised of 65% crustose taxa, 29% foliose taxa, and 6% fruticose taxa; iv) one wherein many species are rare (e.g., 55% of species were collected fewer than three times) and fruticose lichens other than *Cladonia* were entirely absent; and v) one wherein cyanolichens were poorly represented, comprising only three species. Taxonomic diversity ranged from 21 to 56 species per site, with the lowest diversity sites concentrated in riparian corridors and the highest diversity sites on ridges. Low Gap Nature Preserve, located within the study area, was found to have comparable species richness to areas outside the nature preserve, although many species rare in the study area were found only outside preserve boundaries. Sets of rare species are delimited and discussed, as are observations as to the overall low abundance of lichens on corticolous substrates and the presence of many unhealthy foliose lichens on mature tree boles. Sixty-four species are newly reported from Indiana and the delimitation of new reports is based on a newly presented modern checklist of Indiana lichens. The new checklist of Indiana lichens includes 222 species, with an additional 72 historically reported taxa considered questionable reports that require verification based on reexamination of the original vouchers.

Keywords: Anthropogenic change, Appalachian Mountains, biodiversity, floristics, obligate symbiosis, Ozarks, taxonomy, temperate eastern North America

INTRODUCTION

Lichens are obligate symbioses formed between fungi and algae or cyanobacteria (Ahmadjian 1993; Nash 1996, 2008). These fungi, and the symbioses that they form, are speciose and ecologically important components of a multitude of terrestrial ecosystems (Galloway 1992; Ahmadjian 1995; Cornelissen et al. 2007; Segerer 2009), including those in temperate eastern North America (Brodo et al. 2001). Although eastern North American lichens have been studied for more than two centuries, substantial gaps remain in the knowledge of distribution patterns of individual species, particularly crustose lichens (see Spribille et al. 2010; Lücking et al. 2011; Lendemer et al. 2013, 2014, 2016). Surprisingly the State of Indiana, a 94,321 km^2 area larger than the country of Portugal, comprises one such gap. Indeed, only a small number of publications have focused on Indiana lichens to date (Fink & Fuson 1918; Herre 1943a, b; Miller & Thomson 1959; Harris 1988; McCune 1988; Muir & McCune 1988; Wetmore 1988a; Bennett et al. 1996; Hyerczyk 1997a). The relative lack of baseline knowledge of Indiana lichens was already recognized, and critiqued more than half a century ago by Herre (1943b) when he published the first, and only, attempt at a comprehensive checklist for the state.

This paucity of study stands in contrast to adjacent Illinois (Calkins 1896; Winterringer & Vestal 1956; Skorepa & Snider 1967; Skorepa 1970, 1973, 1984; Stotler 1976; Wilhelm & Ladd 1985; McKnight et al. 1987; Wilhelm & Parker 1988; Basinger et al. 1996; Hyerczyk 1996, 1997b, 1998a-e, 2004, 2005; Ladd & Wilhelm 1998; Gillespie & Methven 2002; Edgin et al. 2004; Watchholder et al. 2004; Harris & Ladd 2005), Michigan (Nichols 1925; Darlington 1931, 1938; Lowe 1936; Hedrick 1940; Thomson 1951, 1993; Bevis 1960, 1962, 1965; Benninghoff & Cramer

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1963; Graham 1969; Hinds 1970; Harris 1973, 1977; Mahoney 1973; Henry & Hampton 1974; Harris & Buck 1978; Wetmore 1988b, 1990; Medlin 1996; Fryday et al. 2001) and Ohio (Tuckerman 1849; Bogue 1893; Fischer 1895; Hambleton 1906, 1910; Claassen 1912, 1917; Fink & Richards 1915; Carrington 1921; Fink 1921; Fulford 1937; Wolfe 1940; Taylor 1967, 1968; Rudolph 1974; Showman 1975, 1977, 1981a, b; Kaucher & Snider 1982; Flenniken & Showman 1990; Showman & Flenniken 2004; Washburn 2005; Andreas et al. 2007), whose lichens have been the subject of extensive and continued study for more than a century (summarized in Fig. 1 and Table 1).

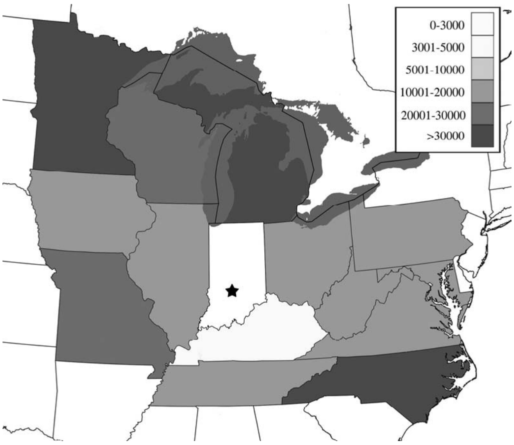


Figure 1.—Graphical comparison of number of voucher specimens available in CNALH (accessed 25 May 2017) for Indiana and surrounding states in the Great Lakes, Mid-Atlantic, and Mid-South regions. (IFA Ecoblitz Study Area is indicated by the black star.)

Given the ecological and physiographic diversity of Indiana, as well as the panoply of lichen species reported from adjacent states, one would reasonably expect lichens to contribute substantially to the overall biodiversity of the state. Further, as is the case in many areas, understanding lichen species diversity, distribution, and frequency in Indiana is particularly important given the breadth and scale of anthropogenic impacts to the natural landscape of the region (Whitaker et al. 2012). Recognizing the critical need for baseline lichen floristic data in Indiana, the Indiana Forest Alliance (IFA hereafter) contacted the present author to inventory the lichens of a 364 ha (900 ac) unit of two state managed forests, a portion of which had already been designated as a state natural area because of its botanical significance (Higgs 2006). The results of this inventory are presented here.

In an effort to place the results of this inventory in a broader context, a new checklist of Indiana lichens was also compiled based on a comprehensive review of previously published literature. The checklist is presented here, together with an accounting of uncertain or questionable literature reports that require verification of the original

Table 1.—Tabular summary comparing the available lichen vouchers in CNALH (accessed 25 May 2017) to the total land area (square kilometers) for Indiana and surrounding states in the Great Lakes, Mid-Atlantic, and Mid-South regions (obtained from U.S. Census Bureau, 3 January 2018). An estimate of average collection density per state is given as the number of vouchers/total land area. Indiana, the state with the smallest number of vouchers in CNALH, and the lowest number of vouchers per-unit land area, is in bold.

State	# of CNALH vouchers	Land area (km^2)	Voucher per square kilometer
Illinois	12855	143793	0.0894
Indiana	**2994**	**92789**	**0.0323**
Iowa	13264	144669	0.0917
Kentucky	3599	102269	0.0352
Maryland	10094	25142	0.4015
Michigan	56594	146435	0.3865
Minnesota	57102	206232	0.2769
Missouri	21040	178040	0.1182
North Carolina	41546	125920	0.3299
Ohio	12501	105829	0.1181
Pennsylvania	18131	115883	0.1565
Tennessee	11519	106798	0.1079
Virginia	17155	102279	0.1677
West Virginia	13154	62259	0.2113
Wisconsin	29625	140268	0.2112

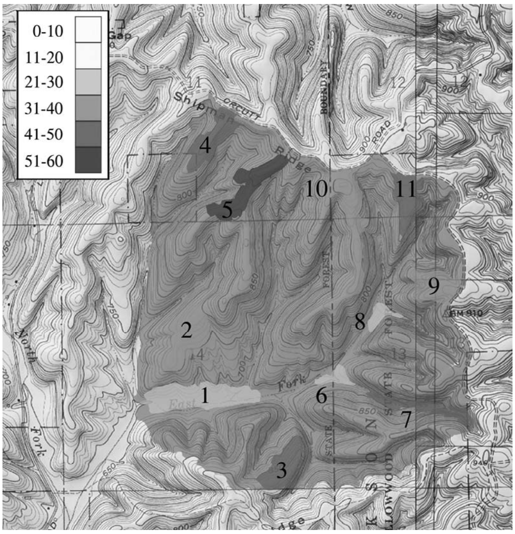


Figure 2.—Topographic map of the study region illustrating the delimitation of the study area (gray) and the delimitation of sites inventoried for this study (numbers follow those outlined in the methods section), with sites color coded based on taxonomic diversity (number of species + infraspecific taxa).

source material before they should be considered as occurring in the state.

MATERIALS AND METHODS

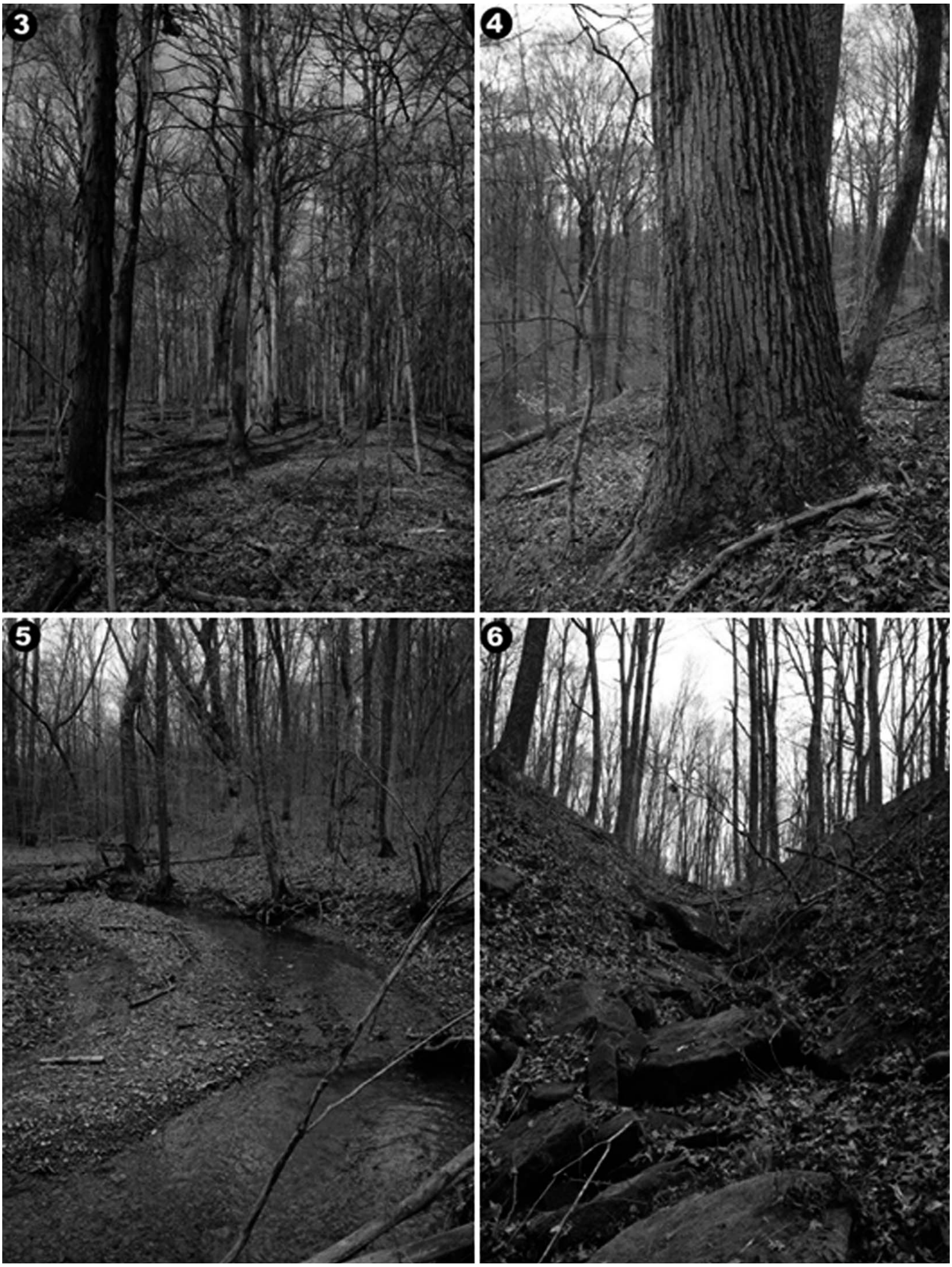
The study area.—This study focuses on the Indiana Forest Alliance Ecoblitz Area, a 364 ha unit of forested ridges and stream ravines associated with the East Fork of Honey Creek, in southern Indiana (Fig. 2). The ridges are forested by mixed hardwoods dominated by oak, hickory and maple. The stream ravines are also forested by mixed hardwoods including beech, sycamore and ironwood. Occasional stands of planted pines, and even spruce, also occur sporadically on the lower slopes of the ridges and along the stream ravines. Rocks are almost entirely absent from the area, except for small, isolated outcroppings of poorly consolidated sandstone located in the upper portions of the stream ravines.

The study area is roughly bisected by the Monroe County-Brown County line, which also serves as the boundary between Morgan-Monroe State Forest and Yellowwood State Forest, the two management units within which the area is located. A 129 ha (320 ac) portion of the study area was formally designated Low Gap Natural Area due to the occurrence of rare plants and animals, as well as its being "one of the largest uninterrupted tracts of high quality forest in Indiana's Brown County Hills Section of the Highland Rim Natural Region (IDNR, undated; Higgs 2006). Extensive reports of the ecology, geology, and vegetation of the study area, together with results of biodiversity inventories for organismal groups other than lichens have been published by IFA (2015, 2016).

Field methods.—The field component of this study was carried out by the author during 10–14 April 2017. During this time total biodiversity inventories were conducted at a total of 11 sites within the EcoBlitz area. The sites spanned the diversity of habitats and vegetation types within the study area (Figs. 3–6) and were each delimited to comprise only a single habitat type (e.g., ridge-top hardwood forest, stream ravine, or riparian floodplain forest; see Figs. 2 & 3). Lichen biodiversity inventory methods followed those outlined in detail by Lendemer et al. (2016) and were performed at each site for up to 1.5 hr (90 min). A voucher specimen of each species encountered at each site was collected and examined using the methods outlined below.

Laboratory and herbarium methods.—All newly collected voucher specimens were deposited in the herbarium of The New York Botanical Garden (NY). Numerous other vouchers already deposited at NY were also used for comparison, or were otherwise revised to determine whether a given taxon had already been reported from Indiana. Georeferenced voucher data for all specimens examined can be accessed via the C.V. Virtual Herbarium at NY (http://sweetgum.nybg.org/science/vh/). Specimens were examined using an Olympus SZ-STB dissecting microscope. Microscopic morphology and anatomy were studied using hand sections prepared with a razor blade, mounted in water, and then examined using an Olympus BX53 compound microscope. The chemistry of specimens was studied using standard spot tests (K, C, KC, P, UV) following Brodo et al. (2001). In cases where it was necessary to study chemistry in more detail, specimens were subjected to Thin Layer Chromatography (TLC) using Solvent C following Culberson & Kristinsson (1970) but as modified for the peanut butter jar by Lendemer (2011).

Assembly of the Indiana lichen checklist.—As part of this study it was necessary to determine



Figures 3–6.—Typical habitat types in the study area. 3. Ridge forest with mixed hardwoods; 4. Ridge forest with mature mixed hardwoods (tulip poplar, *Liriodendron tulipifera*, pictured); 5. Floodplain hardwood forest; 6. Narrow stream ravine with occasional sandstone boulders.

whether species collected in the study area had previously been reported from Indiana. Because no checklist of Indiana lichens had been published since that of Herre (1943b), and the taxonomy of that list has become greatly outdated, the author decided to compile the existing literature and create a modern checklist for the state (see Appendix II). This list was prepared by compiling the taxa reported in publications indexed in Recent Literature on Lichens (Culberson et al. 2017) that had been tagged with the keyword "Indiana". Each publication was carefully examined and only taxa actually reported from the state were included (e.g., Wetmore (1988a) published a checklist of lichens from Indiana Dunes that included both his own collections from Indiana and taxa reported from adjacent Illinois by Calkins (1896); only the Indiana records were included here). The nomenclature and taxonomy were updated from the original publications to follow that of Esslinger (2016). In order to provide transparency to this process a translation table was prepared and appended to the end of the checklist. The compiled list of originally reported names and updated names was then examined in detail and parsed into three categories: 1) *checklist names*: names derived from reliable records published in modern times (e.g., Harris 1988, Wetmore 1988a, Hyerczyk 1997a); 2) *synonyms and excluded species*: names derived from records that were misidentified, correspond to species that are very unlikely to occur in Indiana (e.g., published modern range maps do not include the region), or represent well-documented taxonomic synonyms; 3) *questionable records*: names derived largely from historicl records whose occurrence in Indiana is possible, but the identity of the source voucher material should be examined and confirmed before the species is added to the checklist.

RESULTS AND DISCUSSION

A total of 11 sites was inventoried in the study area over the span of three field days. This inventory resulted in the collection of 460 vouchers representing 108 species of lichens (100, 93%), lichenicolous fungi (2, 2%), and non-lichenized fungal species traditionally treated with lichens (6, 6%) (see Appendix I). The number of species documented by this inventory comprises nearly half (49%, or 108 of 222 taxa) of the total diversity of lichens and allied fungi currently considered to occur in Indiana (see Appendix II). That such a large percentage of Indiana lichens were found in such a small study area, in comparison to the total land area of the state, likely reflects the overall lack of study of lichens in Indiana. Nonetheless it is also possible that the number reflects a naturally occurring local concentration of lichen biodiversity found in a large area of unfragmented, high quality forest.

Of the 100 species of lichen-forming fungi, the majority (80 species, 80%) was associated with green coccoid algal photobionts and 17 species (17%) were associated with the chain-forming green algal photobiont *Trentepohlia*. Lichen-forming fungi that associate with *Trentepohlia* are more diverse and frequent in tropical regions (Aptroot & van Herk 2007, Marini et al. 2011) and thus the small number of species associated with this photobiont genus likely reflects the northern temperate climate and biogeographic history of the biota. Cyanolichens were the most poorly represented in the dataset, both in terms of total species diversity (3 species, 3% of all lichens found) and with respect to the number of vouchers made (8 vouchers, 1.9% of the total vouchers collected). With respect to dominant reproductive modes, species that reproduce primarily asexually through the dispersal of lichenized propagules comprised nearly half (53 taxa, 49%) of the diversity while sexually reproducing species comprised 44% (47 taxa) of the diversity. The remainder of the species either reproduce through the dispersal of asexual non-lichenized propagules (*Dictyocatenulata alba*), or were treated as polymorphic because they are members of the genus *Cladonia* that produce abundant lichenized propagules together with pycnidia and apothecia on the same thallus. Approximately half (59, 55%) of 108 species found during the inventory were collected fewer than three times, while only a small percentage were commonly encountered (Fig. 7). Similar patterns of lichen species frequency across sites have been documented elsewhere in North America (e.g., Lendemer et al. 2016) and suggest that, at the landscape level, a substantial proportion of the lichens in a given region may be infrequent, rare, or otherwise highly localized. In the study area, the majority of species were found on the trunks and bases of hardwood trees (Figs. 8–11), and several species were found to be highly localized on the bases of mature hardwoods (e.g., *Collema subflaccidum* on a single hickory at site 10, or *Anaptychia palmulata* on a single chestnut oak at site 3).

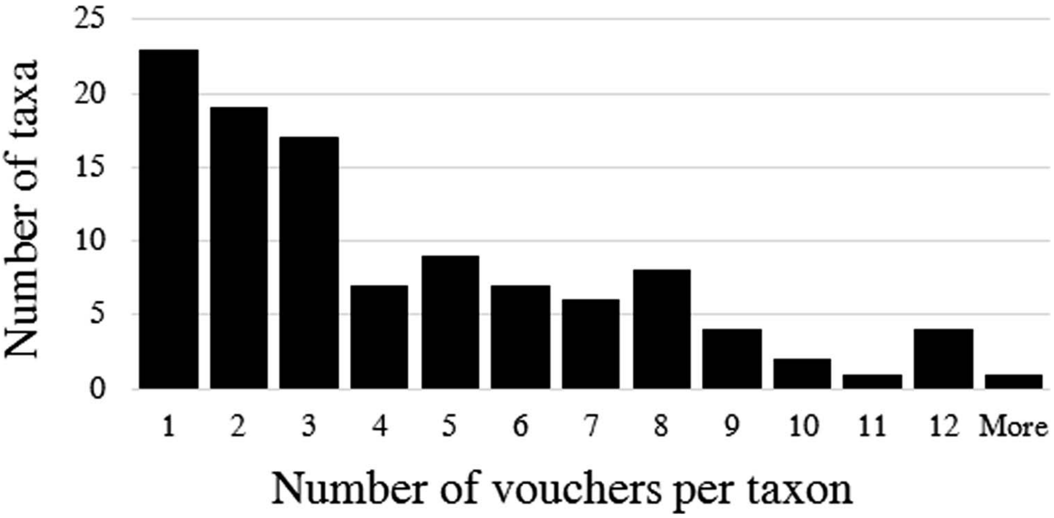
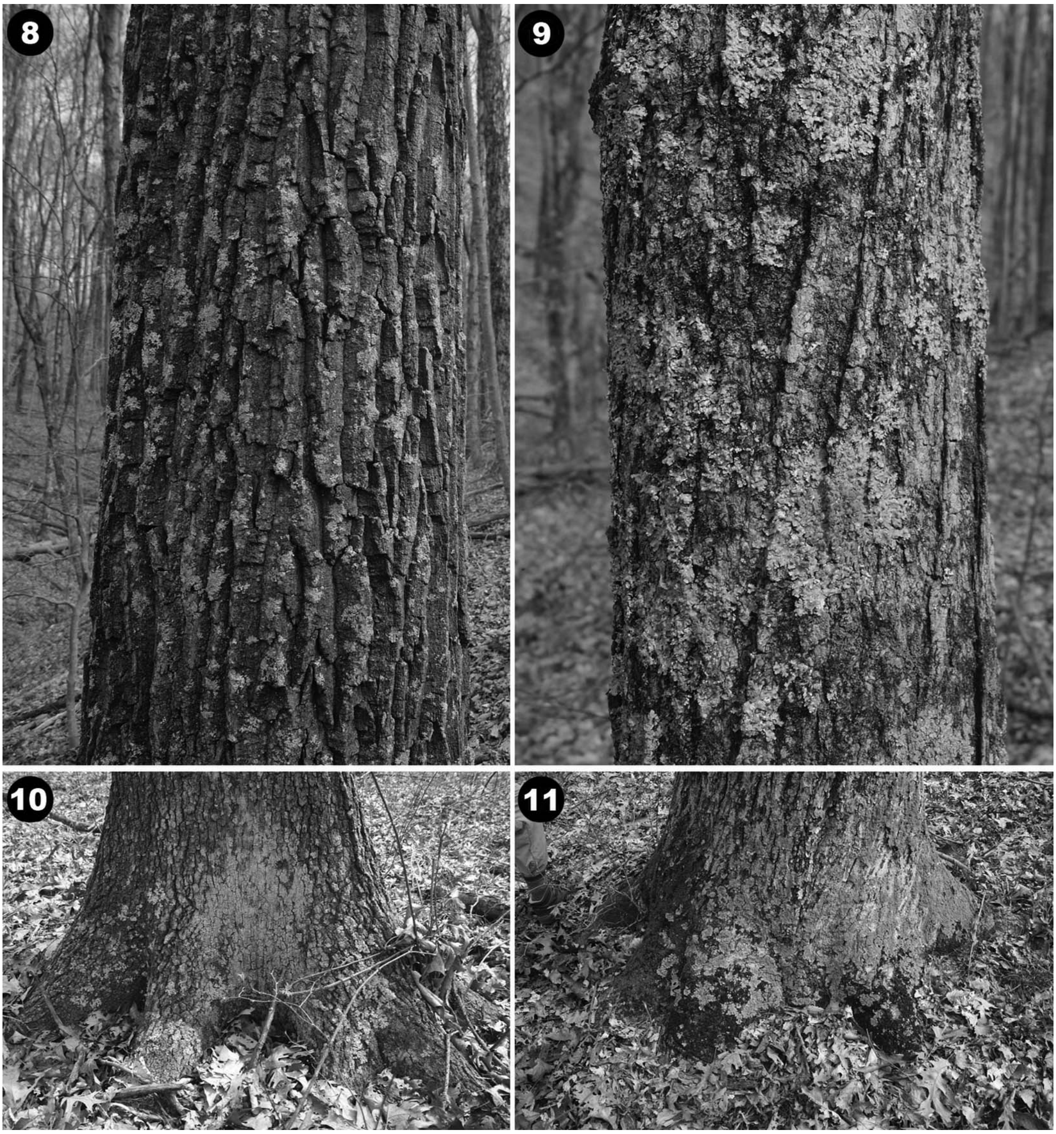


Figure 7.—Bar chart summarizing the numbers of vouchers collected per taxon as part of this study.

The most frequent, or commonly encountered, species, as defined by having been collected more than ten times, were *Dictyocatenulata alba* (12 vouchers), *Flavoparmelia caperata* (11 vouchers), *Graphis scripta* (10 vouchers), *Lepraria finkii* (12 vouchers), *Myelochroa aurulenta* (11 vouchers), *Punctelia missouriensis* (12 vouchers), *Punctelia rudecta* (13 vouchers), and *Pyxine subcinerea* (10 vouchers). All of those species have been documented to be common, disturbance tolerant, widespread species with wide ecological amplitudes (e.g., Brodo et al. 2001; Lendemer & Harris 2004; Hinds & Hinds 2007). In contrast, the species that were collected only once were: *Anaptychia palmulata, Anisomeridium leucochlorum, Arthonia apatetica, Bacidia purpurans, Cladonia peziziformis, Collema subflaccidum, Fellhanera silicis, Heterodermia obscurata, Lecanora hybocarpa, Lecidea cyrtidia, Lecidea erythrophaea, Lepraria harrisiana, Micarea micrococca, Micarea prasina, Opegrapha varia, Parmelia squarrosa, Pyrenula laevigata, Sarea difformis, Scoliciosporum chlorococcum, Thelidium minutulum, Trapeliopsis flexuosa, Violella fucata*, and *Xanthomendoza weberi*. Similarly, the following taxa were collected only twice: *Acrocordia megalospora, Arthonia helvola, Arthonia quintaria, Chaenothecopsis debilis, Cladonia petrophila, Heterodermia speciosa, Lecanora appalachensis, Lecanora layana, Lepra pustulata, Lepraria* sp.*, Leptogium cyanescens, Lithothelium hyalosporum, Micarea soralifera, Nectriopsis* sp., *Opegrapha vulgata, Parmotrema gardneri, Pertusaria pustulata, Porpidia albocaerulescens*, and *Trapelia placodioides*.

The taxa encountered one or two times during the inventory can be subdivided into several groups as follows: i) cyanolichens (*Collema subflaccidum, Leptogium cyanescens*); ii) species characteristic of mature or high-quality forests (*Anaptychia palmulata*); iii) seemingly rare or infrequent species (*Acrocordia megalospora, Anisomeridium leucochlorum, Arthonia apatetica, Bacidia purpurans, Lecidea erythrophaea, Lithothelium hyalosporum, Pyrenula laevigata, Sarea difformis, Parmotrema gardneri*); iv) saxicolous species whose occurrences in the study area were limited by the availability of rock substrates (*Cladonia petrophila, Fellhanera silicis, Porpidia albocaerulescens, Thelidium minutulum, Trapelia placodioides*); and v) species that are typically more frequent based on studies in the central Appalachians and Ozarks (*Arthonia helvola, Arthonia quintaria, Chaenothecopsis debilis, Cladonia peziziformis, Heterodermia obscurata, Heterodermia speciosa, Lecanora appalachensis, Lecanora hybocarpa, Lecanora layana, Lecidea cyrtidia, Lepra pustulata, Lepraria* sp.*, Lepraria harrisiana, Micarea micrococca, Micarea prasina, Micarea soralifera, Nectriopsis* sp., *Opegrapha varia, Opegrapha vulgata, Parmelia squarrosa, Pertusaria pustulata, Scoliciosporum chlorococcum, Trapeliopsis flexuosa, Violella fucata,* and *Xanthomendoza weberi*). Although the apparent rarity of some species, such as those belonging to groups iii and iv, is not surprising, others merit



Figures 8–11.—Appearance of trees in the study area with moderate to abundant lichen growth. 8. Mature chestnut oak (*Quercus prinus*) bole; 9. Sugar maple (*Acer saccharum*) bole; 10. Base of mature red oak (*Quercus rubra*), with conspicuous colony of *Bacidia sorediata*; 11. Base of mature hickory (*Carya*) with colonies of *Collema subflaccidum* and *Leptogium cyanescens* growing on roots.

comment. The overall low frequency of cyanolichens, is unusual given that the species found to be rare in the study area are among the most common and widespread members of this group (e.g., Brodo et al. 2001; Hinds & Hinds 2007; McMullin & Anderson 2014). Similarly, based on the experience of the author (Lendemer unpublished data) the small number of species typical of mature forests is unusual given the overall apparent maturity of tree stands and lack of fragmentation in the study area. By the same token the low frequency of species that are common elsewhere in their ranges (i.e., group v) is noteworthy. The cause of the low frequency of certain otherwise common species and cyanolichens, coupled with the absence of fruticose lichens other than those of the genus *Cladonia*, is unclear and requires further study. Air pollution

Figures 12–19.—Appearance of trees with noticeable lack of lichen cover (12–18) and typical appearance of damaged thallus of foliose lichen (19). 12. White oak (*Quercus alba*) bole; 13. Sugar maple (*Acer saccharum*) bole; 14. Beech (*Fagus grandifolia*) bole; 15. Shagbark hickory (*Carya laciniata*) bole; 16. Mature white oak in forest stand; 17. Mature sassafras (*Sassafras albida*) in forest stand; 18. Tulip poplar (*Liriodendron tulipifera*) bole; 19. Detail of damaged *Punctelia rudecta* thallus.

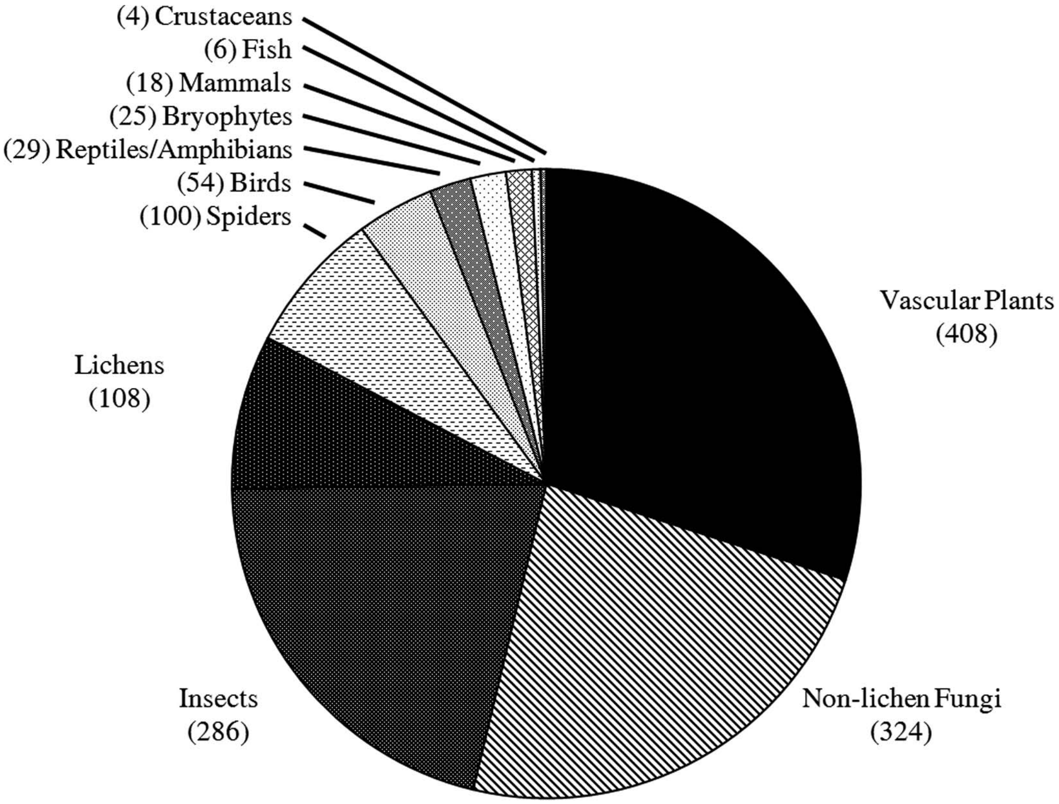


Figure 20.—Comparison of taxonomic diversity of organismal groups in the IFA Ecoblitz Area (numbers of taxa for groups other than lichens follows IFA (2016))

has been implicated as a primary player in such impacts to lichen communities in the past (e.g., McCune 1988; McCune et al. 1997; Cleavitt et al. 2015; Root et al. 2015; Will-Wolf et al. 2015, 2017) and as levels of certain pollutants such as sulfur dioxide have declined in many areas of the United States, lichens have responded accordingly (Showman 1981a, 1990, 1997; McClenahen et al. 2012). While legacy impacts from air pollution could account for patterns of rarity for some species in the study area, this neither explains the unusually low levels of lichen cover observed on many corticolous substrates (Figs. 12–18) nor the unhealthy and dead thalli of common species observed on mature trees on the ridgetops in the study area (Fig. 19).

Taxonomic diversity varied considerably across the inventoried sites ranging from a minimum of 21 species to a maximum of 56 species, and an average of 38 ± 10 species per site. Seven of the inventoried sites comprised dry forest ridges and the upper slopes of ridges, while four comprised riparian corridors and floodplain forests. The four riparian and floodplain sites were the least species-rich inventoried (all sites < 30 taxa) in contrast to the forested ridge sites, all of which hosted more than 30 taxa (Fig. 2). Overall, species assemblages were moderately similar across sites (Sørensen Coefficient 0.44 ± 0.12, n = 55), and species assemblages among ridge top sites were more similar to each other (Sørensen Coefficient 0.54 ± 0.08, n = 19) than species assemblages among riparian sites (Sørensen Coefficient 0.41 ± 0.08, n = 6). Taxonomic diversity was also similar between the two habitats that were surveyed, with 87 species found in riparian habitats and 92 species found in ridge habits, and the lichen assemblages found in the two habitats also overlapped substantially (Sørensen Coefficient 0.78 comparing pooled riparian vs. ridge assemblages).

Four sites (sites 1, 2, 4 and 5) were located within Low Gap Nature Preserve, while the remaining seven sites were located on adjacent state forest lands. Species richness was similar between the nature preserve (83 species) and the adjacent area (94 species), as were the lichen species assemblages in the two areas (Sørensen 0.78 comparing pooled nature preserve vs. non-nature preserve sites). Nonetheless, despite the large number of taxa located both within the nature presence and on adjacent lands, the species only found outside of the nature preserve included members of several rare or sensitive groups outlined above (group i: *Collema subflaccidum, Leptogium cyanescens*; group ii: *Anaptychia palmulata*; group iii: *Bacidia purpurans*, *Lithothelium hyalosporum,* and *Pyrenula laevigata*).

Of the species located during the inventory, 70 (65%) were crustose, 31 (29%) were foliose, and 7 (6%) of were species of *Cladonia* with polymorphic thalli comprised of a squamulose primary thallus and fruticose secondary thallus. Thus, crustose microlichens comprise nearly two thirds (65%) of the species richness in the study area, while foliose, fruticose and squamulose macrolichens comprise only slightly more than one third (36%) of the species richness. No fruticose lichens other than members of the genus *Cladonia* were found in the study area. Generally, fruticose lichens such as members of the genera *Ramalina* and *Usnea* are considered to be sensitive to air pollution (Will-Wolf et al. 2015), and their absence from the study area is noteworthy.

The results presented here from the lichen biodiversity inventory of the IFA Ecoblitz Area offer a timely and nuanced perspective of lichen diversity in southern Indiana. A total of 108 species of lichens, lichenicolous, and allied fungi were documented in a single 364 ha tract of core forest habitat. Despite more than a century of study, albeit of a static nature and limited in scope, 64 of the species found during this study appear to be new records for Indiana. Comparison with levels of species richness for other taxonomic groups illustrates that lichens contribute substantially to the overall biodiversity of the study area (Fig. 20). Indeed, of the 1362 taxa reported from the study area to date, insects and spiders together with lichens and other non-lichenized fungi comprise more than half (60%, 818 species) of the total biological diversity. This result is significant because direct comparisons of diversity across taxonomic groups are rare as they are typically hindered by of a lack of consistency in the areas studied for different groups (see discussion in Lendemer & Allen 2014).

Although 108 may be a surprising number of lichens for such a small area, it must be recognized that more than half of these appear to be rare in the study area and many of those rare species were found only in mature forest stands on ridgetops, often outside the boundaries of the existing nature preserve. Likewise, despite the levels of documented lichen diversity, the low frequency and diversity of cyanolichens coupled with the absence of fruticose lichens other than *Cladonia* is noteworthy. Also notable was the observed lack of lichen cover on many tree boles, and the occurrence of many dead or unhealthy lichen thalli on the boles of some mature ridgetop hardwood trees. Nonetheless, these observations must be placed in the broader context that the study area comprises a significant area of intact core-forest surrounded by a dense, complex matrix of lands fragmented by agriculture, development, infrastructure, and forests managed for resource extraction. This core-forest likely functions as an essential reservoir for lichen diversity that has been substantively impacted elsewhere in the region.

ACKNOWLEDGMENTS

This study was supported by the Indiana Forest Alliance (IFA) and permission to carry out the study was provided by the Indiana Department of Natural Resources.

APPENDIX I

CHECKLIST OF LICHENS AND ALLIED FUNGI IN THE IFA ECOBLITZ STUDY AREA

The checklist presented below comprises all of the species collected as part of the present study in the IFA Ecoblitz Study Area. The checklist is arranged alphabetically by genus and species. Taxonomy largely follows Esslinger (2016), although any deviations from that work reflect the opinions of the present author. All cited voucher specimens were collected by the author and as such only the collection number for each voucher is given below. The vouchers have been deposited in the herbarium of The New York Botanical Garden (NY). Lichenicolous fungi are denoted by an asterisk (*) and non-lichenized fungi treated with lichens are denoted by a dagger (†). B = Brown County collections; M = Monroe County collections.

Acrocordia megalospora (Fink) R.C. Harris (hardwood bark) – B: *51043*. M: *50846*.

Amandinea polyspora (Willey) E. Lay & P. May (fallen hardwood branches) – B: *52092, 51207*. M: *50894*.

Anaptychia palmulata (Michx.) Vain. (hardwood bark) – M: *51181*.

Anisomeridium leucochlorum (Müll. Arg.) R.C. Harris (fallen hardwood branches) – M: *50862*.

Anisomeridium polypori (Ellis & Everh.) M.E. Barr (hardwood bark) – B: *50960, 51071, 51134, 51223*.

Arthonia apatetica (A. Massal.) Th. Fr. (hardwood bark) – M: *50832*.

Arthonia helvola (Nyl.) Nyl. (hardwood bark) – B: *50997*. M: *51250*.

†*Arthonia quintaria* Nyl. (fallen hardwood and conifer branches) – B: *51208*. M: *51274*.

Bacidia purpurans R.C. Harris, Lendemer & Ladd (hardwood bark) – B: *51106*.

Bacidia schweinitzii (Fr. *ex* Tuck.) A. Schneid. (hardwood bark) – B: *50978, 51013, 51107, 51137, 51211*. M: *50084, 50928, 51184, 51255*.

Bacidia sorediata Lendemer & R.C. Harris (hardwood bark) – B: *50953, 50962, 51019, 51078, 51128*. M: *50890, 50927, 51254-A, 51269*.

Biatora printzenii Tønsberg (hardwood bark) – B: *50961, 50983, 50996, 51030, 51061, 51076*. M: *50865, 51164, 51254*.

Buellia wheeleri R.C. Harris (hardwood bark) – B: *51023, 51094*. M: *50918,*

The discovery of this species in Indiana is noteworthy and as it is a northern range extension beyond the currently established range (Lendemer & Hodkinson 2009).

Candelaria concolor (Dicks.) Stein (hardwood bark) – B: *51037, 51054, 51149, 51203*. M: *50835, 50902, 51259*.

Candelariella cf. *efflorescens* R.C. Harris & Buck (hardwood bark and fallen branches) – B: *50954, 51109, 51059, 51093, 51150*. M: *51263*.

All of the specimens of this species collected during the inventory lacked apothecia, and thus it is not possible to determine with certainty that they represent *C. efflorescens* (Lendemer & Westberg 2010).

Canoparmelia texana (Müll. Arg.) Elix & Hale (hardwood bark and canopy branches) – B: *50987*. M: *50859, 51157*.

Catillaria nigroclavata (Nyl.) Schul. (hardwood bark and canopy branches) – B: *51005, 51041, 51060*. M: *50933, 51262*.

†*Chaenothecopsis debilis* (Turner & Borrer *ex* Sm.) Tibell (decorticate standing trunks) – M: *50909, 51271*.

Chrysothrix caesia (Flot.) Ertz & Tehler (hardwood bark and fallen branches) – B: *50947, 50952, 51068, 51074, 51092, 51209*. M: *50892, 50936*.

Cladonia caespiticia (Pers.) Flörke (lignum) – B: *51053*. M: *50875, 50914*.

Cladonia macilenta var. *bacillaris* (Genth.) Schaer. (lignum and hardwood bark) – B: *51103*. M: *50863, 50871, 50910, 51176, 51241*.

Cladonia ochrochlora Flörke (lignum) – B: *50949, 51004, 51052, 51096*. M: *50873, 50911, 51177, 51242*.

Cladonia parasitica Hoffm. (lignum) – B: *50950*. M: *50876, 51243*.

Cladonia petrophila R.C. Harris (sandstone) – B: *51111*. M: *51194*.

Cladonia peziziformis (With.) J.R. Laundon (hardwood bark) – B: *51028*.

Cladonia ramulosa (With.) J.R. Laundon (lignum) – B: *51002, 51097*. M: *50874, 50913, 51178*.

Coenogonium pineti (Ach.) Lumbsch & Lücking (lignum and hardwood bark) – B: *51102*. M: *50940, 51179, 51244, 51247, 51248*.

Collema subflaccidum Degel. (hardwood bark) – B: *51016*.

Crespoa crozalsiana (Harm.) Lendemer & B.P. Hodk. (hardwood bark) – B: *51040*. M: *50881, 50908, 51155*.

Dictyocatenulata alba Finley & E.F. Morris (hardwood bark) – B: *50975, 51029, 51066, 51080, 51133, 51220*. M: *50836, 50889, 50904, 51166, 51229, 51249*.

Fellhanera silicis R.C. Harris & Ladd (sandstone) – B: *51115*.

Flavoparmelia caperata (L.) Hale (hardwood bark) – B: *50951, 50989, 51039, 51056, 51087, 51148, 51199*. M: *50852, 50930, 51191, 51237*.

Graphis scripta (L.) Ach. (hardwood bark) – B: *50956, 50994, 51070, 51079, 51218, 51219*. M: *50837, 50937, 51156, 51277*.

Heterodermia obscurata (Nyl.) Trevis. (hardwood bark) – M: *51154*.

Heterodermia speciosa (Wulfen) Trevis. (hardwood bark) – M: *51173, 51227*.

Hypotrachyna livida (Taylor) Hale (fallen hardwood branches) – B: *51145, 51200*. M: *51187*.

†*Julella fallaciosa* (Stizenb.) R.C. Harris (hardwood bark) – B: *50968, 51064*. M: *50847, 50922, 51175*.

Lecania croatica (Zahlbr.) Kotlov (hardwood bark) – B: *50957, 50963, 51048, 51049, 51108*. M: *50878, 50903*.

Lecanora appalachensis Lendemer & R.C. Harris (hardwood bark) – B: *50976*. M: *51251*.

Lecanora hybocarpa (Tuck.) Brodo (hardwood bark) – B: *51224*.

Lecanora layana Lendemer (hardwood bark) – B: *51036*. M: *51258*.

Lecanora nothocaesiella R.C. Harris & Lendemer (hardwood bark) – B: *51026, 51077, 51124, 51141*. M: *50880, 50886, 51282*.

Lecanora strobilina (Spreng.) Kieff. (fallen hardwood and conifer branches) – B: *51008, 51090, 51206*. M: *50891, 51189, 51275*.

Lecanora thysanophora R.C. Harris (hardwood bark) – B: *50980, 51140, 51215*. M: *50883, 50935, 51169*.

Lecidea cyrtidia Tuck. (non-calcareous pebbles) – B: *50993*.

Lecidea erythrophaea Flörke *ex* Sommerf. (hardwood bark) – M: *51281*.

Lepra pustulata (Brodo & Culb.) Lendemer & R.C. Harris (hardwood bark) – B: *51225*. M: *51168*.

Lepraria caesiella R.C. Harris (hardwood bark) – B: *50998*. M: *50870, 50917, 51172*.

Lepraria finkii (de Lesd.) R.C. Harris (hardwood and conifer bark, sandstone) – B: *50979, 51034, 51065, 51118, 51122, 51139*. M: *50869, 50921, 51159, 51256, 51264, 51280*.

Lepraria harrisiana Lendemer (conifer bark) – M: *51273*.

Lepraria hodkinsoniana Lendemer (hardwood bark) – B: *51020, 51120, 51131*. M: *50920*.

Lepraria sp. (hardwood bark) – M: *50851, 51257*.

This species does not belong to *Lepraria* in a strict sense because it produces usnic acid and zeorin (Lendemer & Hodkinson 2013); further study with molecular methods is needed to determine its true generic affinities.

Leptogium cyanescens (Rabenh.) Körb. (hardwood bark) – B: *51017*. M: *51165*.

Lithothelium hyalosporum (Nyl.) R.C. Harris (hardwood bark) – B: *51138, 51210*.

Micarea micrococca (Körb.) D. Hawksw. (conifer bark) – M: *51267*.

Micarea peliocarpa (Anzi) Coppins & R. Sant. (lignum and sandstone) – B: *51098, 51119*. M: *51195*.

Micarea prasina Fr. (lignum) – B: *51050*.

Micarea soralifera Guz.-Krzemiń., Czarnota, Łubek & Kukwa (lignum) – M: *50877, 51246*.

Myelochroa aurulenta (Tuck.) Elix & Hale (hardwood bark) – B: *50977, 50999, 51086, 51135, 51213*. M: *50843, 50856, 50857, 50900, 51153, 51287*.

Myelochroa galbina (Ach.) Elix & Hale (hardwood bark and fallen branches) – B: *50985, 51146*. M: *50898, 51186*.

Nadvornikia sorediata R.C. Harris (hardwood bark) – B: *51221, 51136*. M: *50882, 51129, 51183*.

**Nectriopsis* sp. (*Physcia stellaris* on fallen branches) – B: *51072*. M: *50861*.

Opegrapha varia Pers. (hardwood bark) – B: *51103*.

Opegrapha vulgata Ach. (hardwood bark) – M: *50888, 50939*.

Parmelia squarrosa Hale (fallen hardwood branches) – B: *51147*.

Parmotrema gardneri (C.W. Dodge) Hale (hardwood bark and fallen branches) – B: *51198*. M: *51289*.

Parmotrema hypotropum (Nyl.) J. Steiner (hardwood bark and fallen branches) – B: *51142, 51204-A*. M: *50838, 51235, 51285*.

Parmotrema reticulatum (Ach.) M. Choisy (hardwood bark and fallen branches) – B: *50984, 50990*. M: *50839*.

Pertusaria pustulata (Ach.) Duby (hardwood bark) – M: *50938, 51162*.

†*Phaeocalicium polyporaeum* (Nyl.) Tibell (*Trichaptum biforme* on dead hardwood trunks) – B: *50967, 51033*. M: *50864, 50897, 51230*.

Phaeophyscia adiastola (Essl.) Essl. (hardwood bark) – B: *50959, 50964, 51027, 51062, 51069, 51126*. M: *50831, 51231*.

Phaeophyscia pusilloides (Zahlbr.) Essl. (hardwood bark) – B: *51042, 51084*. M: *50834, 50901, 51283*.

Phaeophyscia rubropulchra (Degel.) Essl. (hardwood bark) – B: *51000, 51081, 51085, 51132*. M: *50844, 51152, 51239, 51288*.

Phaeophyscia squarrosa Kashiw. (hardwood bark) – B: *51212, 51012, 51018, 51127*. M: *50923, 51174*.

Physcia americana G. Merr. (hardwood bark) – B: *50955, 51032, 51125, 51214*. M: *50850, 50896, 51182, 51252, 51284*.

Physcia millegrana Degel. (hardwood bark and branches) – B: *50958, 51006, 51088, 51204*. M: *50854, 50879, 50931, 51233*.

Physcia stellaris (L.) Nyl. (fallen branches) – B: *50946, 51007, 51058, 51073*. M: *50895, 50907, 51190, 51236*.

**Piccolia nannaria* (Tuck.) Lendemer & Beeching (*Scoliciosporum pensylvanicum* on hardwood bark) – B: *50972*. M: *50868, 51170*.

As has been discussed by Lendemer & Harris (2014) it is unclear whether this species is always a juvenile parasite on other crustose lichens. Although those authors illustrated and discussed the species as a parasite on *Pyrrhospora varians*, the material collected during this study was consistently associated with *S. pensylvanicum*. Further study of this species is clearly required.

Placynthiella icmalea (Fr.) Coppins & P. James (lignum and conifer bark) – B: *51051, 51121*. M: *50872, 50912, 51245*.

Porpidia albocaerulescens (Wulfen) Hertel & Knoph (sandstone) – B: *51113*. M: *51197*.

Pseudosagedia cestrensis (Tuck.) R.C. Harris (hardwood bark) – B: *51067, 51110, 51130, 51222*. M: *50887, 51253, 51279*.

Pseudosagedia isidiata (R.C. Harris) R.C. Harris (hardwood bark) – B: *51031*. M: *50849, 51185*.

Punctelia caseana Lendemer & B.P. Hodk. (fallen branches) – B: *51205*. M: *50860, 50906, 51192, 51232*.

Punctelia graminicola (de Lesd.) R.S. Egan (hardwood bark) – B: *50945, 50991, 50992, 50995, 51046, 51083*. M: *51160*.

Punctelia missouriensis G. Wilh. & Ladd (hardwood bark) – B: *50982, 51024, 51045, 51082, 51144*. M: *50841, 50853, 50934, 51151, 51193, 51238, 51286*.

Punctelia rudecta (Ach.) Krog (hardwood bark) – B: *50944, 50981, 51025, 51044, 51095, 51143, 51201*. M: *50842, 50855, 50929, 51158, 51228, 51260*.

**Pyrenidium aggregatum* K. Knudsen & Kocourk. (*Phaeophyscia rubropulchra* on hardwood bark) – B: *51001*. M: *50905, 50926*.

Pyrenula laevigata (Pers.) Arnold (hardwood bark) – B: *51104*.

Pyrenula pseudobufonia (Rehm) R.C. Harris (hardwood bark) – B: *50973, 51101*. M: *50866*.

Pyrenula subelliptica (Tuck.) R.C. Harris (hardwood bark) – B: *51105, 51123, 51216*.

Pyrrhospora varians (Ach.) R.C. Harris (fallen hardwood and conifer branches) – B: *51010, 51089*. M: *51276*.

Pyxine sorediata (Mont.) Tuck. (hardwood bark) – B: *50974, 50986, 50988, 51035*. M: *50858, 50919, 51161, 51270*.

Pyxine subcinerea Stirt. (hardwood bark and fallen branches) – B: *51015, 51038, 50155, 51109, 51202*. M: *50885, 50899, 50932, 51163, 51261*.

Rinodina papillata H. Magn. (hardwood bark) – B: *50943*. M: *50833, 50941, 51047*.

Rinodina pyrina (Ach.) Arnold (fallen branches) – B: *50948, 51057*. M: *50893, 51188*.

The discovery of this species in Indiana is noteworthy as it is an eastern extension of the range of this species (Sheard 2010).

Ropalospora viridis (Tønsberg) Tønsberg (hardwood bark) – B: *50942, 50965, 51021, 51075*. M: *50845, 50915, 51167*.

†*Sarea difformis* (Fr.) Fr. (conifer resin) – M: *51265*.

†*Sarea resinae* (Fr.) Kunze (conifer resin) – M: *51266, 51272*.

Scoliciosporum chlorococcum (Stenh.) Vězda (fallen branches) – B: *51011*.

Scoliciosporum pensylvanicum R.C. Harris (hardwood bark) – B: *50966, 51022*. M: *50840, 50867, 50916, 51171*.

Scytinium dactylinum (Tuck.) Otálora, P. M. Jørg. & Wedin (hardwood bark and sandstone) – B: *50969, 50971, 51014, 51099, 51117*. M: *50848, 51180*.

Thelidium minutulum Körb. (sandstone) – B: *51116*.

Trapelia placodioides Coppins & P. James (sandstone) – B: *51114*. M: *51196*.

Trapeliopsis flexuosa (Fr.) Coppins & P. James (lignum) – M: *51240*.

Trypethelium virens Tuck. (hardwood bark; *Carpinus* and *Fagus*) – B: *51100, 51217*. M: *51278*.

Verrucaria phloeophila Breuss (bryophytes and bark of white oaks) – B: *50970, 51063*. M: *50924, 51226*.

Violella fucata (Stirt.) T. Sprib. (hardwood bark) – M: *50925*.

Xanthomendoza weberi (Kondr. & Karnef.) L. Lindblom (fallen branches) – M: *51234*.

APPENDIX II

MODERN CHECKLIST OF INDIANA LICHENS

The checklist presented below is arranged alphabetically by genus and species. Lichenicolous fungi are denoted with an asterisk (*) and allied fungi are denoted with a dagger (†). Species newly reported herein for Indiana are printed in bold text. The source, or sources, of the original literature reports are presented following each name. Nomenclature and name usage follows Esslinger (2016) although any deviations (e.g., lack of recognition of the recent generic seggragtes in *Caloplaca*) from that work represent the opinions of the present author. Questionable historical reports that require verification or further study before being formally incorporated into the Indiana checklist are detailed at the end of the list. A translation table that details the updates of names used in original literature is also appended following the list of questionable historical reports.

Checklist of Lichens, Lichenicolous and Allied Fungi Reported from Indiana

***Acrocordia megalospora* (Fink) R.C. Harris**

Acarospora immersa Fink (Wetmore 1988a)

Amandinea dakotensis (H. Magn.) P. May & Sheard (Sheard & May 1997: Fig. 1)

***Amandinea polyspora* (Willey) E. Lay & P. May**

Amandinea punctata (Hoffm.) Coppins & Scheid. (Fink & Fuson 1918 as *Buellia myriocarpa*, Herre 1943b; Wetmore 1988a; Hyerczyk 1997a)

Anaptychia palmulata (Michx.) Vain. (Miller & Thomson 1959)

Anisomeridium biforme (Borr.) R.C. Harris (Wetmore 1988a; Hyerczyk 1997a)

***Anisomeridium leucochlorum* (Müll. Arg.) R.C. Harris**

***Anisomeridium polypori* (Ellis & Everh.) M.E. Barr**

***Arthonia apatetica* (A. Massal.) Th. Fr.**

Chrysothrix caesia (Flot.) Ertz & Tehler (Fink & Fuson 1918 as *Arthonia lecideella*; Herre 1943b as *A. lecideella*; Miller & Thomson 1959; Wetmore 1988a; Hyerczyk 1997a)

***Arthonia helvola* (Nyl.) Nyl.**

Arthonia lapidicola (Taylor) Branth & Rostr. (Herre 1943b)

†***Arthonia quintaria* Nyl.**

Arthonia radiata (Pers.) Ach. (Harris 1988)

Arthothelium spectabile A. Massal. (Herre 1943b; Harris 1988)

Bacidia granosa (Tuck.) Zahlbr. (Harris 1988 as *B. trachona*)

***Bacidia purpurans* R.C. Harris, Lendemer & Ladd**

Bacidia schweinitzii (Fr. *ex* Tuck.) A. Schneid. (Fink & Fuson 1918; Herre 1943b; Miller & Thomson 1959)

***Bacidia sorediata* Lendemer & R.C. Harris**

Bagliettoa calciseda (DC.) Gueidan & Cl. Roux (Miller & Thomson 1959)

***Biatora printzenii* Tønsberg**

Blennothallia crispa (Hudson) Otálora, P. M. Jørg. & Wedin (Harris 1988 as *Collema crispum*)

***Buellia wheeleri* R.C. Harris**

Caloplaca atroalba (Tuck.) Zahlbr. (Harris 1988)

Caloplaca cerina (Hedw.) Th. Fr. (Wetmore 1988a)

Caloplaca citrina (Hoffm.) Th. Fr. (Miller & Thomson 1959)

Caloplaca feracissima H. Magn. (Wetmore 1988a; Hyerczyk 1997a)

Caloplaca flavovirescens (Wulfen) Dalla Torre & Sarnth. (Herre 1943b; Miller & Thomson 1959)

Caloplaca holocarpa (Ach.) M. Wade (Harris 1988; Hyerczyk 1997a)

Caloplaca microphyllina (Tuck.) Hasse (Fink & Fuson 1918; Herre 1943b; Hyerczyk 1997a)

Caloplaca oxfordensis Fink *ex* J. Hedrick (Herre 1943b)

Caloplaca sideritis (Tuck.) Zahlbr. (Fink & Fuson 1918; Herre 1943b)

Caloplaca ulmorum (Fink) Fink (Fink & Fuson 1918; Herre 1943b)

Candelaria concolor (Dicks.) Stein (Herre 1943b; Miller & Thomson 1959; Harris 1988; Wetmore 1988a; Hyerczyk 1997a)

Candelariella aurella (Hoffm.) Lettau. (Fink & Fuson 1918; Herre 1943b)

Candelariella efflorescens R.C. Harris & Buck (Wetmore 1988a)

Candelariella xanthostigma (Ach.) Lettau (Wetmore 1988a)

Candelariella xanthostigmoides (Müll. Arg.) R.W. Rogers (Hyerczyk 1997a)

***Canoparmelia texana* (Müll. Arg.) Elix & Hale**

***Catillaria nigroclavata* (Nyl.) Schul.**

†*Chaenothecopsis debilis* (Turner & Borrer ex Sm.) Tibell

Cladonia apodocarpa Robbins (Harris 1988)

Cladonia arbuscula (Wallr.) Flot. (Harris 1988)

Cladonia bacilliformis (Nyl.) Sarnth. (Wetmore 1988a)

Cladonia caespiticia (Pers.) Flörke (Herre 1943b; Miller & Thomson 1959; Harris 1988; Wetmore 1988a)

Cladonia chlorophaea (Flörke *ex* Sommerf.) Spreng. (Herre 1943b; Miller & Thomson 1959; Harris 1988; Wetmore 1988a)

Cladonia conista (Ach.) A. Evans (Harris 1988 as *C. humilis*)

Cladonia cristatella Tuck. (Herre 1943a; Miller & Thomson 1959; Harris 1988; Wetmore 1988a)

Cladonia cryptochlorophaea Asah. (Harris 1988; Wetmore 1988a)

Cladonia cylindrica (A. Evans) A. Evans (Herre 1943b; Miller & Thomson 1959; Harris 1988; Wetmore 1988a)

Cladonia fimbriata (L.) Fr. (Herre 1943a, 1943b; Wetmore 1988a)

Cladonia furcata (Huds.) Schaer. (Herre 1943a, 1943b; Miller & Thomson 1959; Harris 1988)

Cladonia grayi G. Merr. *ex* Sandst. (Herre 1943b; Miller & Thomson 1959; Harris 1988; Wetmore 1988a)

Cladonia macilenta var. *bacillaris* (Genth.) Schaer. (Fink & Fuson 1918; Herre 1943b; Miller & Thomson 1959; Harris 1988; Wetmore 1988a)

Cladonia macilenta Hoffm. var. *macilenta* (Fink & Fuson 1918; Herre 1943b)

Cladonia mitis Sandst. (Wetmore 1988a)

Cladonia multiformis G. Merr. (Harris 1988)

Cladonia ochrochlora Flörke (Fink & Fuson 1918 as *C. coniocraea*; Herre 1943b as *C. coniocraea*; Miller & Thomson 1959 as *C. coniocraea*; Harris 1988; Wetmore 1988a)

Cladonia parasitica Hoffm. (Miller & Thomson 1959 as *C. delicata*)

***Cladonia petrophila* R.C. Harris**

Cladonia peziziformis (With.) J.R. Laundon (Herre 1943a, 1943b as *C. mitrula*; Miller & Thomson 1959 as *C. capitata* f. *microcarpa* and f. *imbricatula*; Harris 1988; Wetmore 1988a; Hyerczyk 1997a)

Cladonia phyllophora Hoffm. (Harris 1988)

Cladonia piedmontensis G. Merr. (Miller & Thomson 1959; Harris 1988)

Cladonia pleurota (Flörke) Schaer. (Harris 1988; Wetmore 1988a)

Cladonia polycarpoides Nyl. (Harris 1988; Wetmore 1988a; Hyerczyk 1997a)

Cladonia pyxidata (L.) Hoffm. (Herre 1943a, 1943b; Wetmore 1988a)

Cladonia ramulosa (With.) J.R. Laundon (Wetmore 1988a; Hyerczyk 1997a)

Cladonia rei Schaer. (Wetmore 1988a)

Cladonia robbinsii A. Evans (Miller & Thomson 1959)

Cladonia sobolescens Nyl. *ex* Vain. (Harris 1988)

Cladonia squamosa Hoffm. (Miller & Thomson 1959)

Cladonia strepsilis (Ach.) Grogn. (Wetmore 1988a)

Cladonia subtenuis (Abbayes) Mattick (Miller & Thomson 1959; Harris 1988)

Cladonia rangiferina (L.) Nyl. (Wetmore 1988a)

Cladonia uncialis (L.) F.H. Wigg. (Herre 1943b as *C. uncialis* f. *obtusata*)

Cladonia verticillata (Hoffm.) Schaer. (Herre 1943b; Miller & Thomson 1959; Harris 1988; Wetmore 1988a)

***Coenogonium pineti* (Ach.) Lumbsch & Lücking**

Collema nigrescens (Huds.) DC. (Herre 1943a, 1943b)

Collema pulchellum Ach. (Herre 1943a, 1943b as *Leptogium pulchella*)

Collema ryssoleum (Tuck.) A. Schneid. (Herre 1943b)

***Collema subflaccidum* Degel.**

***Crespoa crozalsiana* (Harm.) Lendemer & B.P. Hodk.**

Cyphelium tigillare (Ach.) Ach. (Hyerczyk 1997a)

Dibaeis absoluta (Tuck.) Kalb & Gierl (Miller & Thomson 1959 as *Baeomyces absolutus*)

***Dictyocatenulata alba* Finley & E.F. Morris**

Diploschistes scruposus (Schreb.) Norman (Wetmore 1988a)

Enchylium conglomeratum (Hoffm.) Otálora, P.M. Jørg. & Wedin (Herre 1943b as *Collema pycnocarpum*)

Enchylium tenax (Sw.) Gray (Harris 1988 as *Collema tenax*)

Evernia mesomorpha Nyl. (Wetmore 1988a)

***Fellhanera silicis* R.C. Harris & Ladd**

Flavoparmelia caperata (L.) Hale (Herre 1943a, 1943b; Miller & Thomson 1959; Harris 1988; Wetmore 1988a)

Flavopunctelia flaventior (Stirt.) Hale (Wetmore 1988a; Hyerczyk 1997a)

Graphis scripta (L.) Ach. (Herre 1943b; Miller & Thomson 1959; Harris 1988)

***Heterodermia obscurata* (Nyl.) Trevis.**

Heterodermia speciosa (Wulfen) Trevis. (Miller & Thomson 1959; Harris 1988)

Hyperphyscia adglutinata (Flörke) H. Mayrh. & Poelt (Hyerczyk 1997a)
Hypogymnia physodes (L.) Nyl. (Herre 1943b)
Hypotrachyna livida (Taylor) Hale
†_Julella fallaciosa_ (Stizenb.) R.C. Harris
Lathagrium fuscovirens (With.) Otálora, P. M. Jørg. & Wedin (Harris 1988 as *Collema fuscovirens*)
Lecania croatica (Zahlbr.) Kotlov (Harris & Lendemer 2010)
Lecania perproxima auct. (Miller & Thomson 1959)
Lecanora appalachensis Lendemer & R.C. Harris
Lecanora hybocarpa (Tuck.) Brodo
Lecanora layana Lendemer
Lecanora nothocaesiella R.C. Harris & Lendemer
Lecanora saligna (Schrad.) Zahlbr. (Wetmore 1988a)
Lecanora strobilina (Spreng.) Kieff. (Hyerczyk 1997a)
Lecanora symmicta (Ach.) Ach. (Hyerczyk 1997a)
Lecanora thysanophora R.C. Harris (Wetmore 1988a)
Lecidea cyrtidia Tuck. (Miller & Thomson 1959)
Lecidea erythrophaea Flörke _ex_ Sommerf.
Lecidea virginiensis Calk. & Nyl. (Miller & Thomson 1959)
Leimonis erratica (Körb.) R.C. Harris & Lendemer (Miller & Thomson 1959)
Lepra pustulata (Brodo & Culb.) Lendemer & R.C. Harris
Lepraria caesiella R.C. Harris
Lepraria finkii (de Lesd.) R.C. Harris (Harris 1988; Wetmore 1988a)
Lepraria harrisiana Lendemer
Lepraria hodkinsoniana Lendemer
Leptogium cyanescens (Rabenh.) Körb. (Miller & Thomson 1959; Harris 1988)
Leptogium juniperinum Tuck. (Herre 1943a, 1943b)
Leptogium lichenoides (L.) Zahlbr. (Herre 1943b; Miller & Thomson 1959; Harris 1988)
Lithothelium hyalosporum (Nyl.) R.C. Harris
Lobaria pulmonaria (L.) Hoffm. (Herre 1943b; Harris 1988)
Lobaria quercizans Michx. (Harris 1988)
Melanelixia subaurifera (Nyl.) O. Blanco, A. Crespo, Divakar, Essl., D. Hawksw. & Lumbsch (Wetmore 1988a; Hyerczyk 1997a)
Micarea micrococca (Korb.) D. Hawksw.
Micarea peliocarpa (Anzi) Coppins & R. Sant. (Harris 1988)
Micarea prasina Fr. (Wetmore 1988a)
Micarea soralifera Guz.-Krzemiń., Czarnota, Łubek & Kukwa
Myelochroa aurulenta (Tuck.) Elix & Hale (Miller & Thomson 1959; Harris 1988)
Myelochroa galbina (Ach.) Elix & Hale
Myriolecis dispersa (Pers.) Śliwa, Zhao Xin & Lumbsch (Fink & Fuson 1918; Herre 1943b; Harris 1988; Wetmore 1988a; Hyerczyk 1997a)
Myriolecis hagenii (Ach.) Śliwa, Zhao Xin & Lumbsch (Fink & Fuson 1918; Herre 1943b; Wetmore 1988a)
Nadvornikia sorediata R.C. Harris
Ochrolechia trochophora (Vain.) Oshio (Harris 1988 as *O. rosella*)
Opegrapha varia Pers. (Fink & Fuson 1918; Herre 1943b)
Opegrapha vulgata Ach.
Parmelia squarrosa Hale (Harris 1988)
Parmelia sulcata Taylor (Wetmore 1988a; Hyerczyk 1997a)
Parmotrema hypotropum (Nyl.) J. Steiner
Parmotrema perforatum (Jacq.) A. Massal. (Herre 1943b; Harris 1988)
Parmotrema reticulatum (Ach.) M. Choisy
Peltigera canina (L.) Willd. (Herre 1943a, 1943b; Harris 1988)
Peltigera didactyla (With.) J.R. Laundon (Herre 1943b as *P. spuria*; Harris 1988)
Peltigera evansiana Gyeln. (Miller & Thomson 1959; Harris 1988)
Peltigera horizontalis (Huds.) Baumg. (Fink & Fuson 1918; Herre 1943b; Harris 1988)
Peltigera hymenina (Ach.) Delise (Harris 1988 as *P. lactucifolia*)
Peltigera malacea (Ach.) Funck (Herre 1943b)
Peltigera neckeri Müll. Arg. (Harris 1988)
Peltigera polydactyla (Neck.) Hoffm. (Herre 1943a, 1943b)
Peltigera praetextata (Sommerf.) Zopf (Fink & Fuson 1918; Herre 1943a, 1943b, Miller & Thomson 1959 as *P. canina* var. *rufescens* f. *innovans*; Harris 1988)
Peltigera rufescens (Weiss) Humb. (Herre 1943b; Miller & Thomson 1959; Harris 1988; Wetmore 1988a)
Pertusaria pustulata (Ach.) Duby (Fink & Fuson 1918; Herre 1943b)
†_Phaeocalicium polyporaeum_ (Nyl.) Tibell
Phaeophyscia adiastola (Essl.) Essl. (Harris 1988)
Phaeophyscia ciliata (Hoffm.) Moberg (Miller & Thomson 1959; Wetmore 1988a)
Phaeophyscia hirsuta (Mereschk.) Essl. (Harris 1988; Wetmore 1988a)
Phaeophyscia kairamoi (Vain.) Moberg (Harris 1988)
Phaeophyscia orbicularis (Necker) Moberg (Miller & Thomson 1959; Harris 1988)
Phaeophyscia pusilloides (Zahlbr.) Essl. (Wetmore 1988a)
Phaeophyscia rubropulchra (Degel.) Essl. (Wetmore 1988a)
Phaeophyscia squarrosa Kashiw.
Physcia adscendens (Th. Fr.) H. Olivier (Wetmore 1988a; Hyerczyk 1997a)
Physcia americana G. Merr.
Physcia aipolia (Humb.) Fürnr. (Harris 1988)
Physcia millegrana Degel. (Miller & Thomson 1959; Harris 1988; Wetmore 1988a; Hyerczyk 1997a)
Physcia stellaris (L.) Nyl. (Herre 1943b; Miller & Thomson 1959; Harris 1988; Wetmore 1988a; Hyerczyk 1997a)
Physciella chloantha (Ach.) Essl. (Wetmore 1988a)
Physconia detersa (Nyl.) Poelt (Wetmore 1988a)
***_Piccolia nannaria_ (Tuck.) Lendemer & Beeching**

Placynthiella icmalea (Ach.) Coppins & P. James (Wetmore 1988a)
Placynthiella oligotropha (J.R. Laundon) Coppins & P. James (Wetmore 1988a)
Placynthiella uliginosa (Schrad.) Coppins & P. James (Fink & Fuson 1918; Herre 1943b)
Placynthium nigrum (Huds.) Gray (Miller & Thomson 1959; Harris 1988)
Porpidia albocaerulescens (Wulfen) Hertel & Knoph (Miller & Thomson 1959; Harris 1988)
Pseudosagedia cestrensis **(Tuck.) R.C. Harris**
Pseudosagedia isidiata **(R.C. Harris) R.C. Harris**
Psorotichia schaereri (A. Massal.) Arnold (Miller & Thomson 1959)
Punctelia bolliana (Müll. Arg.) Krog (Wetmore 1988a)
Punctelia caseana **Lendemer & B.P. Hodk.**
Punctelia graminicola **(de Lesd.) R.S. Egan**
Punctelia missouriensis G. Wilh. & Ladd (Wilhelm & Ladd 1992)
Punctelia rudecta (Ach.) Krog (Fink & Fuson 1918; Herre 1943b; Miller & Thomson 1959; Harris 1988; Wetmore 1988a; Hyerczyk 1997a)
******Pyrenidium aggregatum*** **K. Knudsen & Kocourk.**
Pyrenopsis fuscoatra Fink (Fink & Fuson 1918; Herre 1943b)
Pyrenula laevigata **(Pers.) Arnold**
Pyrenula pseudobufonia **(Rehm) R.C. Harris**
Pyrenula subelliptica **(Tuck.) R.C. Harris**
Pyrrhospora varians **(Ach.) R.C. Harris**
Pyxine sorediata (Mont.) Tuck. (Fink & Fuson 1918; Herre 1943b; Miller & Thomson 1959)
Pyxine subcinerea **Stirt.**
Ramalina americana Hale (Harris 1988)
Rinodina papillata **H. Magn.**
Rinodina pyrina **(Ach.) Arnold**
Ropalospora viridis **(Tønsberg) Tønsberg**
†*Sarea difformis* **(Fr.) Fr.**
†*Sarea resinae* **(Fr.) Kunze**
Scoliciosporum chlorococcum (Stenh.) Vězda (Miller & Thomson 1959; Wetmore 1988a)
Scoliciosporum pensylvanicum **R.C. Harris**
Scytinium dactylinum (Tuck.) Otálora, P. M. Jørg. & Wedin (Herre 1943a, 1943b as *Leptogium dactylinum*)
Strigula submuriformis (R.C. Harris) R.C. Harris (Harris 1988)
Thelidium microcarpum (Leight.) A.L. Smith (Hyerczyk 1997a)
Thelidium minutulum **Körb.**
Thelocarpon laureri (Flot.) Nyl. (Wetmore 1988a)
Thrombium epigaeum (Pers.) Wallr. (Herre 1943b)
Trapelia glebulosa (With.) J.R. Landon (Wetmore 1988a)
Trapelia placodioides **Coppins & P. James**
Trapeliopsis flexuosa (Fr.) Coppins & P. James (Wetmore 1988a)
Trypethelium virens Tuck. (Fink & Fuson 1918; Herre 1943b)
Usnea strigosa (Ach.) A. Eaton (Harris 1988)
Verrucaria muralis Ach. (Fink & Fuson 1918; Harris 1988; Wetmore 1988a)
Verrucaria iovensis Servít (Miller & Thomson 1959)
Verrucaria phloeophila **Breuss**
Verrucaria nigrescens Pers. (Fink & Fuson 1918; Herre 1943b)
Verrucaria sordida Fink (Fink & Fuson 1918; Herre 1943b)
Violella fucata **(Stirt.) T. Sprib.**
Willeya diffractella (Nyl.) Müll. Arg. (Harris 1988 as *Staurothele catalepta*)
Xanthomendoza fallax Søchting, Kärnefelt & S.Y. Kondr. (Miller & Thomson 1959; Wetmore 1988a; Hyerczyk 1997a)
Xanthomendoza weberi (Kondr. & Karnef.) L. Lindblom (Lindblom 1997, 2006 as *Xanthoria fulva*)
Xanthoria polycarpia (Hoffm.) Rieber (Harris 1988)

QUESTIONABLE HISTORICAL REPORTS

Taxa listed in this section are those that have been previously reported from Indiana, but whose identities require further study. In many cases these are reports that were made in the 19th or early 20th centuries and there is a strong probability that the supporting voucher specimen represents a taxon distinct from that to which the name is currently applied.

Acarospora cervina A. Massal. (Fink & Fuson 1918; Herre 1943b) – The identities of these records require verification.
Arthonia dispersa (Schrad.) Nyl. (Fink & Fuson 1918; Herre 1943b) – The identities of these records require verification.
Arthonia radiata (Pers.) Ach. (Fink & Fuson 1918; Herre 1943b) – The identities of these records require verification.
Bacidia inundata (Fr.) Körb. (Fink & Fuson 1918; Herre 1943b) – This species is now treated as *Bacidina inundata* (Fr.) Vězda. However, the name was widely applied to nearly any saxicolous *Bacidina* species historically and thus many records represent other taxa.
Bacidia rubella (Hoffm.) A. Massal. (Fink & Fuson 1918, Herre 1943b sub. *B. luteola*) – While it is possible that *B. rubella* occurs in Indiana, it is likely that the records represent other taxa.
Caloplaca lactea (A. Massal.) Zahlbr. (Miller & Thomson 1959) – The identity of this record requires verification.
Catillaria chalybeia (Borrer) A. Massal. (Miller & Thomson 1959) – While this species is still recognized, the majority of historical records from eastern North America belong to other members of the genus such as *C. lenticularis*.
Cladonia cariosa (Ach.) Spreng. (Fink & Fuson 1918; Herre 1943a, 1943b) - The identities of these records require verification, particularly given that Brodo et al. (2001) did not map the species as occurring in Indiana.

Cladonia clavulifera Vain. (Miller & Thomson 1959) – This name was often used for members of the *C. subcariosa* group historically. However, the supporting vouchers for such records need to be studied both morphologically and chemically to assign them to species as currently delimited.

Cladonia rangiformis Hoffm. (Herre 1943b) – This name was widely applied to various highly branched *Cladonia* species historically in North America, but the only confirmed report of the species from the continent is of a single population on the Avalon Peninsula of Newfoundland, Canada.

Cladonia subcariosa Nyl. (Herre 1943b; Miller & Thomson 1959) – This name was often used for members of the *C. subcariosa* group historically. However, the supporting vouchers for such records need to be studied both morphologically and chemically to assign them to species as currently delimited.

Cladonia subcariosa var. *evoluta* Vain. (Herre 1943b) – This name was often used for members of the *C. subcariosa* group historically. However, the supporting vouchers for such records need to be studied both morphologically and chemically to assign them to species as currently delimited.

Cladonia symphycarpia (Flörke) Fr. (Herre 1943b) – This name was often used for members of the *C. subcariosa* group historically. However, the supporting vouchers for such records need to be studied both morphologically and chemically to assign them to species as currently delimited.

Cladonia tenuis (Flörke) Harm. (Herre 1943b) – Historical records under this name from eastern North America often represent *C. subtenuis*. However, study of the supporting vouchers is needed to verify this.

Dermatocarpon hepaticum (Ach.) Th. Fr. (Miller & Thomson 1959) – Following Esslinger (2016) most records under this name would belong to *Placidium squamulosum* (Ach.) Breuss. However, the name was widely misapplied in the past to multiple squamulose pyrenolichens in eastern North America and the record requires verification.

Lecanora subfusca (L.) Ach. (Herre 1943b) – This name was widely misapplied historically to a multitude of taxa (Brodo 1984).

Lecanora varia (Hoffm.) Ach. (Fink & Fuson 1918; Herre 1943b) – This name was widely misapplied historically to a multitude of taxa and the majority of historical reports correspond to *L. strobilina* (see e.g., Printzen 2001).

Lecidea coarctata (Turner) Ach. (Fink & Fuson 1918; Herre 1943b) – Although this species is now treated as *Trapelia coarctata* (Turner) M. Choisy, many historical records belong to other members of the genus and thus verification of the supporting vouchers is required (see e.g., Brodo & Lendemer 2015).

Lecidea enteroleuca Ach. (Fink & Fuson 1918) – The identity of this record requires verification.

Lecidea myriocarpoides Nyl. (Fink & Fuson 1918; Herre 1943b) – The identity of this record requires verification.

Lecidea russellii Tuck. (Herre 1943a, 1943b) – Record likely is *Psora pseudorussellii* but requires verification.

Lecidea vulgata Zahlbr. (Herre 1943b) – This report refers back to the report of *L. enteroleuca* from Fink and Fuson (1919).

Leptogium chloromelum (Ach.) Nyl. (Herre 1943a, 1943b) – The identities of these records require verification, particularly given that it is not mapped as occurring in Indiana (Brodo et al. 2001; Sierk 1964).

Leptogium lichenoides var. *pulvinatum* (Hoffm.) Zahlbr. (Herre 1943b) – The identity of this record requires verification.

Leptogium tremelloides (Ach.) Gray (Fink & Fuson 1918; Herre 1943b) – Records likely are *L. cyanescens* but require verification.

Microthelia macularis Hampe ex A. Massal. (Herre 1943b) – The identity of this record requires verification.

Parmelia borreri (Sm.) Turner (Herre 1943b) – This species is now treated as *Punctelia borreri* (Sm.) Krog, however, historical records are often misidentifications of other members of the genus and require verification.

Parmelia centrifuga (L.) Ach. (Herre 1943b) – This species is now treated as *Arctoparmelia centrifuga* (L.) Hale. However, the range of the species as mapped by Brodo et al. (2001) does not include Indiana.

Parmelia cetrata Ach. (Herre 1943b) – This species is now treated as *Parmotrema cetratum* (Ach.) M. Choisy, however, historical records could refer to this taxon or several other morphologically similar species such as *P. despectum* Kurok.

Parmelia ciliata (DC.) Nyl. (Fink & Fuson 1918) – The identity of this record requires verification.

Parmelia conspersa (Ach.) Ach. (Fink & Fuson 1918; Herre 1943b) – While this species is now treated as *Xanthoparmelia conspersa* (Ach.) Hale, historical specimens could represent any number of species within that genus that are now recognized.

Parmelia conspersa f. *imbricata* A. Massal. (Herre 1943b) – The identity of this record requires verification.

Parmelia perlata (Huds.) Ach. (Herre 1943b) – While this species is now treated as *Parmotrema perlatum* (Huds.) M. Choisy, the identity of this record requires verification, particularly given that Brodo et al. (2001) did not map the species as occurring in Indiana.

Parmelia saxatilis (L.) Ach. (Herre 1943b) – The identity of this record requires verification, particularly given that Brodo et al. (2001) did not map the species as occurring in Indiana.

Parmelina quercina (Willd.) Hale (Herre 1943a, 1943b) – The exact identities of these reports requires further study. Most historical records of *P. quercina* refer to *Hypotrachyna livida*, although they can also refer to *Myelochroa galbina* and even other species.

Parmeliopsis diffusa (Körb.) Poetsch (Herre 1943b) – The identity of this record requires verification.

Pertusaria copiosa Erichsen (Miller & Thomson 1959) – This species is now treated as *Lepra commutata* (Müll. Arg.) Lendemer & R.C. Harris (Lendemer & Harris 2017), however, that species is not known to occur in Indiana (Dibben 1980) and the record requires further study.

Physcia aquila (Ach.) Nyl. (Fink & Fuson 1918, Herre 1943b sub. *Anaptychia fusca*) – The identities of these records require verification, although it is likely that they refer to *A. palmulata*.

Physcia astroidea Nyl. (Fink & Fuson 1918) – The identity of this record requires verification.

Physcia clementiana (Ach.) J. Kickx (Herre 1943b) – The identity of this record requires verification, although it likely corresponds to *Physcia americana*.

Parmelia dubia (Hoffm.) Röhl. (Fink & Fuson 1918) – The identity of this record requires verification, particularly given that Brodo et al. (2001) did not map the species as occurring in Indiana.

Physcia endochrysea (Nyl.) Hampe (Fink & Fuson 1918; Herre 1943b) – The identities of these records require verification.

Physcia leucoleiptes (Tuck.) Lettau (Fink & Fuson 1918; Herre 1943b) – The identity of this record requires verification, although it likely is correct and if so, then *Physconia leucoleiptes* (Tuck.) Essl. should be added to the Indiana checklist.

Physcia obscura (Ehrh.) Hampe ex Fürnr. (Fink & Fuson 1918; Herre 1943b) – The identities of these records require verification.

Physcia pulverulenta (Schreb.) Hampe ex Fürnr. (Fink & Fuson 1918; Herre 1943b) – The identities of these records require verification, although it is likely that they refer to *Physconia subpallida* Essl.

Physcia setosa (Ach.) Nyl. (Herre 1943a, 1943b) – The identities of these records require verification.

Physcia tribacia (Ach.) Nyl. (Fink & Fuson 1918; Herre 1943b) – The identities of these records require verification.

Physcia virella (Ach.) Flagey (Herre 1943a, 1943b) – The identities of these records require verification.

Peltigera praetextata var. *isidiata* Gyeln. (Herre 1943b) – The identity of this record requires verification, although it likely refers to *P. evansiana*.

Placodium pyraceum (Ach.) Anzi (Fink & Fuson 1918, Herre 1943b sub. *Caloplaca pyracea*) – The identities of these records require verification.

Placodium variabile (Pers.) Hepp (Fink & Fuson 1918, Herre 1943b sub. *Caloplaca variabilis*) – The identities of these records require verification.

Pyrenula cinerella (Nyl.) Branth & Rostr. (Fink & Fuson 1918) – The identity of this record requires verification.

Pyrenula farrea (Ach.) Branth & Rostr (Herre 1943b) – The identity of this record requires verification.

Pyrenula leucoplaca (Wallr.) Körb. (Fink & Fuson 1918) – The identity of this record requires verification.

Pyrenula nitida (Weigel) Ach. (Fink & Fuson 1918; Herre 1943b) – The identities of these records require verification.

Ramalina calicaris (L.) Röhl. (Herre 1943b) – The identity of this record requires verification.

Ramalina fraxinea (L.) Ach. (Fink & Fuson 1918; Herre 1943b) – The identities of these records require verification.

Ramalina subamplicata (Nyl.) Fink (Herre 1943b) – The identity of this record requires verification.

Rhizocarpon albineum (Tuck.) Fink (Herre 1943b) – The identity of this record requires verification. Nonetheless, it is likely to be *R. reductum* Th. Fr.

Rhizocarpon concentricum (Davies) Beltr. (Miller & Thomson 1959) – The identity of this record requires verification.

Rinodina lecanorina (A. Massal.) A. Massal. (Fink & Fuson 1918; Herre 1943b, sub. *R. ocellata*) – The identities of these records require verification.

Sticta weigelii Isert (Herre 1943b) – The identity of this record requires verification, although it likely refers to *S. beauvoisii* Delise.

Teloschistes lychneus (Ach.) Tuck. (Fink & Fuson 1918; Herre 1943b sub. *Xanthoria candelaria*) – While this species is now treated as *Xanthoria candelaria* (L.) Th. Fr., it was not mapped as occurring in Indiana by Lindblom (1997) or Brodo et al. (2001).

Thelidium microbolum (Tuck.) Hasse (Herre 1943b) – The identity of this record requires verification.

Thelocarpon prasinellum Nyl. (Fink & Fuson 1918; Herre 1943b) – The identities of these records require verification.

Usnea dasopoga Ach. (Herre 1943b) – The identity of this record requires verification.

Usnea florida (L.) F.H. Wigg. (Herre 1943b) – This species does not occur in eastern North America and the historical record likely refers to either *U. endochrysea* Stirt. or *U. strigosa*.

Verrucaria epigaea (Pers.) Ach. (Fink & Fuson 1918) – The identity of this record requires verification.

Verrucaria rupestris Schrad. (Fink & Fuson 1918; Herre 1943b) – The identities of these records require verification.

Verrucaria viridula (Schrad.) Ach. (Fink & Fuson 1918; Herre 1943b) – The identities of these records require verification.

Xanthoria candelaria var. *laciniosa* (Dufour) Arnold (Herre 1943b) – The identity of this record requires verification, especially given that *X. candelaria* is not considered to occur in Indiana (Brodo et al. 2001; Lindblom 1997).

Xanthoria parietina (L.) Th. Fr. (Herre 1943b) – While this species is now still recognized, the identity of this record requires verification given that it is not considered to occur in Indiana (Brodo et al. 2001; Lindblom 1997).

SYNONYMS AND EXCLUDED SPECIES

This section comprises a translation table between previously used names and current names, as well as an enumeration of species reported from Indiana but whose supporting vouchers represent other taxa.

Allarthonia caesia (Flot.) Zahlbr. = *Chrysohrix caesia*
Allarthonia lapidicola (Taylor) Zahlbr. = *Arthonia lapidicola*
Anaptychia speciosa (Wulfen) A. Massal. = *Heterodermia speciosa*
Anisomeridium nyssigenum (Ellis & Everh.) R.C. Harris = *A. polypori*
Arthonia caesia (Flot.) Körb. = *Chrysohrix caesia*
Arthonia lecideella Nyl. = *Chrysohrix caesia*
Bacidia chlorococca (Graewe *ex* Stenh.) Lettau = *Scoliciosporum chlorococcum*
Bacidia trachona (Ach.) Lettau – Record published by Harris (1988) is *B. granosa*
Baeomyces absolutus Tuck. = *Dibaeis absoluta*
Buellia punctata (Hoffm.) A. Massal. = *Amandinea punctata*
Candelaria concolor var. *effusa* (Tuck.) G. Merr. & Burnham = *C. concolor*
Candelariella reflexa (Nyl.) Lettau = records from North America are *C. xanthostigmoides*
Cladina arbuscula (Wallr.) Hale & Culb. = *Cladonia arbuscula*
Cladina mitis (Sandst.) Hustich = *Cladonia mitis*
Cladina rangiferina (L.) Nyl. = *Cladonia rangiferina*
Cladina subtenuis (Abbayes) Hale & Cub. = *Cladonia subtenuis*
Cladonia bacillaris Nyl. = *C. macilenta* var. *bacillaris*
Cladonia bacillaris f. *clavata* (Ach.) Vain. = *C. bacillaris*
Cladonia bacillaris var. "*abbreviata*" = *C. bacillaris*
Cladonia borbonica f. *cylindrica* A. Evans = *C. cylindrica*
Cladonia capitata f. *imbricatula* (Nyl.) A. Evans = *C. peziziformis*
Cladonia capitata f. *microcarpa* (A. Evans) A. Evans = *C. peziziformis*
Cladonia chlorophaea f. "*simplex*" = *C. chlorophaea*
Cladonia coniocraea (Flörke) Spreng. – Records likely correspond to *C. ochrochlora*
Cladonia coniocraea f. *ceratodes* (Flörke) Dalla Torre & Sarnth. = *C. ochrochlora*
Cladonia cristatella f. *beauvoisii* (Delise) Vain. = *C. cristatella*
Cladonia cristatella f. "*ochrocarpia*" = *C. cristatella*
Cladonia cristatella f. "*vestita*" = *C. cristatella*
Cladonia cristatella f. "*squamosissima*" = *C. cristatella*
Cladonia cylindrica f. *squamulosa* (Robbins) A. Evans = *C. cylindrica*
Cladonia delicata (Ehrh.) Flörke = *C. parasitica*
Cladonia fimbriata var. *simplex* (Weiss) Flot. *ex* Vain. = *C. fimbriata*
Cladonia fimbriata var. coniocraea (Flörke) Nyl. = *C. coniocraea*
Cladonia furcata f. *foliolosa* (Duby) Vain. = *C. furcata*
Cladonia furcata f. *squamulifera* Sandst. = *C. furcata*
Cladonia furcata var. *corymbosa* (Ach.) Nyl. = *C. furcata*
Cladonia furcata var. *pinnata* (Flörke) Vain. = *C. furcata*
Cladonia furcata var. *racemosa* (Hoffm.) Flörke = *C. furcata*
Cladonia grayi f. *carpophora* A. Evans = *C. grayi*
Cladonia grayi f. *squamulosa* Sandst. = *C. grayi*
Cladonia humilis (With.) J.R. Laundon – Records are *C. conista*
Cladonia mitrula Tuck. = *C. peziziformis*
Cladonia mitrula f. *imbricatula* (Nyl.) Vain. = *C. peziziformis*
Cladonia mitrula f. *squamulosa* G. Merr. = *C. peziziformis*
Cladonia piedmontensis f. *lepidifera* (Vain.) Robbins = *C. piedmontensis*
Cladonia pyxidata f. *simplex* (Ach.) Harm. = *C. pyxidata*
Cladonia uncialis f. *obtusata* (Ach.) Vain. = *C. uncialis*
Cladonia verticillata var. *evoluta* Th. Fr. = *C. verticillata*
Cladonia verticillata f. *phyllocephala* (Flot.) Vain = *C. verticillata*
Collema crispum (With.) J.R. Laundon = *Blennothallia crispa*
Collema fuscovirens (With.) J.R. Laundon = *Lathagrium fuscovirens*
Collema pycnocarpum Nyl. = *Enchylium conglomeratum*
Collema tenax (Sw.) Ach. = *Enchylium tenax*
Dermatocarpon miniatum (L.) Mann. – Records likely are other members of the genus (e.g., *D. muhlenbergii*).
Endocarpon pusillum Hedw. – Records are either *E. pallidulum* or *E. petroleptideum* (see Lendemer 2007).
Lecanora dispersa (Pers.) Röhl. = *Myriolecis dispersa*
Lecanora hagenii (Ach.) Ach. = *Myriolecis hagenii*
Leptogium dactylinum Tuck. = *Scytinium dactylinum*
Leptogium pulchellum (Ach.) Nyl. = *Collema pulchella*
Lecidea albocaerulescens (Wulfen) Ach. = *Porpidia albocaerulescens*
Lecidea erratica Körb. = *Leimonis erratica*
Melanelia subaurifera (Nyl.) Essl. = *Melanelixia subaurifera*
Ochrolechia rosella (Tuck.) Ves. – Record published by Harris (1988) is *O. trochophora*
Parmelia aurulenta Tuck. = *Myelochroa aurulenta*
Parmelia bolliana Müll. Arg. = *Punctelia bolliana*
Parmelia caperata (L.) Ach. = *Flavoparmelia caperata*
Parmelia flaventior Stirt. = *Flavopunctelia flaventior*
Parmelia physodes (L.) Ach. = *Hypogymnia physodes*
Parmelia rudecta Ach. = *Punctelia rudecta*
Parmelia subaurifera Nyl. = *Melanelixia subaurifera*
Peltigera canina var. *rufescens* (Weiss) Mudd = *P. rufescens*

Peltigera canina f. *innovans* (Körb.) J.W. Thomson = *P. praetextata*
Peltigera lactucifolia (With.) J.R. Laudon = *P. hymenina*
Peltigera spuria (Ach.) DC. = *P. didactyla*
Phaeophyscia cernohorskyi (Nádv.) Essl. = *P. hirsuta*
Phaeophyscia chloantha (Ach.) Moberg = *Physciella chlorantha*
Physcia ciliata (Hoffm.) Du Rietz = *Phaeophyscia ciliata*
Physcia orbicularis (Baumg.) Poetsch = *Phaeophyscia orbicularis*
Physcia tribacioides Nyl. – Records are *Physcia americana* (Esslinger 2016)
Placodium aurellum (Hoffm.) Hepp = *Candelariella aurella*
Placodium microphyllinum Tuck. = *Caloplaca microphyllina*
Placodium sideritis (Tuck.) Fink = *Caloplaca sideritis*
Placodium ulmorum (Fink) Fink = *Caloplaca ulmorum*
Staurothele catalepta sensu Malme – Record published by Harris (1988) is *Willeya diffractella*
Trapelia involuta (Taylor) Hertel = *T. glebulosa*
Verrucaria calciseda DC. = *Bagliettoa calciseda*
Xanthoria fallax (Hepp) Arn. = *Xanthomendoza fallax*

Xanthoria fulva (Hoffm.) Poelt & Petut. – Although this species is now treated as *Xanthomendoza fulva* (Hoffm.) Søchting, Kärnefelt & S.Y. Kondr. (Lindblom 1997), the eastern North American records belong to *X. weberi* (Lindblom 2006; Knudsen et al. 2011).

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ESTIMATING INVADING CALLERY PEAR (*PYRUS CALLERYANA*) AGE AND FLOWERING PROBABILITY IN AN INDIANA MANAGED PRAIRIE

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ABSTRACT. Callery pear (*Pyrus calleryana* Decne.) is an invasive species in North America originating from Asia. As an ornamental tree, Callery pear has been widely planted throughout much of the United States and has subsequently spread into natural areas. Callery pear individuals that had naturally colonized a managed prairie in Indiana were collected. Tree height and root collar diameter were measured and the presence of flower buds was identified. After harvesting the trees, age was measured as ring counts. Height, root collar diameter, and age were all significantly greater for flowering individuals compared to non-flowering trees. Root collar diameter was the only independent variable that resulted in a significant linear model for predicting tree age. Additionally, root collar diameter effectively predicted the likelihood of flowering in Callery pear, with a tree root collar diameter of 45.6 mm predicting a 50% chance of flowering. Age was an ineffective independent variable in predicting flowering potential in Callery pear. Root collar diameter can provide a rapid assessment of invasion age, as well as predicting flowering potential outside of the growing season. Management focus can be on larger individuals.

Keywords: Bradford pear, Callery pear, invasive species, prairie, *Pyrus calleryana*

INTRODUCTION

Callery pear (*Pyrus calleryana* Decne. [Rosaceae]) was introduced to North America from Asia in the late 1910s due to apparent resistance to fire blight (Reimer 1925; Culley & Hardiman 2007). In 1952, Callery pear began to be tested as an ornamental tree, became commercially available in 1962, and by the 1970s became a commonly planted tree in sub-division developments (Whitehouse et al. 1963; Creech 1973). This popularity in ornamental plantings has led to widespread distribution of Callery pear throughout much of the United States (Vincent 2005; Culley & Hardiman 2007).

While cultivars of Callery pear (specifically 'Bradford') were promoted as being sterile, this sterility was likely only self-incompatibility and led to reproductively successful individuals via cross-pollination with intraspecific and interspecific hybridization (Westwood & Bjornstad 1971; Vincent 2005; Culley & Hardiman 2009). Fruits are readily consumed by birds, which are effective seed dispersal agents (Reichard et al. 2001; Culley & Hardiman 2007). Due to reproductive abilities, Callery pear has consequently spread out of cultivation into disturbed habitats, which include old-fields, fence rows, and other early- to mid-successional areas (Vincent 2005).

Because of limited shading and potential for repeat disturbances, natural and constructed prairie habitats are vulnerable to invasion by Callery pear (Taylor et al. 1996; Freeman et al. 2003). Reduced light availability in closed canopy forests likely limits the ability of Callery pear to colonize those ecosystems (Flory & Clay 2006). In locations colonized by Callery pear, cutting and herbicide applications are typically the only management tool that is effective (Swearingen et al. 2010). Controlled burns in prairies as a management technique does not appear to reduce Callery pear density and results in more shoots per individual root stock due to epicormic sprout production (Warrix 2016).

Intuitively, control of invasive species is more effective if applied before reproductive events (i.e., before further dispersal can occur). Determining variables that allow for prediction of the likelihood of Callery pear flowering could help resource managers in their efforts to control this invasive species. The objectives of this study were to 1) predict Callery pear individual ages using easily measured metrics (height and root collar diameter); and 2) evaluate tree size and age as

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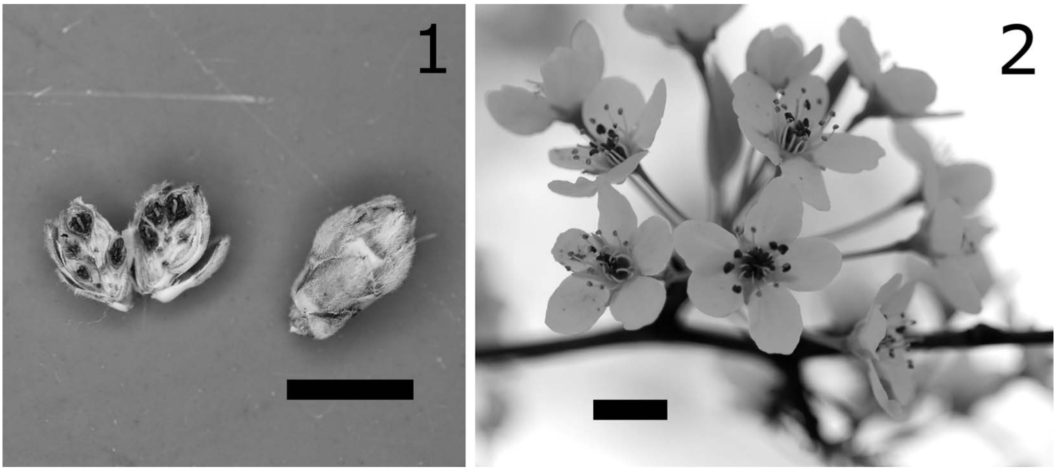

Figures 1 & 2.—Callery pear (*Pyrus calleryana*). 1. Flower buds. 2. Flowers. Black bars represent 1 cm.

variables in predicting Callery pear individual flowering.

METHODS

Callery pear individuals were collected from Arrowhead Prairie, Allen County, Indiana (41°00′13″ N, -85°19′7″ W). The property was acquired by Little River Wetlands Project in 2000 and has undergone conversion from row crop agriculture to native prairie plant species. This conversion to native species was conducted with several plantings in 2005, 2006, and 2009 (LRWP no date a, b). We harvested trees from the western edge of the property outside of an area that is actively managed with fire (Betsy Yankowiak, Pers. Comm.). In March 2016, trees were randomly selected as they were encountered during a stochastic survey ($N = 32$), assessed for presence of flower buds (Figs. 1 & 2), measured for height to the terminal bud (cm) and root collar diameter (stem diameter at the soil surface, mm), and then harvested by cutting at the soil surface. Stumps were treated with 50% glyphosate immediately after cutting as a courtesy to Little River Wetlands Project. The base 10 cm of each tree were collected, air dried, sanded with 500 grit sandpaper, dyed with phloroglucinol (20 % HCl), and rings were counted.

Height, root collar diameter, and age were compared between flowering and non-flowering individuals using individual Student's t-tests. Pearson's correlation coefficient was calculated relating height and root collar diameter for all trees pooled. The assumption of normally distributed data was tested using Shapiro-Wilk normality tests.

To predict Callery pear individual ages based on tree height and root collar diameter, tree data were randomly separated into two equal, non-overlapping groups: model development and model testing. To select individuals randomly, a stratified selection technique was used to ensure that both flowering and non-flowering trees were equally represented in the two model groups. Model development trees (i.e., tree data to develop prediction models) were used to calculate linear regression models predicting age (dependent variable) based on height and root collar diameter (independent variables). Akaike information criterion (AIC) was used to rank models (Akaike 1973). Ranking models based on AIC values takes into account model goodness of fit and complexity (i.e., models with better goodness of fit and fewer independent variables rank higher than models with poorer fit and more variables). Model testing trees were then used to test selected model effectiveness in predicting age by paired t-test comparing observed and predicted ages. Using logistic regression, we fit a sigmoidal model predicting probability of flowering using the independent variables from the best age predicting models, as well as age. All statistical tests were conducted in R (R Core Team 2015).

RESULTS

Of the 32 trees collected, eight had flower buds (Fig. 1). Height, root collar diameter, and age all met the assumption of normality. Height and root collar diameter were greater in flowering individ-

Table 1.—Comparison of mean height, root collar diameter, and age (with standard error) between Callery pear (*Pyrus calleryana*) individuals with and without flower buds.

Status	Count	Height (cm)	Root collar (mm)	Age (years)
Flowering	8	266.4 (7.9)	59.6 (2.0)	6.12 (0.35)
Non-flowering	24	198.1 (10.1)	35.1 (2.0)	5.13 (0.19)

uals compared to non-flowering individuals (height: $t_{(1)}=5.31$, df$=30$, $P < 0.001$; root collar: $t_{(1)}=6.73$, df$=30$, $P < 0.001$; Table 1). Flowering trees were significantly older ($t_{(1),29} = -2.58$, $P = 0.008$); however, the difference between these two groups was only one year (Table 1). Additionally, height and root collar diameter were significantly correlated (Fig. 3).

Simple linear models relating Callery pear age to height alone, root collar diameter alone, height and root collar diameter without interaction, and height and root collar diameter with interaction were tested. However, the model with root collar diameter was the only one to result in a significant linear regression (age = 3.469 + 0.049*root collar diameter, $F_{1,14}=5.03$, $P=0.042$, $R^2=0.26$). Since none of the other models were significant, comparison of AIC values was moot. From this single linear equation, age was calculated for the model testing group of trees (i.e., predicted age). Paired mean observed and predicted ages were not significantly different for the model testing group of trees using the root collar diameter model (t$=-0.94$, df$=14$, $P=0.366$). Additionally, the observed ages and predicted age residuals were not significantly correlated ($r=0.45$, $P=0.094$).

Using logistic regression, we calculated sigmoidal curves using our model development group to predict the probability of flowering and tested those models with our model test group. Using root collar diameter as the independent variable to predict flowering probability resulted in a significant logistic regression ($F=17.88$, df$=2,13$, $P < 0.001$, $R^2=0.86$; Eq. 1).

$$p(\mathit{flowering}) = \frac{0.800}{1 + e^{-\frac{(root\ \ collar\ \ diameter - 45.508)}{0.172}}} \qquad \text{(Equation 1)}$$

A probability of 0.5 was selected as an arbitrary threshold to predict if a tree would flower. Using that threshold, the root collar model correctly predicted flowering for 93.8% of trees in the model test group. The model incorrectly predicted flowering for a tree that did not flower, which coincidently happened to be an individual with an asymmetrical stem due to damage on one side. The logistic regression model that included root collar diameter predicted greater than 0.5 probability of flowering for individual trees with root collar diameters greater than 45.6 mm. Using observed age as the independent variable to predict flowering probability resulted in a significant logistic regression model ($F=4.88$, df$=2,13$, $P=0.026$, $R^2=0.65$; Eq. 2).

$$p(\mathit{flowering}) = \frac{0.571}{1 + e^{-\frac{(age - 5.326)}{0.027}}} \qquad \text{(Equation 2)}$$

Using the same 0.5 probability threshold, the age logistic regression model correctly predicted flowering 68.8% of the trees in the model test group. Incorrect flowering predictions occurred in both flowering and non-flowering trees.

DISCUSSION

Callery pear has effectively spread out of cultivation and has established self-sustaining populations in natural areas (Vincent 2005). Birds

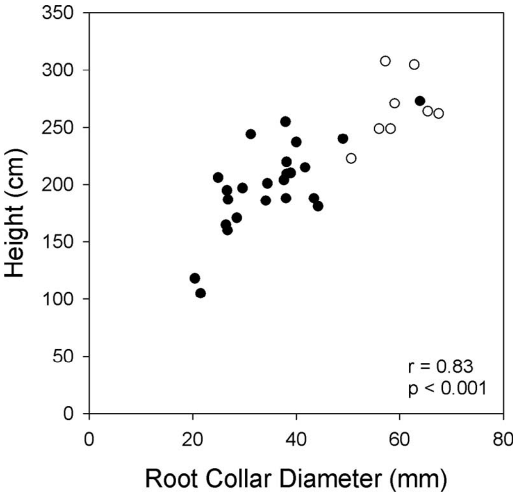

Figure 3.—Scatter plot of Callery pear (*Pyrus calleryana*) root collar diameter versus height with Pearson's correlation. Closed circles represent individuals without flower buds; open circles represent individuals with flower buds.

regularly feed on fruits when available and act as effective seed vectors (Culley & Hardiman 2007). Curtailing this spread requires use of labor intensive control methods, such as cutting and herbicide application (Swearington et al. 2010).

Even though height and root collar diameter were correlated, height was not an effective predictor of age. The correlation between these two growth variables was expected (e.g., Hara et al. 1991). Our root collar diameter model successfully predicted ages when compared to the observed ages. Differences in paired t-tests (and rejecting the null hypothesis that the paired observed and predicted values were equal) would have suggested poor age prediction by the model. However, no age difference was found with a paired t-test between our predicted and observed ages in the model testing group. Significant correlation between observed ages and predicted age residuals would have suggested poor age prediction of either young or old trees (e.g., positive correlation would have resulted from greater predicted residuals as trees increase in age, which would suggest the model was effective only for young trees). The correlation null hypothesis (i.e., rho is equal to zero) was not rejected. Since neither of these two tests rejected the null hypotheses, we interpret the model as being effective.

Using our sigmoidal curve equation, trees with a root collar diameter of 45.6 mm had a flowering probability of 0.5, which aligned with an age prediction of nearly six years old. In our complete data set, ten trees were greater than 45.6 mm, two of which did not flower. Those two non-flowering trees are identifiable in the height and root collar diameter correlation clustering with flowering trees. Conversely, 12 trees in our complete data set were six years old or older, half of those were non-flowering trees. This supports our interpretation that age is a poor predictor of flowering potential. Culley & Hardiman (2007) stated that Callery pear trees can start flowering as early as three years old. None of our trees that young were flowering nor were they large enough to flower, based on the results presented here. The potential for a Callery pear individual to flower at three years old likely relies on optimal growing conditions. Due to high root:shoot ratios of dominant prairie plants, belowground competition in prairies is high and subsequently reduces aboveground biomass of trees (Wilson 1993). Our results suggest that age is not a strong predictor of flowering potential in Callery pear, especially in sub-optimal growing conditions. By using root collar diameter, we were successful in predicting the flowering potential of Callery pear invading a managed prairie.

Predicting flowering potential for Callery pear may be important in actively managing this species. Ages we observed in this prairie suggest that there was a time-lag between the cessation of row crop agriculture following acquisition by Little River Wetlands Project and when Callery pear began colonizing the property (oldest trees were 8 years old). Competition for light, space, and other resources, may make some natural areas sub-optimal for Callery pear growth and may then extend the maturation time leading to flowering. This extended time window may provide more opportunity for successful control of Callery pear in natural areas, which is promising since effective management technique is a time consuming and labor intensive method. Hence, managers should focus control efforts on the largest Callery pear individuals, since smaller individuals are unlikely to flower and produce seed for further colonization in the immediate future. Further research is needed into the effect of prescribed fires on the association between tree size and flowering. Sprouts post-fire will be associated with large root collars and large root systems. This may alter the association between tree size and flowering.

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SPOTTAIL DARTER (*ETHEOSTOMA SQUAMICEPS*) SPAWNING ECOLOGY IN SOUTHWESTERN INDIANA: A LONG-TERM STUDY

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ABSTRACT. From 1994 to 2015, the spawning biology of two populations of spottail darters (*Etheostoma squamiceps*) was monitored using artificial nest sites in two first-order streams that are part of the Bayou Creek drainage in southwestern Indiana. During the mid-March to May breeding season, size (standard length) of breeding individuals of both sexes captured under nest sites was measured, and the presence of eggs was noted. In addition, laboratory experiments examined the relationship between female size and both the number of mature ova and the number of eggs spawned. Larger males spawned earlier and were more likely to be defending eggs throughout the breeding season; larger females also spawned earlier. Both the number of mature ova and the number of eggs spawned varied positively with female size; however, for females of the same size the number of ova was consistently greater than the number of eggs spawned, suggesting that spottail darters are fractional spawners. While female size and spawning statistics were similar to those of an Illinois population, males in the current study were much larger than their counterparts in Illinois, which may be due to either more rapid growth or a longer lifespan.

Keywords: Spottail darter, *Etheostoma squamiceps*, resource defense polygyny, nest site competition, standard length, fractional spawning

INTRODUCTION

The spottail darter (*Etheostoma squamiceps*) is found in drainages in western and central Kentucky, southern Illinois, and southwestern Indiana (Page et al. 1992). In a survey of sites in southwest Indiana where spottail darters were found historically, Page et al. (1976) found them at only two sites, both in Posey County. As a result, the species received a designation of Special Concern by the Indiana Department of Natural Resources (Whitaker & Gammon 1988). Subsequent surveys expanded the range to include Gibson, Vanderburgh, Warrick, and Spencer Counties, where they are typically found in small streams draining watersheds of < 260 km^2 (Fisher 2008), and the Special Concern status was removed. However, this species has a patchy distribution within this range, probably due to the limited availability of nesting habitat. As with other members of the subgenus *Catonotus*, *E. squamiceps* females attach eggs in clusters to the ceilings of benthic structures such as slab-rocks where they are guarded by males (Page 1974). Many streams in southwestern Indiana lack these structures due to siltation associated with agricultural activities. Streams with populations of spottail darters often are located in suburban areas with reduced siltation compared to agricultural lands.

For over two decades, sections of ceramic field tile have been added to streams containing spottail darters to serve as artificial nest sites. Males, which practice resource-defense polygyny, readily guard them, and the broods deposited by females on the ceilings of the tiles do not differ in number of eggs from those under rocks at the same sites (Bandoli et al. 1991). Males guarding tiles are easily captured, facilitating studies of male reproductive strategies (Bandoli 1997, 2002; Bandoli et al. 2004). Additionally, attaching lightly sanded acetate sheets to the undersides of the tiles allowed the manipulation of broods to address questions related to filial cannibalism (Bandoli 2006, 2016).

All of the studies cited above were conducted partially or wholly in the field. During these investigations, records of tile guarding by males and the presence of spawning females and eggs were maintained to aid in establishing the timing of concurrent studies of male reproductive strategies. These data, extraordinary for their quantity and time span, allow questions regarding the role of male size in nest defense and attraction of females, associations between males and

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females at the nest site, and temporal patterns in spawning to be addressed.

Female spottail darters do not participate in egg defense, but leave the nest site immediately after spawning. It is not known whether females spawn multiple times during a breeding season (fractional spawning) or just once. Page (1974) found that in an Illinois population, ovary weight peaked just prior to the spawning season and declined during, with no regrowth until the following spring, suggesting that the number of ova is fixed at the start of the spawning season. He also reported that the number of mature ova was linearly related to female size. However, data on the number of eggs spawned was limited to four females, and apparently no other study has addressed this. In an attempt to better understand female reproductive ecology, gravid females were allowed to spawn with mature nest-guarding males in laboratory conditions; additional gravid females were dissected and the number of eggs in their ovaries counted to examine the relationship between female size and both the number of mature eggs in the ovaries and the number of eggs spawned per breeding.

METHODS

Study sites.—All observations reported herein are from two sites – Carpentier Creek at Bohene Camp Road (latitude 37° 59.362′N; longitude 87° 38.595′W) and an unnamed stream paralleling Nurrenbern Road (hereafter Nurrenbern Creek; 37° 56.710′N; 87° 39.417′W). Both streams are first-order tributaries of Bayou Creek, which drains approximately 80 km^2 in southwest Vanderburgh County, Indiana, before joining the Ohio River.

Field methods.—Nest sites are 15 cm long half-cylinders cut from 10 cm diameter ceramic field tile. Except for 2002 and 2006 when no tiles were placed, a mean of 17.5 tiles (range 9–23) was added to a 100 m reach of Carpentier Creek each March from 1994 through 2015. During 13 of those years (1998–2001; 2003–2004; 2007–2011; 2013; 2015), a mean of 8.3 tiles (range 4–18) was also added to a 50 m reach of Nurrenbern Creek, also in March. Frequency of checking the tiles varied from once per week to twice per month during the spawning season (mid-March through late May) depending on the nature of the concurrent studies. Occasional flooding washed some tiles downstream, interrupting or abbreviating some field seasons.

Tiles were checked by placing a hand net over one opening and sweeping it toward the other opening while the tile was lifted, which captured all fish under the tile most of the time. Males that were seen but not captured were often captured later if the tile was re-checked after 10 min. Captured breeding males (signified by the enlarged, darkened head; Page 1974) were usually measured (standard length (SL)) on first capture. Male spottail darters have high nest site fidelity (Bandoli 1997); therefore, the SL of males captured on subsequent surveys during the same spawning season that appeared to be repeat captures based on capture location and size was not usually recorded. Gravid females captured with males were considered to be spawning. They were usually measured (SL); females captured alone, which were often under empty tiles, were viewed as using the tile as a shelter rather than a spawning site and therefore not measured. The presence of eggs under a tile was noted; the number of eggs in a brood is dynamic over time due to new females adding eggs and egg loss due to hatching and filial cannibalism (Bandoli 2016). Therefore, the presence or absence of eggs, not brood size, is the only reproductive variable included in this analysis. Unless the nest site was taken to the lab, the tile and any fish captured were replaced at their original locations (spottail darters released under a tile tend to stay there; Bandoli 1997). These observations allowed the evaluation of the role of size in male reproductive success by comparing SL in males (1) with and without eggs, and (2) defending nest sites in the first and second halves of the spawning season. Additionally, observations of females captured with males permitted an assessment of temporal patterns in spawning, the role of male size in attracting females, and whether larger females spawn earlier.

Female fecundity.—During the spawning seasons of 1989–1992, laboratory aquaria with gravel substrate collected from Carpentier Creek were maintained. Water temperature was not controlled, ranging from 19–22° C. Each aquarium contained a breeding male spottail darter and a tile to defend. Gravid females collected during the spawning season from Carpentier Creek were added individually to aquaria. Thirty spawned, and clutch size (number of eggs) and SL of each female were determined before they were released into their streams of capture.

In 1990 and 1991, an additional 37 gravid females collected in Carpentier and Nurrenbern creeks were measured (SL) and sacrificed to count the number of mature ova, which are translucent orange as opposed to the opaque or yellow appearance of immature eggs (Page 1974). This quantified the number of mature ova that a female could spawn immediately and related it to female size. These data, along with size-based clutch data, were used to assess whether females spawn all mature eggs during a spawning bout. To test whether fecundity varies geographically, the relationship between female size and the number of mature ova of this population was compared to the same metric in a population in Big Creek, Illinois studied by Page (1974).

Statistical analyses.—To determine whether the size of spawning males changed over the 22 years of the study, mean SL of males captured between 1994 and 2003 was compared to that of males captured between 2004 and 2015 using a 2-sample *t*-test (two tails) assuming equal variance. The same test was used to compare the SL of males in Carpentier Creek to those in Nurrenbern Creek. To determine whether larger males were more likely to be guarding eggs than smaller males and whether larger males spawn earlier in the breeding season, the measured males were divided into four groups based on the presence or absence of eggs and on the date of capture (15 March through 15 April and 16 April through the end of May). A two-way GLM ANOVA with eggs and time as factors was used to test for differences between SL in these groups. A two-sample *t*-test (one tail) assuming equal variance was used to compare mean SL of measured females captured with males during the first half of the spawning season to those captured during the second half.

To test whether larger males attract more females, a two-sample *t*-test (one tail) assuming unequal variance was used to compare SL of males that were captured with and without one or more females. However, in many fish species the attractiveness of a male to females is confounded by female preference for nests containing eggs (e.g., fathead minnow, *Pimephales promelas*, Unger & Sargent 1988; fantail darter, *E. flabellare,* Knapp & Sargent 1989; and sand goby, *Pomatoschistus minutus*, Forsgren et al. 1996). To avoid this potential bias, only males guarding empty nest sites were used in this analysis.

Linear regression was used to investigate the relationships between female SL and the number of mature ova and between female SL and the number of eggs spawned. If females spawn most or all of their mature eggs at a spawning, the slopes and intercepts of these regressions should not differ. Because the data sets are independent and normally distributed, the slopes were compared using a *t* statistic (one-tailed since females cannot lay more eggs than mature ova) generated by dividing the difference in the coefficients of the slopes for SL by the square root of the combined squares of the standard errors of the coefficients (Wackerly et al. 2008). Linear regression was similarly used to compare SL with the number of mature ova counted in 18 females in a Big Creek, Illinois population (Table 2 in Page (1974)). The *t* statistic described above (two tails) was used to compare size-dependent fecundity between the Indiana and Illinois populations. Statistical analyses were conducted using SigmaPlot 12 (Systat Software, Inc.) and EXCEL ver. 14 (Microsoft, Inc.). All means are reported ± 1 standard error.

RESULTS

Of the 504 males captured while defending tiles, 302 were first captures (based on location and size); the remaining 202 were considered recaptures and were not included in subsequent SL analyses. Males captured from 1994–2003 ($n = 142$) had the same mean SL (69.5 ± 0.5 mm) as the 160 males captured during 2004–2015 (69.8 ± 0.5 mm; $t = 0.30$, $p = 0.77$). Mean SL did not differ between males from Carpentier Creek (69.8 ± 0.4 mm; $n = 277$) and males from Nurrenbern Creek (67.7 ± 1.4 mm; $n = 25$; $t_{300} = 1.59$, $p = 0.11$); therefore data from all years and both streams were combined for all analyses.

The mean SL of all males measured was 69.7 ± 0.4 mm (range 53–88 mm with a near-normal distribution; Fig 1). The mean SL of the 153 males captured while defending eggs was 71.2 ± 0.5 mm, significantly larger than the 149 males defending empty tiles (68.3 ± 0.5 mm; $F_{1,301} = 14.98$, $p < 0.001$). Males defending tiles between 15 March and 15 April ($n = 135$) were significantly larger (mean SL = 71.0 ± 0.5 mm) than 167 males defending tiles after that period (68.5 mm; $F_{1,301} = 12.27$, $p < 0.001$). The interaction between date and the presence of eggs was not significant.

The mean SL of 68 measured females captured with males was 44.4 ± 1.2 mm (range 30–65 mm

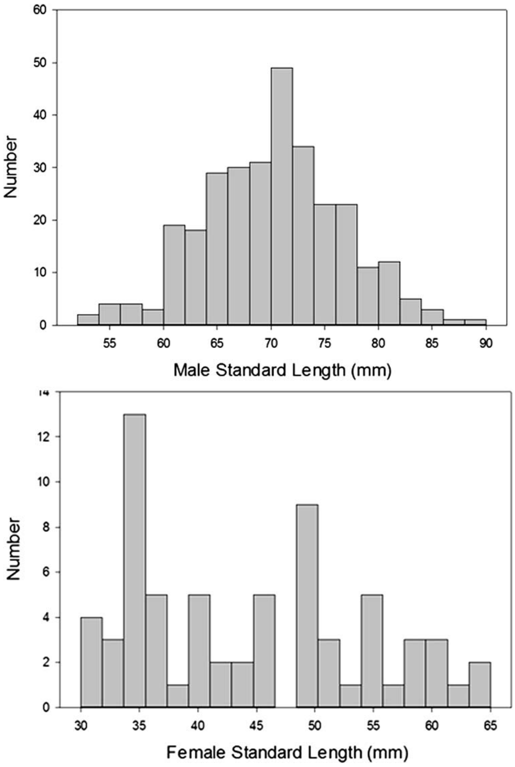

Figure 1.—Standard length distributions for breeding male and female spottail darters (*Etheostoma squamiceps*) in Carpentier and Nurrenbern Creeks between 1994 and 2015.

with a relatively flat distribution; Fig 1). The 22 females captured with males during the first half of the spawning season were significantly larger than the 46 females captured during the second half (47.7 ± 2.0 mm and 42.8 ± 1.4 mm, respectively; $t_{66} = 1.9$, $p = 0.03$).

Seventeen percent of the 504 males captured had females under their tile. Most of these (68.6%) had a single female; 22.1% had two females, 8.1% had three females, and one male had six females. Instances of males captured with two or more females were twice as common during the second half of the spawning season. Mean SL of females alone with a male (46.0 ± 1.6 mm) was not different from that of the largest female in cases of multiple females captured with a male (47.3 ± 3.1 mm; $t_{20} = 0.39$, $p = 0.71$); in captures of multiple females the smaller females averaged 17.4% smaller than the largest female. For males not defending eggs, the mean SL of males captured with least one female (69.7 ± 0.9 mm) was not significantly larger than males captured alone (68.2 ± 0.6 mm; $t_{57} = 1.34$, $p = 0.09$).

There was a significant relationship between female SL and the number of mature ova (O) in the ovaries ($F_{1,36} = 12.3$, $p < 0.001$), with $O = -141.4 + 5.48*SL$; Fig. 2. The number of eggs laid (L) also varied significantly with SL ($F_{1,29} = 7.47$, $p = 0.011$), with $L = -87.8 + 3.24*SL$. The intercepts were similar, but the slopes were significantly different ($t_{63} = 1.77$, $p < 0.05$). The SL vs. mature ova regression for the Illinois population was also significant ($F_{1,17} = 17.0$, $p < 0.001$), with $O = -262.3 + 8.03*SL$. The slope of this regression was not different from that of the mature ova regression for the Indiana population ($t_{51} = 1.28$, $p < 0.20$).

DISCUSSION

The importance of size in reproductive success of male spottail darters was confirmed in this study. Males guarding eggs were larger than those guarding empty tiles, and larger males spawned earlier in the breeding season. These factors did not interact; males guarding eggs were larger than those guarding empty tiles throughout the spawning season. Larger females also spawned earlier in the season. These results confirm earlier observations (Bandoli 1997), and given the positive relationship between female SL and the number of eggs spawned, suggest that earlier-spawning males also benefit by receiving more eggs per female.

A previous laboratory study found that females given a choice between two males defending equal-sized empty nest sites spawned with the larger male (Bandoli 1997), yet male spottail darters with empty nest sites captured with one or more females in the current study were not significantly larger than males captured without a female. Timing of spawning suggests a possible resolution. Larger males spawn earlier in the season, at which time larger females are also spawning. Females in an Illinois population of spottail darters are generally similar in size (weighted mean SL = 42.6 mm, range 32–59 mm, $n = 58$; Page 1974 (Table 4)) to Indiana females. Assuming this size similarity implies similar ages, early-spawning females in Indiana are likely to be two- and three-year-olds. Later-spawning females would also include one-year-olds, which are more numerous than older females, increasing their likelihood of capture with nest-guarding males, which are also smaller than earlier-breeding males. Additionally, cap-

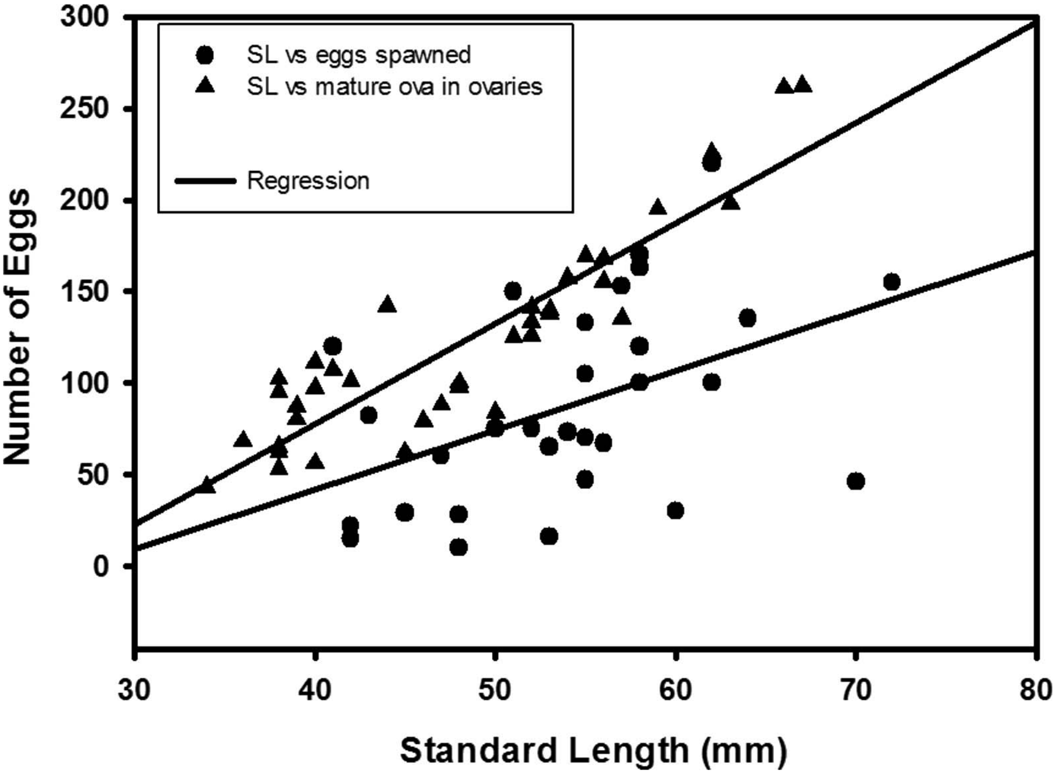

Figure 2.—Linear regressions of the number of mature ova in ovaries ($n = 37$; upper line) and eggs spawned ($n = 30$; lower line) on standard length for female spottail darters (*Etheostoma squamiceps*). The slopes are significantly different.

tures of a male with multiple females were twice as common during the second half of the breeding season and typically included one or two smaller (= younger) females along with a larger female. Many of these smaller females may have been naïve yearling females that may copy the mating choices of older females (Witte & Noltemeier 2002).

During the breeding season, association between males and females is limited to courtship and spawning (Page 1974). Since 17% of males captured had one or more females under their tiles, this may approximate the proportion of time males spend spawning during the breeding season. However, spottail darters occasionally spawn at night (Page 1974; Bandoli, personal observation (laboratory)), so this may be a minimum estimate since all observations in the current study were made during daytime hours.

As is typical for ectotherms in general and fishes in particular, female spottail darters in both Indiana and Illinois have a positive linear relationship between size (age) and egg production. Page (1974) counted scale annuli and found that females first spawned at 11–13 months (28–43 mm in SL), and contained $\leq$ 80 mature ova, whereas those at 35–36 months (56–59 mm in SL) contained 200–400 mature ova. Indiana females also are likely to start spawning at age one and continue through age three given the similarities between the ranges of spawning female SL in the two populations, and the similar slopes relating size and number of mature ova in the two populations suggest that same-sized females spawn similar numbers of eggs.

Despite numerous attempts, I have never witnessed a female spottail darter spawning more than once in the laboratory even when placed with a new male for several hours; however, this may have been a function of the artificial environment and generally short duration of these casual experiments. In this study the number of eggs spawned was consistently less than the number of mature ova for females of a given size, and larger females in particular spawned fewer eggs than expected; limited data for the Illinois population show a similar pattern (Page 1974). This supports the hypothesis that females may not spawn all mature ova during a single spawning event. Fractional spawning is typical for small fishes with prolonged breeding seasons (Burt et al. 1988), and has been observed in tessellated darters (*E. olmstedi*; Gale & Deutsch 1985) and Kentucky darters (*E. rafinesquei*; Weddle & Burr 1991), and inferred for others (Hubbs 1985). Fractional spawning, especially with different males, may be an adaptive form of bet-hedging. Egg development time varies inversely with water temperature (Gillooly et al. 2002); in spottail darters, development to hatching takes approximately 15 days at 15° C (Bandoli, pers. observation) to 11 days at 22° C (Page 1974), a temperature range typical for Carpentier and Nurrenbern streams in April and May. Males may vary in their ability to defend eggs for this long, and lacking reliable cues, a female may hedge her bets by spreading eggs among two or more males. Additionally, the fate of spottail darter eggs is influenced by (1) egg infection by water molds such as *Saprolegnia* (Bruno et al. 2011), and (2) filial cannibalism by the defending male, either to control infection directly (Bandoli 2016) or indirectly through a reduction in egg density (Lehtonen & Kvarnemo 2015), or as an energetic strategy to reduce foraging time away from the nest (Rohwer 1978). The potential for egg loss due to each variable is in turn influenced by the number and density of eggs present when a female spawns; more eggs may increase the potential for infection from adjacent eggs (Bruno et al. 2011) while decreasing the possibility of consumption via the dilution effect (Wrona & Dixon 1991). A female that spawns with a male that is not defending eggs (possibly lower infection risk but increased probability of loss to filial cannibalism) and another already defending eggs (higher infection probability but reduced loss to cannibalism) may have higher reproductive success compared to one that spawns all eggs with only one male.

Page (1974; Table 4) determined that breeding males captured in Big Creek were all 2-year-olds ranging from 38–59 mm in SL and 3-year-olds (the maximum age) ranging from 53–66 mm. The smallest measured male captured guarding a tile in the current study had an SL of 53 mm, and over 95% ranged from 60–88 mm, suggesting that males in Indiana either grow more quickly or live longer than three years. I have attempted to use scale annuli to age male spottail darters collected from Carpentier and Nurrenbern streams, but patterns were too inconsistent for confidence; a more accurate and precise technique may be needed to test the different-lifespan hypothesis (Zymonas & McMahon 2009).

The hypothesis that same-age males are larger in Indiana due to more rapid growth gains support from three differences between the streams. First, at the time of Page's work, Big Creek was a forested spring-fed stream with little to no anthropogenic influences (Lewis 1957); the food base of *E. squamiceps* was primarily chironomid and mayfly larvae, copepods, amphipods, and isopods (Page 1974). Conversely, Carpentier and Nurrenbern creeks flow through suburban and agricultural areas and are subject to fertilizer and field bed runoff. These factors may increase the densities of some of these macroinvertebrates, especially isopods and chironomids (Polls et al. 1980; Lenat & Crawford 1994), both of which were found to be important food items for spottail darters in Sanders Creek, another tributary of Bayou Creek in southwest Indiana (Strange 1992). Second, Big Creek includes three species of *Etheostoma* in addition to *E. squamiceps*; one, the rainbow darter (*E. caeruleum*) is among the more abundant fishes in that stream (Lewis 1957). All these darters would be competing for the same food items. No other darter species occurs consistently in either Carpentier or Nurrenbern streams; while there are other species in these streams with food habits similar to spottail darters (e.g., bluntnose minnows (*Pimephales notatus*) and creek chubs (*Semotilus atromaculatus*)), the lack of other darters may reduce competition for food compared to that of the Big Creek population. Third, the limited number of nest sites in Carpentier and Nurrenbern streams promotes competition, which larger males usually win (Bandoli 1997). In Big Creek, 1-year-old males do not attempt to breed, possibly due to competition for nest sites. Growth curves show that males do not start becoming larger than females until the start of their second year (Page 1974, Fig. 9A), and the increased growth rate may be due to young males not investing energy into reproduction. Low nest site density in Carpentier and Nurrenbern creeks may enhance competition, driving both 1-year-old and smaller 2-year-old males to defer reproduction another year, with the energy savings potentially producing the larger 3-year-old males.

Since a bigger food base and less competition should also promote growth in females, the apparent similarity in size of females in the

Indiana and Illinois populations seems to argue against the hypothesis of more rapid growth in the Indiana population. However, this similarity may be misleading. Page's size data were based on females collected in April, the height of the spawning season. I captured spawning females from late March through late May, but most were taken in the second half of the season when smaller females are spawning; therefore the apparent similarity in mean spawning female SL may be due to sampling differences. Additionally, while more food and less competition should promote growth in both sexes, the energy required for egg production starting at age 1 may moderate this in females (Folkvord et al. 2014), while growth continues in males for an additional year or two to allow them to compete for nest sites. Regardless of whether spottail darters are larger in southwest Indiana due to longer survival or better food resources, size is clearly an important factor in spawning success in both sexes.

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RESULTS OF THE 2016 INDIANAPOLIS BIODIVERISTY SURVEY, MARION COUNTY, INDIANA

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ABSTRACT. Surprising biodiversity can be found in cities, but urban habitats are understudied. We report on a bioblitz conducted primarily within a 24-hr period on September 16 and 17, 2016 in Indianapolis, Indiana, USA. The event focused on stretches of three waterways and their associated riparian habitat: Fall Creek (20.6 ha; 51 acres), Pleasant Run (23.5 ha; 58 acres), and Pogue's Run (27.1 ha; 67 acres). Over 75 scientists, naturalists, students, and citizen volunteers comprised 14 different taxonomic teams. Five hundred ninety taxa were documented despite the rainy conditions. A brief summary of the methods and findings are presented here. Detailed maps of survey locations and inventory results are available on the Indiana Academy of Science website (https://www.indianaacademyofscience.org/).

Keywords: Bioblitz, Indianapolis, urban biodiversity, urban waterways, urban wildlife

INTRODUCTION

Cities can be home to surprisingly high levels of biodiversity (e.g., Aronson et al. 2014), yet biodiversity harbored in cities is understudied and few formal inventories have been conducted. We held a 24-hr biological survey, or bioblitz, in the city of Indianapolis, Indiana, USA to document flora and fauna present. Indianapolis, located in Marion County, is the 12th largest city in the United States. It is in the Central Till Plain natural region of Indiana (Homoya et al. 1985). Historically, the area currently covered by the city was 98% forested, the vast majority comprised of

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beech-maple association (Barr et al. 2002). Land conversion to row crop agriculture preceded urban expansion. Only 13% forest cover remained by the late 1900s (Barr et al. 2002).

Our urban bioblitz covered 72.2 ha (176 acres) along three waterways: Fall Creek, Pogue's Run (including Brookside Park and Spades Park), and Pleasant Run (including Garfield Park), and their mostly-vegetated riparian borders (Fig. 1). These areas were chosen primarily because they have been the focus of recent broad-based community efforts to re-establish these waterways as assets to their surrounding neighborhoods (Dolan et al. 2015). Part of that effort has been directed at ecological restoration along the creeks, primarily the removal of Amur honeysuckle (*Lonicera maackii* (Rupr.) Herder). This invasive shrub grows so prolifically that it blocks citizens' view of the waterways, while inhibiting growth of native plants (Gould & Gorchov 2000) and negatively impacting wildlife (Ingold & Carycroft 1983; Schmidt & Whelan 1999). In addition to providing the first time-limited semi-comprehensive inventory of flora and fauna in the city, the 2016 bioblitz data provide a baseline of some species that are present. This may aid in future studies that examine the response of flora and fauna to riparian restoration efforts. The waterways were also selected for study because they and their riparian borders may serve as corridors for wildlife.

BRIEF HISTORY OF THE WATERWAYS OF INDIANAPOLIS

The study areas on the creeks were located along parkways on city-owned land. The parkways were all part of the historic Kessler Plan of the early 1900s. This plan created a series of linear parks and associated roads, with the goal of improving water quality in the creeks, while providing greenspace and parks to city dwellers (Diebold 1994). The three creeks are tributaries of the White River, part of the Mississippi River system. All are impacted by typical factors affecting urban streams, including high loads of contaminants such as *E. coli* and agricultural chemicals from farming in areas north of the city (City of Indianapolis 2006). These problems are exacerbated by combined storm water and sanitary sewer lines with overflow outlets that feed directly into the creeks during heavy rains. Infrastructure improvements are currently underway that will greatly reduce the frequency of overflow events in the future.

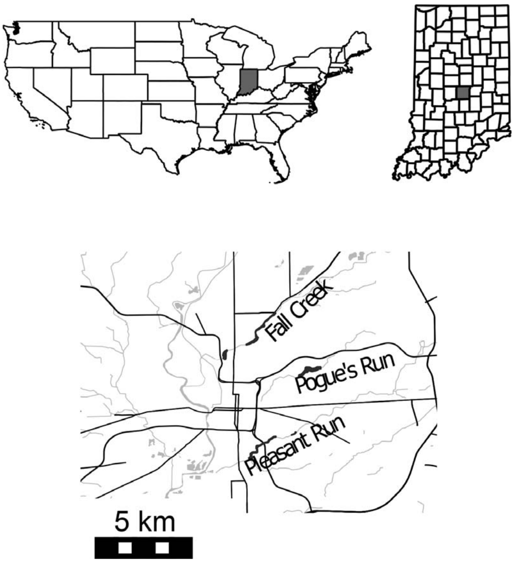

Figure 1.—Map of bioblitz locations within the city of Indianapolis with insets showing the locations of Marion County within Indiana and the State of Indiana within USA.

SUMMARY OF METHODS AND RESULTS

This bioblitz used the efforts of 50 taxonomic experts and students and 25 citizen volunteers to survey the diversity of 14 different taxonomic groups over a 24 hr period, from 5:00 P.M. on September 16 to 4:59 P.M. on September 17, 2016. Five hundred ninety different taxa (species or genera) were found (Table 1). All efforts were hampered by nearly 4 cm of rain that fell during the period. The complete lists of species and detailed site maps have been archived on the Indiana Academy of Science (IAS) website at https://www.indianaacademyofscience.org/resource-center/bioblitz-events-data. The event concluded with taxonomic teams reporting their preliminary results, followed by refreshments at a local brewery. A short video documenting the bioblitz can be viewed at: http://ourwaterways.org/indy-urban-bioblitz/ and through the IAS archive.

Bees.—Twenty species, approximately 5% of the Indiana bee fauna, representing all five common bee families in Indiana were collected during the survey. Bees were collected using passive (bowl trapping) and active (netting at flowers) sampling techniques. Three areas were sampled, Pogue's Run, Fall Creek, and Pleas-

Table 1.—Summary of the 590 taxa reported at the 2016 Indy Urban Bioblitz, Marion County, Indiana, USA.

Team	Leader	Taxa observed
Bees	Robert Jean	20 species; mostly common; only 1 non-native species; relatively intact native bee fauna
Beetles	Jeffrey Holland	16 taxa (species or genera); all common
Birds	Roger Hedge	58 species; state endangered osprey and 4 species of concern in Indiana
Butterflies	Kirk Roth	21 species
Dragonflies & damselflies	Tom Swinford	5 species
Fish	Brant Fisher	40 species, none state-listed; for 4 species, documentation of their most upstream tributary in the West Fork White River drainage
Freshwater mussels	Brant Fisher	23 species; only 5 native species; shell material of 2 federal/state endangered freshwater mussels and 3 state species of special concern; invasive zebra mussel and Asian clam present
Fungi/mushrooms	Nick Harby	33 taxa; all common
Herpetofauna	Michael Finkler	6 species (4 turtles, 1 anuran, 1 snake); all common
Mammals	Jeremy Sheets	17 taxa (5 bats, 12 terrestrial mammals); state listed evening bat and proposed for federal listing tricolored bat; *Myotis* sp. could be a federally listed one; mammals all common
Mosses & lichens	Bill McKnight	10 species (7 mosses, 3 lichens); all common
Singing insects	Carl Strang	31 species; mostly common; a katydid species at the northern edge of its distribution and one at its southern edge
Spiders	Marc Milne	37 species; all common; hampered by weather
Vascular plants	Paul Rothrock	275 species, none rare or endangered, 26% non-native and no high C-value species, but good diversity of trees

ant Run. Each area was sampled with a single transect of 30 bowls (ten white, ten fluorescent blue, and ten fluorescent yellow) for a total of 90 bowls across the Indianapolis Urban Bioblitz focal area. Bowls were separated by 5 m along each transect. Approximately 10 hr of net collecting was performed by the team on several flowering species at Pleasant Run. Net collections were not performed at Pogue's Run and Fall Creek due to the lack of floral availability. Overall floral diversity was very low and bee activity was modest.

Sweat bees in the family Halictidae represented a large portion of the species richness (10 spp.) and much of the bee abundance (41%). Only two bumble bee species were collected, *Bombus impatiens* and *B. griseocollis*, with the former being much more common and the latter represented by a single specimen. In general, most of the bees encountered were common species and expected in collections throughout the state. Interesting species include *Lasioglossum anomalum*, which is very small sweat bee often associated with prairies and grasslands and *Lasioglossum platyparium*, a cuckoo bee that parasitizes other bees. The European honey bee (*Apis mellifera*), the only non-native bee collected, was the most common bee species, representing over 18% of total specimens. At the same time, with only one introduced species (5% of total species collected), Indianapolis seems to have a relatively intact native bee fauna.

These collections provide baseline data of the bee species richness and relative abundance and demonstrate the importance of corridors for bee conservation and habitat. Further management to increase native wildflower diversity and reduce invasive plant species will likely enhance bee populations and thus local pollination and ecological services. Collections in these areas earlier in the year would likely add many species since solitary bees are highly seasonal and some social bee species are only active until mid-late August. Voucher specimens are housed in the Environmental Solutions & Innovations, Inc. (ESI) entomology collection in Indianapolis.

Beetles.—The beetle crew consisted of four people. They spent approximately 40 person-hours searching for beetles with sweepnets, beating sheets, and hand collecting. On Friday evening, a 1000 W metal halide light, a 175 W mercury vapor light, and a small UV light were run for three hr to attract beetles. Sixteen beetle species from 10 families were found. This extremely low number of species was the result of very heavy rains Friday evening. In addition, urban habitats contain lower diversity of habitats and vegetation than more natural settings. However, the small semi-natural areas along the waterways likely do contain hundreds of beetle species.

Three of the sixteen species of beetles were exotic species. All of these are well-established and well-known. The most diverse group of beetles collected was from the Carabidae, or the ground beetles. These are active running species whose activity was likely less impacted by the weather than the beetles that fly more often. The ground beetles were quite active at the lights, darting across the white sheets under the lights to seize prey insects that were attracted to the lights. Several beetle specimens were prepared for identification during the event to allow viewing by participants (Fig. 2). Beetle species were identified by JDH. Voucher specimens of all beetle species have been deposited in the Purdue Entomological Research Collection.

Birds.—Twelve participants surveyed birds using binoculars and occasional owl audio recordings and were divided equally among the three pre-selected sites. A fourth unit, the Pogue's Run Art and Nature Park, approximately 0.60 km northeast of Brookside Park and immediately south of I-70, was also surveyed because it offered a series of artificial wetlands consisting of open water, marsh, and shrub swamp that are not present in the other sites. Green heron and ruby-throated hummingbird were the only species recorded in this site. Habitats in the originally selected sites consisted primarily of city park lawn with scattered trees and riparian woodland in the midst of urban and residential neighborhoods. Despite the dismal weather (overcast and periodic rain), 942 individuals of 58 species were tallied in 48.75 person-hours.

Incidental observations were received from three additional participants who were focusing on other taxonomic groups. These observations included barred owl (*Strix varia*), peregrine falcon (*Falco peregrinus*), veery (*Catharus fuscescens*), American redstart (*Setophaga ruticilla*), chestnut-sided warbler (*Setophaga pensylvanica*), and black-throated green warbler (*Setophaga virens*). The peregrine falcon was seen near the intersection of Rural Street and I-70. The barred owl was recorded on the evening of 16 September in a nearby neighborhood outside the survey units. Pre-dawn owling on 17 September was met with intermittent rain, making it difficult to attract or hear any owls. In fact, none were recorded, aside from the single barred owl heard the previous evening.

State listed species that were recorded include the state endangered osprey (*Pandion haliaetus*) at Pleasant Run and state special concern red-shouldered hawk (*Buteo lineatus*) at Brookside Park, common nighthawk (*Chordeiles minor*) at Fall Creek, peregrine falcon (I-70 and Rural St.), and black-and-white warbler (*Mniotilta varia*) at Brookside Park (Division of Fish & Wildlife 2015). A couple of migrants that were somewhat unusual were recorded because of their relatively early and late seasonal occurrences, i.e., yellow-rumped warbler (*Setophaga coronata*) and Baltimore oriole (*Icterus galbula*) respectively (Brock 2006). The nomenclatural authority used for birds was Chesser et al. (2016).

Butterflies.—Butterfly observations during the bioblitz likely under-represent their actual diversity due to rainy conditions during the survey causing butterflies to be less active. Nevertheless, 224 individual butterflies of 21 species were detected. Two sulphurs (*Colias* sp.) that were unable to be identified to species also were seen. The most abundant species were the tawny-edged skipper (*Polites themistocles*) with 47 individuals detected and the pearl crescent (*Phyciodes tharos*) with 45 individuals detected. Both of these are common species of fields and edge habitats. Other well-represented species include cabbage white (*Pieris rapae*) with 33 individuals, Peck's skipper (*Polites peckius*) with 21 individuals, clouded sulphur (*Colias philodice*) with 16 individuals, and orange sulphur (*Colias eurytheme*) with 13 individuals. However, there were fewer observations of the larger species of butterfly, for example, only seven individual monarchs (*Danaus plexippus*) were found, and the single observation of a swallowtail was a black swallowtail (*Papilio polyxenes*) at the Fall Creek Trail.

The Garfield Park Gardens showed the most diversity (14 species) and abundance (67 individ-

Figure 2.—Beetle team leader Jeffrey Holland preparing specimens. Photo by Mark Kesling.

Figure 3.—Dragonfly wandering glider (*Pantala flavescens)* seen at Pogue's Run. Photo by Mark Kesling.

Figure 4.—Shorthead redhorse (*Moxostoma macrolepidotum*) from Fall Creek. This occurrence represents the most upstream tributary in the West Fork White River drainage in which the species has been found. Photo by Brant Fisher.

Figure 5.—Camera trap photo of red fox provided by Julia Angstmann.

Figure 6.—Spider team leader Marc Milne extracting spiders from litter sample. Photo by Mark Kesling.

Figure 7.—Plant Team leader Don Ruch, Adam Rickert of the Marion County Health Department, and students from Ball State University. Photo by Mark Kesling.

uals) with Brookside Park having similar butterfly numbers (12 species and 65 individuals). However, this may be an artifact of the sampling time—Garfield Park Gardens was sampled repeatedly during differing weather, while Brookside Park was searched after the rain had largely stopped and sun was beginning to warm the ground. As may be expected, Garfield Park Gardens has a diversity of nectar sources. Most of the butterflies at Brookside Park were found nectaring on red clover (*Trifolium pratense*) in patches of the meadow which had not been recently mowed.

Dragonflies and damselflies.—Five species of Odonata were documented during the bioblitz. Heavy precipitation throughout the sample period greatly diminished the ability to characterize the odonate fauna. Adult odonate flight activity is greatly curtailed under persistent storm conditions of rain, wind, and darkness. Benthic and vegetative sampling of larval stream odonates was next to impossible with dangerously flooded creeks. No ponds were sampled for larval odonates. Three sites were sampled: Garfield Park (Bean Creek and adjacent mowed and landscaped areas); Brookside Park (forest edge, mowed areas, stormwater retention basin, and some aquatic sampling of Pogue's Run), and Spades Park (prairie plantings adjacent to Pogue's Run).

At Garfield Park, *Aeshna umbrosa*, shadow darner, was observed making foraging patrols in a linear mowed area along Bean Creek. The same species was collected at Spades Park foraging in an open mowed lawn approximately 30 m from Pogue's Run near a prairie planting. *Aeshna umbrosa* is a species known for crepuscular activity and this may explain its presence on such a dark and dreary day.

In the large open retention pond area of Garfield Park, *Pantala flavescens*, wandering glider, was the most abundant dragonfly of the day (Fig. 3). Seven were observed flying in a loose swarm during a lull in the rainfall.

Four larval *Calopteryx maculata*, ebony jewelwing, were taken from Pogue's Run at Brookside Park. These large damselflies are tolerant of relatively impaired streams. One *Libellula luctuosa*, widow, was seen at Garfield Park. One *Ishnura verticalis*, eastern forktail, was observed in a small pond at the Children's Garden at Garfield Park Conservatory.

Fish.—A total of 40 species of fish was found from the six sites sampled in Pogue's Run (1 site), Pleasant Run (2 sites), and Fall Creek (3 sites). As might be expected, species diversity increased as drainage area increased. Ten species were collected from Pogue's Run, 22 from Pleasant Run, and 38 from Fall Creek. Two species not collected from Fall Creek but found elsewhere were white sucker (*Catostomus commersonii*) and blackside darter (*Percina maculata*). Six species were collected from all six sites sampled: central stoneroller (*Campostoma anomalum*), yellow bullhead (*Ameiurus natalis*), green sunfish (*Lepomis cyanellus*), bluegill (*L. macrochirus*), and largemouth bass (*Micropterus salmoides*). All six of these species are common statewide. Eleven other species were collected from five of the six sites sampled. Only five species were collected from a single site: bullhead minnow (*Pimephales vigilax*), golden redhorse (*Moxostoma erythrurum*), channel catfish (*Ictalurus punctatus*), flathead catfish (*Pylodictis olivaris*), and blackside darter. Even though seemingly rare during this survey, all are common statewide and are probably more common in the streams sampled than the survey indicated. No state listed fish species were collected from the three streams surveyed and the fish communities present are typical for tributaries of the Middle West Fork White River drainage. Interestingly, for four species, bullhead minnow, shorthead redhorse (*Moxostoma macrolepidotum*), spotted bass (*Micropterus punctulatus*), and dusky darter (*Percina sciera*), the Fall Creek drainage represents the most upstream tributary in the West Fork White River drainage in which they are found (Fig. 4).

Freshwater mussels.—Evidence of 21 native species of freshwater mussels and two non-native mollusks was found from the six sites sampled in Pogue's Run (1 site), Pleasant Run (2 sites), and Fall Creek (3 sites). Similarly to the fish diversity, freshwater mussel diversity was greatest in Fall Creek, where evidence of 21 species was found. A few unidentifiable old shell fragments were found in Pogue's Run, while shell material of only one native species was found in Pleasant Run. Unfortunately, a once very diverse mussel community from Fall Creek in the stretch sampled is now relegated to only five live species: mucket (*Actinonaias ligamentina*), plain pocketbook (*Lampsilis cardium*), fatmucket (*L. siliquoidea*), fragile papershell (*Leptodea fragilis*), and lilliput (*Toxolasma parvum*). All are common statewide. Interestingly, the only known fish host for reproduction of the fragile papershell is the freshwater drum (*Aplodinotus grunniens*), which was not collected during fish sampling, but is undoubtedly present in Fall Creek.

Two non-native mollusks, Asian clam (*Corbicula fluminea*) and zebra mussel (*Dreissena polymorpha*), were collected during the survey. Both are thriving in Fall Creek; Asian clam was also found live in Pogue's Run. The zebra mussel population in Fall Creek is a direct result of its inhabitation of Geist Reservoir further upstream in the watershed. Shell material of two federal and state endangered freshwater mussels (snuffbox (*Epioblasma triquetra*) and clubshell (*Pleurobema clava*)) and three state species of special concern (wavyrayed lampmussel (*Lampsilis fasciola*), kidneyshell (*Ptychobranchus fasciolaris*), and little spectaclecase (*Villosa lienosa*) was collected, but none are still found live in the Fall Creek drainage.

Fungi.—Thirty-three taxa were documented, 27 were identified to species. The fungi seen at the Garfield Park/Pleasant Run location were not unusual; one might expect to find any of these species in such a setting throughout Indiana. The antler form of *Ganoderma sessile* (Reishi) was encountered popping up in the lawn at one place in Garfield Park. The shelf-like form of *G. sessile* is normally more commonly seen in Indiana. The team did not survey Fall Creek or Pogue's Run.

Herpetofauna.—The amphibian and reptile group conducted surveys on the Fall Creek and Pogue's Run sites. Baited turtle traps were placed in Fall Creek at various locations along its west bank, and team members visually searched and sampled under cover objects in the riparian habitat, wooded, and woodland edge habitat at both sites. Anurans were identified by call. The combined effort at the two sites totaled approximately 38 person-hours and 14 trap-days.

In total, 11 reptiles and amphibians representing six species were observed. Six turtles representing three species were observed in Fall Creek (*Graptemys geographica*, *Sternotherus odoratus*, and *Trachemys scripta*). One species of turtle (*Chelydra serpentina*) and one species of anuran (*Lithobates clamitans*) were observed at Pogue's Run. In addition, members of another survey group observed one snake (*Nerodia sipedon*) at the Garfield Park site. All six species are common in central Indiana. Both the abundance and diversity of reptiles and amphibians observed during the bioblitz was less than expected. This likely was due, in part, to the cool, rainy weather and high water levels at the time of the survey which would have curbed basking behavior. It is likely that actual abundance is considerably higher, and that other common species of turtles, snakes, and anurans inhabit these sites. Indeed, the species observed likely represent less than half of the species inhabiting these sites.

Mammals.—Eight Anabat SD2 bat detectors (Titely Scientific) were placed along forested or riparian commuting and foraging flyways (four at Fall Creek, two at Pogue's Run, and two at Pleasant Run) for a single night. Ultrasonic microphones were placed on a ten foot pole and connected via cable to the waterproofed detector. The detectors were programmed to begin recording one half-hour before sunset and end one half-hour after sunrise. A total of eight detector nights were completed recording 14,880 audio files. The audio files were analyzed using BCID (version 2.7d, Bat Call Identification C. Ryan Allen, Bat Call Identification, Inc.), an automated acoustic identification software, which identified 90 bat passes and removed the bulk of audio files that where not produced by bats (99.4%). The identified bat passes were then visually analyzed in AnalookW (Titley Scientific) to confirm the identification of each bat pass. Based upon these audio files, four bat species were identified: big brown bat (*Eptesicus fuscus*), eastern red bat (*Lasiurus borealis*), tricolored bat (*Perimyotis subflavus*), and evening bat (*Nycticeius humeralis*). Additionally, one genus (*Myotis*), and six unknowns (poor quality passes) were detected. There also were 16 recordings not made by bats (noise). The *Myotis*, evening and tricolored bat recordings are of interest. Two of the three potential *Myotis* are federally listed, the tricolored bat is being considered for federal listing, and the evening bat is state-endangered.

A total of ten species of mammals in addition to the bat species recorded were identified by sight or sign during daytime meander surveys: Virginia opossum (*Didelphis virginiana*), red squirrel (*Sciurus vulgaris*), coyote (*Canis latrans*), raccoon (*Procyon lotor*), groundhog (*Marmota monax*), fox squirrel (*Sciurus niger*), eastern mole (*Scalopus aquaticus*), North American beaver (*Castor canadensis*), eastern cottontail (*Sylvilagus floridanus*), and human (*Homo sapiens*). Many mammal signs such as feces, prints, burrows, etc., determined presence only and could not differentiate between individuals. Many small mammals such as shrews and rodents likely occur in relative abundance, but are difficult to observe without additional forms of sampling such as snap, pitfall, or Sherman trapping. Small carnivores (e.g., foxes and skunks) were absent from the survey likely due to their nocturnal behavior and secretive lifestyles.

Two additional mammal sightings (red fox and domestic cat) were provided by Travis Ryan using camera traps deployed in bioblitz survey areas as part of an ongoing study being conducted by Butler University faculty and staff (https://www.butler.edu/cue/IWW). Each camera was mounted on a tree at approximately breast height and a fatty acid scent lure (USDA Pocatello Supply) was affixed to another tree within 8–10 m of the camera's field of view. Cameras were set to capture images when triggered by motion at a rate of not more than one image every 30 s. To minimize disturbance of wildlife in the area, the cameras were mounted at least 48 hr prior to the start of the bioblitz and removed once the observation period ended. Cameras were placed at densities of approximately 3 per ha. All images captured were reviewed and wildlife during the bioblitz time period were identified to one of seven species: red fox (Fig. 5), raccoon, opossum, fox squirrel, groundhog, domestic cat (*Felis silvestris catus*), and human. Coyote, domestic dog (*Canis lupus familiaris*), gray squirrel (*Sciurus carolinensis*), and white-tailed deer (*Odocoileus virginianus*) where seen the day just before and just after the bioblitz.

Mosses and lichens.—Samples of mosses and lichens were collected by the plant team for later identification by Bill McKnight. Seven mosses and three lichens were documented. All are very common in central Indiana.

Singing insects.—Twenty-seven species of singing crickets, katydids, cicadas, and grasshoppers were found on the three sites combined. Four additional species outside those groups were photographed at the beetle team's light station following the opening night event. Most of the species observed are common and expected in these habitats. A few are worthy of additional notes.

Green-striped grasshopper (*Chortophaga viridifasciata*): This is primarily a spring to early summer species. It can have two seasonal generations in the south, and the one found at Brookside Park suggests that such may be the case as far north as Indianapolis.

Japanese burrowing cricket (*Velarifictorus micado*): The loud chirping series produced by this introduced species were the dominant singing insect sounds everywhere surveyed in Indianapolis. This Asian cricket has spread outward from its introduction site at Mobile, Alabama, often transported in landscape materials.

Agile meadow katydid (*Orchelimum agile*): This southern species was found recently at Buzzard's Roost Nature Center in Ohio, at a latitude slightly south of Indianapolis. Photographs and a sound recording taken in a little meadow area along Pleasant Run best fit this species.

Dusky-faced meadow katydid (*Orchelimum campestre*): A surprisingly dense population was heard in the small patches of cattails, grasses, and sedges in the end of the disc golf course at Brookside Park. Dusky-faced meadow katydids have become locally distributed in northern Indiana, apparently because they are intolerant of invasive species (hybrid cattails, reed canary grass, *Phragmites*, and purple loosestrife). The authors do not know their status in central and southern Indiana.

Spiders.—The Indianapolis bioblitz spider team was considerably hampered by the weather on the collection date. Throughout the day, the spider team attempted to collect spiders through intermittent rain showers—a difficult experience when depending on dry equipment for efficient collection (Fig. 6). After approximately 25 person-hours of sampling, only 37 species were found, most of which are considered common or abundant in Indiana. Most of the specimens were immatures that could not be identified to species.

We suspect that Indianapolis has much greater spider diversity than what was recorded during this event

Vascular plants.—The plant team consisted of three subteams of 4–5 members each. One subteam led by Ben Hess surveyed Pogue's Run, the second led by Don Ruch (Fig. 7) surveyed Garfield Park, and the third led by Paul Rothrock surveyed the Fall Creek site.

Pogue's Run had 202 species, of which 144 were native (Table 2). This richness of species, greater than either Garfield Park or Fall Creek, can be attributed to the broad range of habitats encountered. These included degraded upland forest and riparian corridor, man-made detention basin, prairie planting, and turf. Pogue's Run also had the highest mean C-value (see Swink & Wilhelm

Table 2.—Floristic metrics for three Indianapolis bioblitz sites. MC = mean C-value.

Site	Number of native species	Total number of species	Native MC	Total MC
Fall Creek	102	142	2.4	1.7
Garfield Park	75	129	2.1	1.2
Pogue's Run	144	202	3.1	2.2

(1994) for details on C-values and Floristic Quality Assessment) at 3.1 for native species, the result of tree plantings and a prairie planting. The former included *Magnolia macrophylla*, the latter included *Bouteloua curtipendula, Potentilla arguta, Silphium integrifolium, Solidago riddellii, Solidago rigida, Symphyotrichum laeve,* and *Zizia aurea.* Among likely spontaneously occurring species the most notable were trees such as *Cornus alternifolia, Fagus grandifolia,* and *Quercus schumardii*; shrubs included *Ribes americana.* No high C-value (i.e., C > 6) herbs were observed but *Silphium perfoliatum* was locally common. Other noteworthy species included *Scrophularia marilandica* as well as monocots such as *Maianthemum racemosum* and a variety of grasses. Some invasive or potentially invasive species were common, at least locally: *Acer platanoides, Euonymous fortunei, Lonicera japonica, Rhamnus cathartica, Rosa multiflora, Ulmus pumila,* and *Viburnum opulus.*

At Fall Creek two areas were particularly inspected for their species content—the southern end in vicinity of 30th Street and the northern end north of the Monon Trail. The area near 30th Street had a narrow riparian zone and steep degraded woods. Thanks to recent efforts, however, it was relatively free of invasive species and had lush stream-side vegetation. The northern area was a broader floodplain forest and had numerous characteristic species, but it also had an abundance of the invasive *Euonymous fortunei.* Overall 142 species were observed in the Fall Creek riparian corridor. Of these 102 were native (Table 2). The trees included *Acer negundo, A. saccharinum, Celtis occidentalis, Platanus occidentalis,* and *Populus deltoides.* Common herbs included *Calystegia silvatica, Cinna arundinacea, Impatiens capensis, Solidago gigantea,* and *Verbesina alternifolia. Fallopia scandens* was particularly abundant. Aside from *E. fortunei, Clematis terniflora* was a second invasive of concern. Mean C for the area was 2.4 (for native species) and reduced to 1.7 with the inclusion of non-native species. Not surprisingly, no native species had a C-value > 6.

Garfield Park and Pleasant Run had rather limited natural habitat. Pleasant Run was often at the base of a steep slope with a narrow woodland border. As one might expect, this site had the fewest native species (75 species). Of note, however, is the presence of 30 native tree species. Common hardwood species included *Acer saccharinum, Celtis occidentalis, Fraxinus americana,* and *Quercus rubra.* Among the infrequent trees were *Acer saccharum, Quercus muehlenbergii, Q. palustris, Liriodendron tulipifera, Tilia americana,* and *Ulmus rubra.* The native vine *Menispermum canadense* also was common. Collectively these tree species suggest that Garfield Park contains a significant urban forest.

In Garfield Park, the remaining native species were those characteristic of early successional habitats (e.g., *Ambrosia* spp. and *Symphyotrichum pilosum*). These also include a few from more hydric habitat (e.g., *Bidens frondosa, Symphyotrichum* spp., and *Vernonia gigantea*). Over 40% of species at Garfield Park were non-native. While most were innocuous, common or abundant problematic species included *Lonicera* spp., *Alliaria petiolata, Clematis terniflora,* and *Humulus japonicus.*

Overall plant summary: The three Indianapolis parks had a total of 275 vascular plants species of which 62 species (26%) were non-native. None of the species are on the state rare-threatened-endangered list and high C-value species were lacking. Nonetheless, a richness of species and of tree species was observed and, based upon their structure and density of vegetation, portions of the riparian zones provide valuable ecological services.

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SUNBURNING SOLAR RADIATION IN CENTRAL INDIANA

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ABSTRACT. This work combines radiative transfer calculations for clear skies with measurements of ultraviolet sunlight obtained over a range of cloudy-sky conditions to define the sunburning solar irradiances experienced in central Indiana. Clear-sky ultraviolet irradiances undergo a large annual cycle primarily in response to the changing elevation of the sun above the horizon over a year, with a lesser influence from the periodic behavior in atmospheric ozone amounts. Erythema, defined as a reddening of the skin after exposure to solar radiation, can occur in less than one hr under clear, haze-free skies during a 5-hr interval centered on solar noon in October, during a 7-hr window in April, and a nearly 9-hr span in July. Scattering by clouds attenuates the ground-level irradiance to values that can vary erratically over time scales of minutes to hours and from one day to the next. One-fourth of the measured ultraviolet irradiances are 52% or less of the clear-sky value during June, July, and August. At the opposite extreme, one-fourth of the measured irradiances fall between 82% and 100% of the expected clear-sky result. In mid-July near solar noon, the time required for a minimal reddening of the skin varies from a minimum of 14 min under clear skies to 27 min or longer for the 25% of cases with the thickest cloud cover.

Keywords: Ultraviolet, sunburn, solar radiation, erythema

INTRODUCTION

Numerous epidemiological studies conducted over several decades point to a role for solar ultraviolet radiation in the occurrence of skin cancer (e.g., Scotto et al. 1974; Fears & Scotto 1983; Vitasa et al. 1990; Urbach 1991; Wu et al. 2016). In recent years approximately 3.3 million people were treated annually for non-melanoma skin cancer in the United States (Rogers et al. 2015), while the more serious form, melanoma, occurs less frequently, with an estimated 87 thousand cases in the country during 2017 (American Cancer Society 2017). According to data reported to the state cancer registry, residents of Indiana experienced 19.8 cases of melanoma per 100,000 residents in 2014 (U.S. Cancer Statistics Working Group 2017), corresponding to approximately 1,300 cases in a total population of 6.595 million people. Analogous statistics for non-melanoma cancers are not reported to state registries, but given a population of 318.6 million in the United States in 2014, one could estimate that roughly 65,000–70,000 cases of non-melanoma occurred in Indiana during that year, where exposure to the sun's ultraviolet radiation is a major risk factor.

This work addresses the solar ultraviolet radiation levels experienced by residents in central Indiana. The index of biological impact adopted here is erythema, defined as a reddening of lightly-pigmented skin that appears several hours after exposure to radiation. A minor sunburn, quantified as a minimal erythema dose or 1 MED, is short-lived, but ongoing exposure to the sun's ultraviolet emission over periods of years is implicated in the development of the non-melanoma cancers noted above (Giese 1976), while more severe cases of sunburn appear related to the eventual appearance of melanoma (Wu et al. 2016).

Ultraviolet irradiances received at the Earth's surface vary with season, latitude, and time of day owing to the changing path length taken by sunlight through the absorbing and scattering atmosphere. Wavelength-dependent absorption by the ozone contained in a vertical atmospheric column determines the amount of energy absorbed, while molecular scattering in the ultraviolet leads to a substantial diffuse component of irradiance, even when clouds are absent. The ultraviolet irradiance received at ground-level under clear, haze-free skies can serve as a useful benchmark to specify the largest radiation levels encountered at a given time of year. Reliable estimates of clear-sky irradiances come from solving the equations of radiative transfer for suitably-chosen model atmospheres, where the column abundance of ozone is the most important input. Two geographic locations at the same

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latitude will experience similar clear-sky irradiances, with small differences arising from changes in surface elevation. Although irradiances under clear-skies provide important reference values, a realistic description of the radiation environment must include attenuation by clouds and haze, and this is a primary cause of differences in climatological irradiance received at sites situated at the same latitude. Given the complex spatial and temporal variability of cloudiness, an empirical, statistical approach is necessary to include these effects in a realistic climatology of ultraviolet radiation for a specific geographic region such as central Indiana.

COMPUTED SOLAR IRRADIANCES

The clear-sky calculations reported in this work utilize a one-dimensional model which solves the radiative transfer equations for the downward scattered solar irradiance incident on the ground as a function of wavelength. The total downward spectral irradiance at wavelength λ reaching the Earth's surface, $dE_{TOT}(\lambda,\theta)/d\lambda$, defined as the energy striking unit horizontal area in unit time per unit wavelength interval in W m^{-2} nm^{-1}, is the sum of direct and scattered contributions computed with the sun at angle θ from the local zenith for the latitude, longitude, and local time of interest:

$$dE_{TOT}(\lambda,\theta)/d\lambda = dE_{DIR}(\lambda,\theta)/d\lambda + dE_{SCT}(\lambda,\theta)/d\lambda \qquad (1)$$

where $dE_{DIR}(\lambda,\theta)/d\lambda$ is the direct attenuated spectral irradiance and $dE_{SCT}(\lambda,\theta)/d\lambda$ is the scattered irradiance, including all orders of multiple Rayleigh scattering. An application of Beer's Law produces the direct component of solar irradiance. The scattered component is obtained by solving the one-dimensional radiative transfer equations for both upward and downward irradiance. The singly and multiply scattered radiation fields are assumed to be isotropic over a hemisphere, leading to the equations presented by Frederick & Lubin (1988).

The calculation includes absorption by atmospheric ozone, with the column amount specified from satellite observations. The lower boundary of the atmosphere is a Lambertian surface whose albedo is set to 0.2, where this value is derived from simultaneous upward and downward solar irradiance measurements made over a grass-covered surface in Hamilton County, Indiana. Additional inputs to the calculation are the extraterrestrial solar irradiance at wavelengths from 290 to 400 nm for an Earth-sun distance of one astronomical unit, cross sections for Rayleigh scattering, and absorption cross sections for ozone. The model adjusts the input extraterrestrial irradiances based on the day of the year to include the varying Earth-sun distance. The literature includes descriptions of similar models (Frederick & Lubin 1988) and of the required input parameters (Frederick et al. 1985) so that no further description of the mathematical development is needed here.

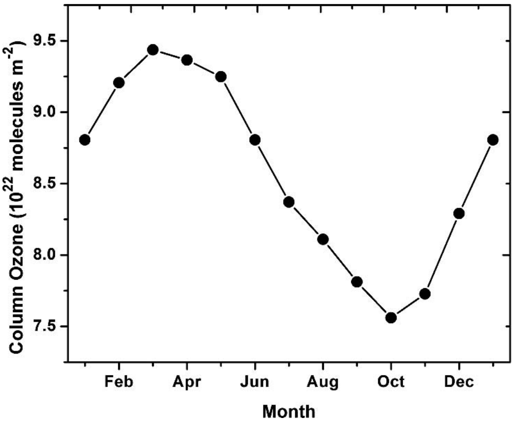

Figure 1.—Annual cycle in column ozone abundance for latitude 40°N appropriate to central Indiana.

The adopted column ozone amounts are appropriate to latitude 40°N, which passes through the southern portion of Hamilton County, Indiana. The dataset from NASA's Total Ozone Mapping Spectrometer (TOMS) on the Earth Probe satellite (Antón et al. 2010) is available in a format well-suited for developing the required climatology. The values used here are averages of all data obtained between 39°N and 41°N in one-month time periods over the years 2000 to 2005, the end of the instrument's operation. When averaged over these years, column ozone amounts in longitude bins 1.25° wide situated over Indiana were within 2% or less of the global zonal-mean values for each month. The final ozone climatology used here is based on the global zonal means. Figure 1 displays the monthly ozone abundances expressed as the number of molecules in a vertical column whose cross sectional area is 1 m^2. The column amounts display the well-known annual cycle (Bojkov & Fioletov 1995) created by transport processes at stratospheric altitudes, with maximum ozone

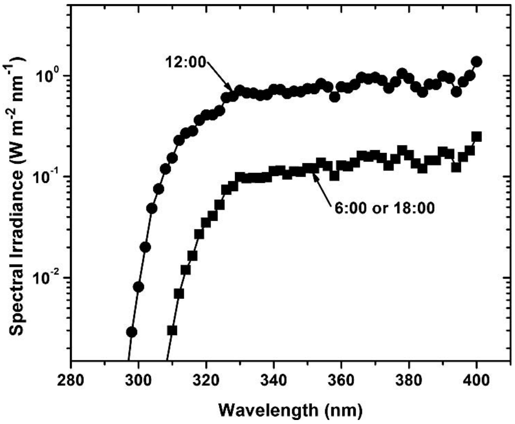

Figure 2.—Solar spectral irradiances reaching the ground appropriate to latitude 40°N in mid-July at solar times of 12:00 noon and 6:00 or 18:00 hours. Values refer to clear skies.

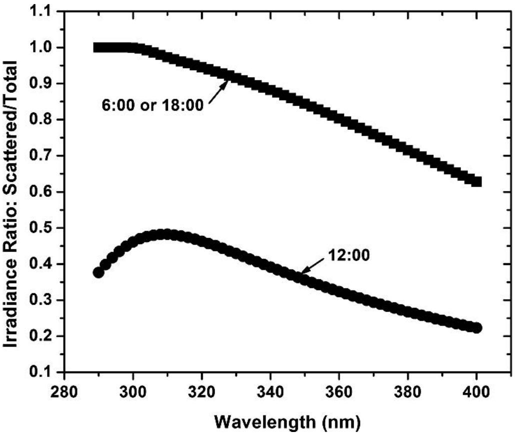

Figure 3.—Ratio of scattered irradiance to total spectral irradiance reaching the ground for latitude 40°N under clear skies in mid-July.

values appearing in spring and a minimum in autumn. The column density in March is nearly 25% larger than the result for October, with a decline taking place over the summer months. This seasonal behavior acts to shift the maximum in sunburning ultraviolet irradiances from the solstice near June 21 into early July.

Figure 2 presents the computed solar spectral irradiance $dE_{TOT}(\lambda,\theta)/d\lambda$ as a function of wavelength from 290 nm to 400 nm under clear, haze-free skies. Values refer to mid-July at 12:00 noon solar time and at times displaced six hours on either side of solar noon, 6:00 and 18:00 hours, where noon solar time is defined by the solar zenith angle θ having its minimum value for the day. Note the logarithmic scale and the steep decline in spectral irradiance due to absorption by ozone as wavelength decreases from 320 nm to 300 nm. The dependence on solar time traces to a changing path length taken by radiation through the absorbing atmosphere over the daylight period. For the direct component of irradiance an additional factor arises from a geometrical effect where a fixed amount of energy is spread over a larger horizontal area as the angle of incidence θ from the vertical increases.

Figure 3 shows the relative contributions of scattered radiation to the totals in Fig. 2 by plotting the ratio of scattered irradiance to total irradiance as a function of wavelength. Figure 3 omits any influence by clouds and haze, and it thereby depicts the minimum possible contribution from scatering. For solar noon conditions, scattered radiation varies from 22% of the total at 400 nm to a maximum of 48% near 310 nm. The decline toward still shorter wavelengths is a consequence of increasingly strong absorption by ozone at $\lambda < 310$ nm. The effective atmospheric path length taken by scattered radiation is longer than that of direct radiation for small solar zenith angles, and this leads to a greater absorption of the scattered component. For solar zenith angles in early morning and late afternoon, 6:00 and 18:00 hours, the scattered component of irradiance is larger on a relative basis than during mid-day hours and varies from 63% of the total irradiance at 400 nm to 99 percent or more for $\lambda <$ 305 nm.

The effectiveness of solar radiation in causing erythema varies with wavelength, where the "biologically effective" spectral irradiance $dE_{EFF}(\lambda,\theta)/d\lambda$ is related to the actual spectral irradiance by:

$$dE_{EFF}(\lambda,\theta)/d\lambda = A(\lambda)dE_{TOT}(\lambda,\theta)/d\lambda \quad (2)$$

where A(λ) is the dimensionless action spectrum for erythema which, by convention, is normalized to 1.0 at its maximum (McKinlay & Diffey 1987). Figure 4 presents A(λ) based on the analytic expression presented in Webb et al. (2011). Note the negative correlation with ground-level irradiance where biological effectiveness is large at wavelengths where spectral irradiance is small. Figure 5 illustrates the biologically effective spectral irradiance in mid-July for the solar times from Fig. 2. Between 12:00 and 6:00/18:00 hours solar time the largest biologically effective spectral irradiances shift in wavelength from 300–310 nm

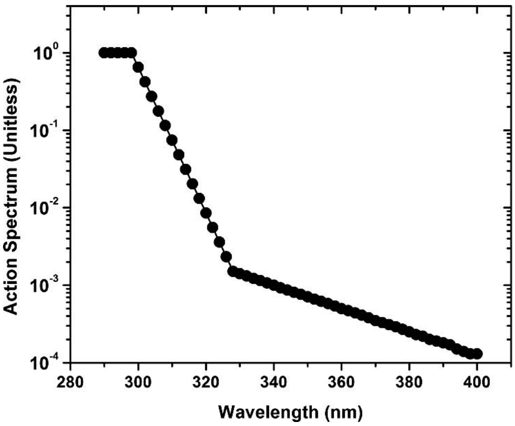

Figure 4.—Action spectrum for erythema over the wavelength range 290–400 nm. Values are normalized to 1.0 for wavelengths shorter than 300 nm and set to 0.0 at wavelengths longer than 400 nm.

to 310–320 nm, and the absolute value declines to less than 3% of the noon maximum. The shift in the peak is a consequence of the wavelength-dependent absorption by ozone. When the atmospheric path length taken by sunlight is relatively long, the shortest ultraviolet wavelengths are preferentially depleted, thereby shifting the maximum in biologically effective irradiance.

The total biologically effective irradiance in J m^{-2} s^{-1} is:

$$E_{EFF} = \int d\lambda A(\lambda) dE_{TOT}(\lambda)/d\lambda \qquad (3)$$

where the integral extends over wavelength from $\lambda = 290$ nm, below which $dE_{TOT}(\lambda)/d\lambda$ is negligibly small, to $\lambda = 400$ nm, above which $A(\lambda) = 0.0$. For health-related and medical applications, a convenient unit is the number of Minimal Erythema Doses (MED) per hour. This measure adopts the definition of 1 MED as the radiation dose that leads to an observable reddening of fair skin, typically taken as equivalent to a time-integrated dose equal to 210 J m^{-2} of biologically effective radiation as defined in Equation 3 (Pathak & Fanselow 1983). The biologically effective irradiance in MED hr^{-1}, E_{MED}, is simply E_{EFF} multiplied by (3600 s hr^{-1})/(210 J m^{-2} MED^{-1}). The quantity E_{MED} is hereafter referred to as the "erythemal irradiance."

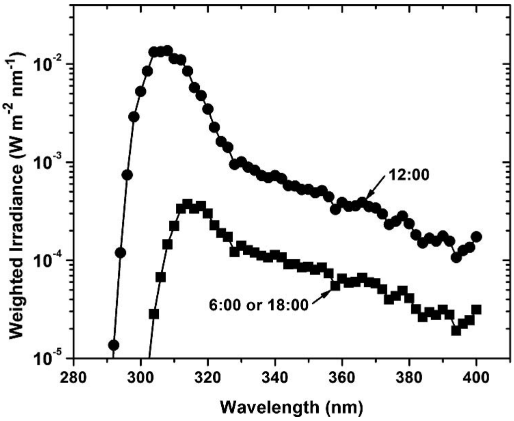

Figure 5.—Biologically-weighted spectral irradiances for latitude 40°N in mid-July at solar times of 12:00 noon and 6:00 or 18:00 hours. Values refer to clear skies.

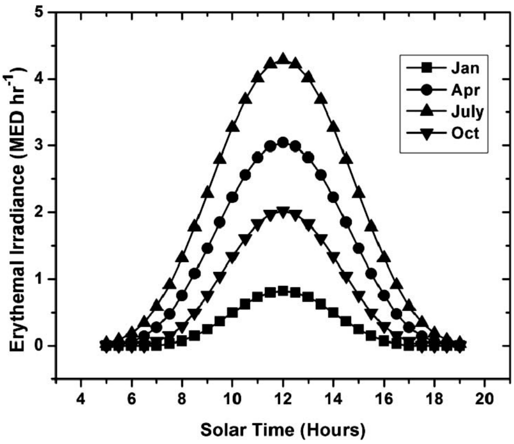

Figure 6.—Variation in ground-level erythemal irradiance with solar time under clear skies at 40°N. Curves from highest irradiance to lowest refer to mid-July, mid-April, mid-October, and mid-January in units of MED hr^{-1}.

Figure 6 illustrates the variation in erythemal irradiance striking a horizontal surface with season and solar time under clear, haze-free skies. Note that for the longitude of Indianapolis, solar noon occurs approximately 1.8 hours after local noon Eastern Daylight Time in summer. The four curves refer to January 16, April 16, July 16, and October 16. The differences between months arise primarily from different solar zenith angles, with seasonal changes in column ozone and in the Earth-sun distance being secondary factors. The peak erythemal irradiances at solar noon are 4.3 MED hr^{-1} in July, 3.0 MED hr^{-1} in April, 2.0 MED hr^{-1} in October, and 0.8 MED hr^{-1} in January. The time required for a horizontal surface to receive a dose equivalent to 1 MED

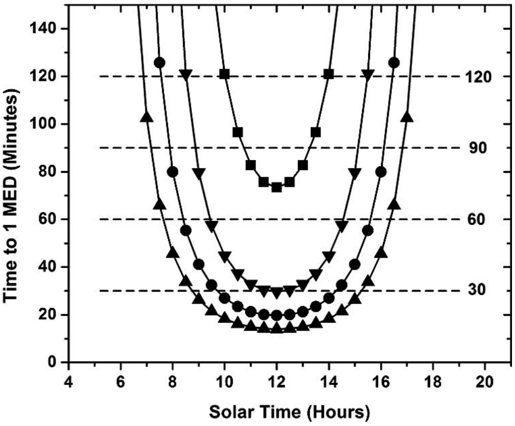

Figure 7.—Time required for a horizontal surface to receive a radiation dose of 1 MED under clear skies at latitude 40°N. Curves from shortest time to longest refer to mid-July, mid-April, mid-October, and mid-January. Horizontal lines denote times of 120, 90, 60 and 30 minutes.

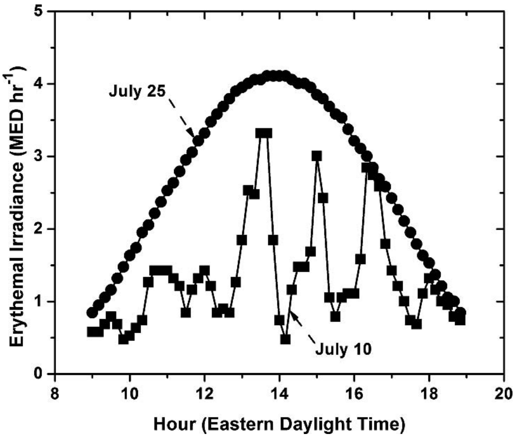

Figure 8.—Erythemal irradiances measured at 10-min intervals during a nearly-clear day and a day with thick and variable cloudiness, July 25 and July 10, 2017, respectively.

under clear skies is a medically-relevant measure of the radiation field. Figure 7 presents this time in minutes for the four months shown in Fig. 6. Dashed horizontal lines in Fig. 7 denote 30, 60, 90, and 120 min. Times-to-1 MED equal to or shorter than 30 min exist in October, April, and July, while substantial portions of the daylight period during these months have times less than one hour. In July, the month of highest ultraviolet radiation levels, the time-to-1 MED is less than 30 min for nearly 7 hr centered on solar noon.

ATTENUATION BY CLOUDS AND HAZE

The clear-sky erythemal irradiances presented above are limiting cases; the actual radiation levels encountered at any location depend on the characteristics of haze and cloudiness, and these can vary substantially from one geographic location to another and with time. The range of possible cloud geometries and thicknesses motivates an empirical approach to incorporating the influence of haze and cloudiness into estimates of climatological radiation exposure. This work uses a dataset obtained by a Davis Instruments Ultraviolet Radiation Sensor, Model 6490, over the period June 2015 through August 2017 to describe the attenuation of erythemal irradiance by clouds and haze in central Indiana. The sensor is located at latitude 40.0°N, longitude 86.1°W in southern Hamilton County, Indiana. The instrument has a spectral response function similar to the action spectrum for erythema in Fig. 4, and it records one measurement comparable to the result of Equation 3 every 10 min. The manufacturer estimates an absolute accuracy of ± 5%. The present work uses the ratio of measured irradiance to clear-sky irradiance at the same solar zenith angle, where both quantities are inferred from the sensor, so that systematic offsets in calibration tend to cancel. The objective is to characterize the attenuation provided by clouds and haze in a statistical sense for time periods measuring three months in duration. The use of a large number of measurements to produce statistical summaries acts to minimize the effect of random errors. Figure 8 presents measured erythemal irradiances for two days, where the sensor's output is converted to MED hr^{-1} for consistency with calculated values. July 25, 2017 was a nearly-clear day, while thick, variable cloudiness prevailed on July 10, 2017. Note that the horizontal scale is Eastern Daylight Time (EDT) where solar noon at the longitude of the sensor occurs near 1:45–1:50 PM EDT. The rapid variations in erythemal irradiance associated with changing cloudiness are apparent.

Figure 9 includes all irradiances measured during June, July, and August during three summer seasons from 2015 through 2017 plotted against solar zenith angle θ for θ ≤ 60°. This is $E_{MS}(i,\theta)$ where i=1,2,..., labels individual data points expressed in W m^{-2} with the normalized action spectrum implicit in the reported values. The upper envelope corresponds to cloud-free conditions with minimal haze and provides the

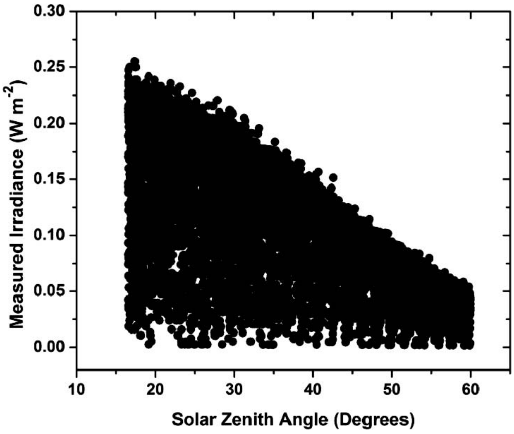

Figure 9.—Erythemal irradiances measured during June, July, and August of 2015, 2016 and 2017 plotted against the corresponding solar zenith angles. The upper envelope defines clear, haze-free skies. (W m^{-2} = watt per meter squared)

basis for defining a clear-sky reference $E_{CLR}(\theta)$ as a function of θ. The quantity:

$$R(i,\theta) = E_{MS}(i,\theta)/E_{CLR}(\theta) \quad (4)$$

characterizes the influence of clouds and haze on the ith irradiance. The measured and clear-sky irradiances vary with solar elevation in essentially the same way, so the dependence on θ tends to cancel in the ratio. The histogram of R-values in Fig. 10 summarizes the influence of clouds and haze for the entire dataset, June 2015–August 2017, where a total of 26,982 measurements enter the plot. Completely clear skies, with R approximately equal to 1.0, are infrequent, although 48% of the measurements correspond to $R \geq 0.75$. Relatively thick cloud cover, with $R \leq 0.50$, occurs in 27% of the observations.

IRRADIANCES INCLUDING CLOUDINESS

The approach developed here allows including the statistical properties of local cloudiness into estimates of erythemal irradiance while avoiding the need to treat the complex behavior evident during cloudy periods. It is convenient to sort the data according to meteorological seasons, where winter encompasses December, January and February, spring includes March, April, and May, summer is June, July, and August, and autumn refers to September, October, and November. Note that the clear-sky calculations shown in Fig. 6 refer to dates at the center of each meteorological season. Table 1 and Fig. 11 summarize the influence of clouds and haze on erythemal irradiance for each season by giving the median value of R, labeled R(50%), the ratio that defines the upper boundary of the smallest quartile of R-values, R(25%), and the ratio that defines the lower boundary of the largest quartile, R(75%). Clouds have the least influence on erythemal irradiance in meteorological autumn, when the median irradiance is equal to 82% of the clear-sky value and the middle half of values lies between 56% and

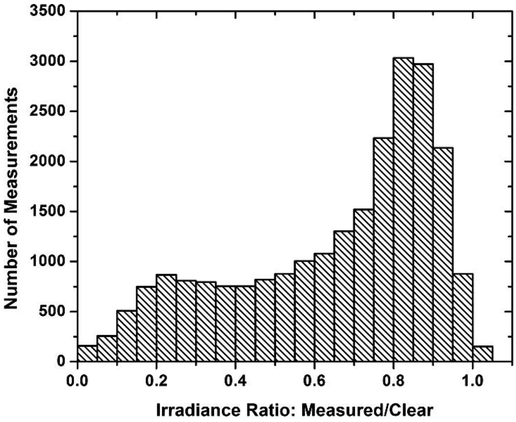

Figure 10.—Histogram of measured-to-clear-sky irradiance ratios derived for solar zenith angles less than 60° over the duration of the dataset, June 2015 through August 2017.

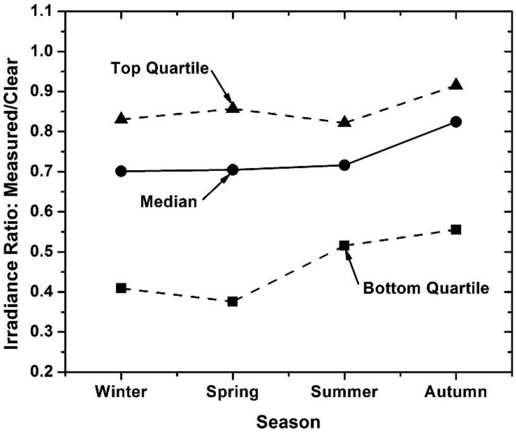

Figure 11.—Statistical summary of attenuation provided by cloudy skies for each season. Solid line defines the median values of the irradiance ratio $R = E_{MS}/E_{CLR}$. Dashed lines refer to boundaries of the top and bottom quartiles.

Table 1.—Influence of cloudy skies on erythemal irradiance based on the irradiance ratio $R = E_{MS}/ E_{CLR}$. R(25%) defines the upper bound of the smallest quartile of irradiance ratios; R(50%) is the median; R(75%) is the lower limit of the largest quartile.

Season (Months)	# Points	R(25%)	R(50%)	R(75%)
Winter (Dec-Jan-Feb)	1,312	0.41	0.70	0.83
Spring (Mar-Apr-May)	7,744	0.38	0.70	0.86
Summer (Jun-Jul-Aug)	13,883	0.52	0.72	0.82
Autumn (Sep-Oct-Nov)	4,043	0.56	0.82	0.92

92% of that for a clear sky. In meteorological summer, the period of largest absolute irradiances, the median is 72% and the interquartile range spans 52% to 82% of the clear-sky values. Similar attenuations occur in winter and spring with median irradiances at 70% of clear-sky levels and interquartile ranges extending from 38–41% to 83–86%.

To estimate biologically effective radiation levels actually experienced in central Indiana, the computed clear-sky erythemal irradiances must be scaled by the fractions in Table 1. The four panels of Fig. 12 present the final distributions for winter, spring, summer, and autumn, where the top curve in each panel is the clear-sky case. At a fixed solar time 25% of the erythemal

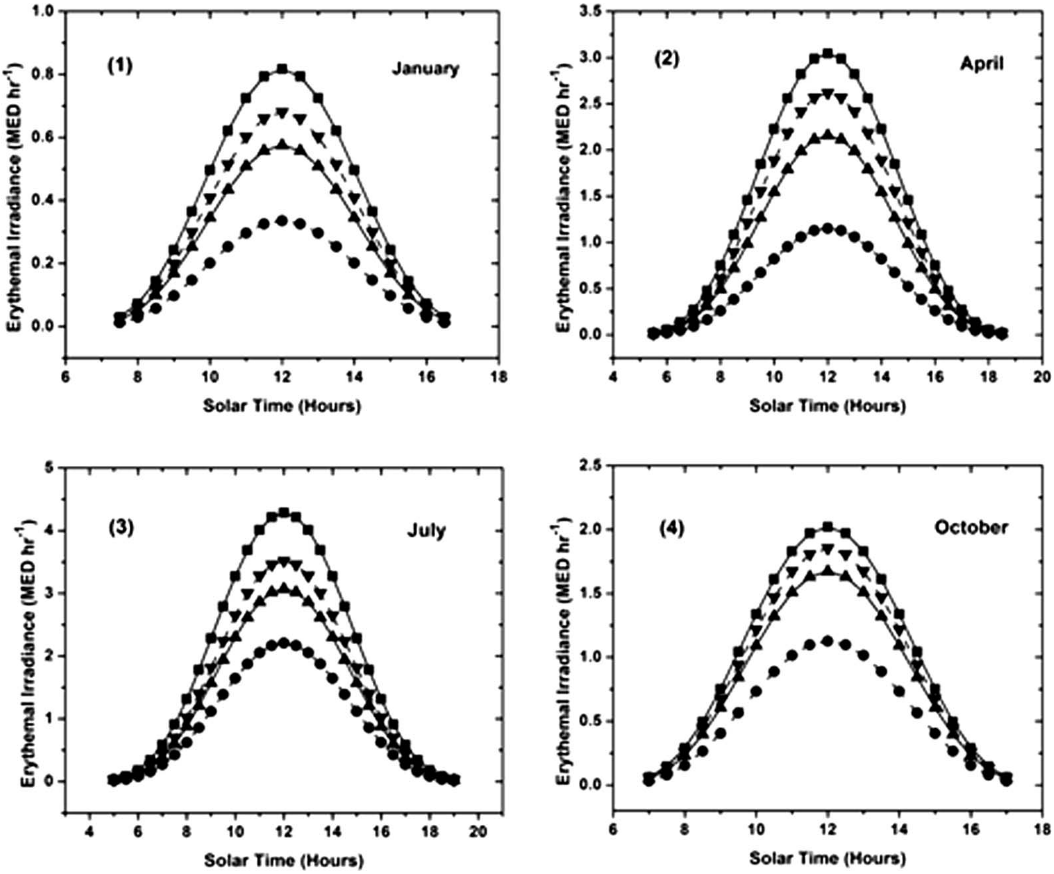

Figure 12.—Erythemal irradiance versus solar time including the influence of cloudiness. The curves, from highest to lowest, refer to clear skies, the lower boundary of the largest quartile of irradiances, the median value, and the upper boundary of the smallest quartile: (1) mid-January, (2) mid-April, (3) mid-July, (4) mid-October.

Table 2.—Time required for a horizontal surface to receive erythemal irradiance equal to 1 MED under cloudy skies typical of central Indiana: Based on irradiances for 12:00 noon and 9:00 or 15:00 hours solar time.

Season	Shortest 25% of cases	Second 25% of cases	Third 25% of cases	Longest 25% of cases
Time (Minutes): 12:00 Hours Solar Time				
Winter	73–88	88–104	104–179	> 179
Spring	20–23	23–28	28–52	> 52
Summer	14–17	17–20	20–27	> 27
Autumn	30–32	32–36	36–53	> 53
Time (Minutes): 9:00 or 15:00 Hours Solar Time				
Winter	247–301	301–357	357–613	> 613
Spring	41–49	49–61	61–115	> 115
Summer	26–32	32–37	37–51	> 51
Autumn	80–89	89–99	99–148	> 148

irradiances encountered during the season lie between two adjacent curves or, when thick clouds are present, beneath the bottom curve in each figure. With summer, July 16 at solar noon, as the most important case, the largest 25% of erythemal irradiances fall between 3.5 and 4.3 MED hr^{-1}, the next 25% fall in the range 3.1 to 3.5 MED hr^{-1}, the next 25% lie between 2.2 and 3.1 MED hr^{-1}, and the smallest 25% are less than 2.2 MED hr^{-1}.

Table 2 presents the times required for a horizontal surface to receive a dose of 1 MED on a day at the midpoint of each meteorological season, including the climatological influence of clouds and haze. Values appear for solar times of 12:00 noon and 9:00/15:00 hours. The times-to-1 MED appear as four ranges corresponding to the shortest 25% to the longest 25% based on the statistical occurrence of different degrees of cloudiness. The times-to-1 MED for summer, mid-July at solar noon, range from 14–17 min in the shortest quartile of cases to greater than 27 min for the longest quartile characterized by the greatest attenuation by clouds. Even in mid-morning and mid-afternoon, the time-to-1 MED in July is less than one hour in more than 75% of the cases. Essentially the same 75% probability applies to noontime conditions in mid-April and mid-October.

The values in Table 2 serve as a guide in estimating safe exposure times to erythemal radiation in central Indiana over seasonal time scales. However, as shown by Figure 8, erythemal irradiances encountered on any given day can be highly variable over periods of hours. Given the rapid variations in irradiance that can occur when clouds are present, it is reasonable that plans for outdoor activity err on the side of caution and assume times-to-1 MED appropriate to clear skies.

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FLORISTIC INVENTORY OF WOOLLEN'S GARDENS NATURE PRESERVE, INDIANAPOLIS, MARION COUNTY, INDIANA, USA, WITH QUANTITATIVE VEGETATION SAMPLING OF PERMANENT PLOTS IN 2003 AND 2016

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ABSTRACT. Urban forest fragments face challenges to habitat quality due to small size, isolation from larger natural areas, and close association with anthropogenic disturbance. Monitoring changes in vegetation can inform management practices targeted at preserving biodiversity in the face of these threats. Woollen's Gardens is a high-quality mesic upland forest preserve in the city of Indianapolis, Indiana, USA, with a beech-maple older-growth forest and a significant display of showy spring wildflowers. The entire preserve was inventoried and quantitative vegetation analysis along seven 100 m transects was conducted in 2003 and again in 2016 to track changes. Data from both years document a high-quality flora with few non-native plants. Floristic Quality Index values for native species, derived from Floristic Quality Assessment, were 50.2 in 2003 and 47.3 in 2016. Native mean C-values of 4.5 and 4.3 for each year support that the site is comparable to the highest quality natural areas in central Indiana. Values declined little when non-natives were included, indicating non-natives are having little negative impact on the flora. Although non-natives comprised less than 10% of the flora, 11 of the 16 species are considered invasive in Indiana. In 2003, invasive Amur honeysuckle (*Lonicera maackii*) was among species in plots with the highest relative importance value. In 2016, invasive wintercreeper (*Euonymus fortunei*) was among these species. Limited public access to Woollen's Gardens minimizes human disturbance, but invasive species are a threat to vegetation quality. Continuation of eradication efforts is strongly recommended before populations of these non-natives become more difficult to control.

Keywords: Floristic quality index (FQI), Indiana flora, invasive species, floristic change, urban forest fragment

INTRODUCTION

Studying changes in floristic composition of natural areas over time provides insight into vegetation quality that can be used to better understand plant community dynamics, to document species introductions and extirpations, and to inform site management. Quantitative vegetation sampling of permanent plots has the additional benefit of providing data on abundance and frequency, allowing floristic change to be more completely documented and monitored through time. Data derived from repeated sampling of permanent plots in locations where the surrounding landscape is undergoing significant habitat alteration, such as in cities, can provide important data for tracking the influences of urbanization on flora. For example, Dolan et al. (2015) documented an increase in the number and coverage of non-native species over a decade in two natural areas in Indianapolis, Indiana, based on permanent plot data.

Supported by funding from the Land Stewardship Office of the City of Indianapolis, we surveyed Woollen's Gardens, an urban forest fragment, in 2003 to get a base-line assessment of the plants present. In 2016, the study was repeated, visiting the preserve multiple times over the course of the year to record an overall inventory and resampling plots along the seven transects established in 2003. To report changes over time, herbaceous vegetation was quantified and overall floristic quality evaluated for both years. Results are reported here, along with management recommendations based on the findings.

Woollen's Gardens is a 38 acre state-dedicated Nature Preserve in northeast Marion County. The preserve is a remnant of a larger gift of land to the city by William Woollen in 1909 (Fig. 1). The land was used at that time for nature study. As a

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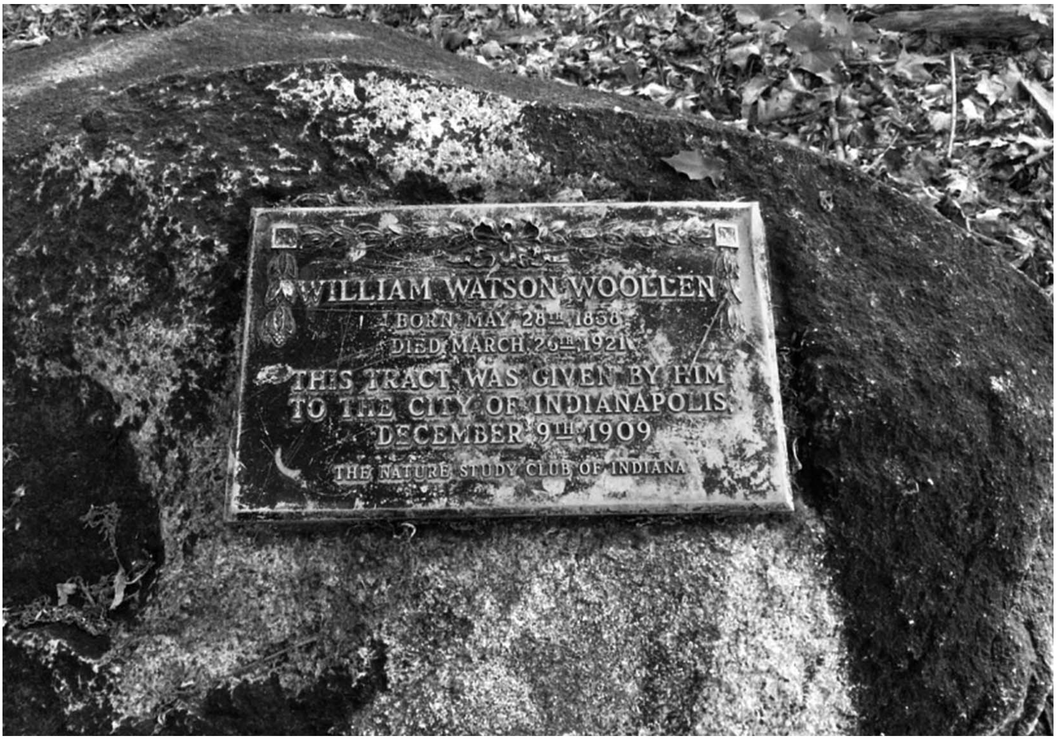

Figure 1.—Memorial plaque at Woollen's Gardens Nature Preserve.

city park, the site was spared from development. The site has been long-recognized as one of the highest-quality forested natural areas in the city (Brothers 1994). Dolan et al. (2011) documented Woollen's Gardens to be among the top three of 14 natural areas inventoried between 1996 and 2007 in Indianapolis, based on a low percentage of non-native plants and other measures of habitat integrity.

The Indiana Department of Natural Resources Directory of Indiana's Dedicated Nature Preserves, (IDNR 1988) describes Woollen's Gardens as "old-growth mesic upland forest dominated by beech, sugar maple, hackberry, red oak, chinquapin oak, black maple, and blue ash, with some trees reaching diameters of up to 40 inches." Indianapolis/Marion County is in the Central Till Plain Natural Region of Indiana (Homoya et al. 1985). This is a region of gently rolling terrain comprised of Wisconsin era glacial till deposits, often over 30 m deep. The area was 98% forested in pre-European settlement times (Barr et al. 2002).

Woollen's Gardens is bounded on the north and west by Fall Creek, on the east by Interstate 465, and on the south by apartments and an upscale neighborhood of estate-style single-family homes. The site is characterized by a floodplain adjacent to the creek and a series of north-facing ridges above the creek, separated by, in some cases, fairly deeply carved ravines (Fig. 2). The upland woodland is visually uniform with prominent mature trees. Areas of disturbance occur in flood-prone sites along the creek and adjacent to the apartment complex and yards. Dumping of trash and yard refuse, along with run-off sites of gray water, are present in these areas but the habitat is more pristine deeper in the preserve. Management has primarily been focused on invasive species removal.

MATERIALS AND METHODS

Floral inventory.—The preserve was visited 12 times from April to November during 2003 and 13 times during the same months in 2016. The flora was inventoried by meander walks that covered all areas of the preserve. Names follow usage from the Indiana Plant Atlas (Dolan & Moore 2017) and/or the online Universal FQA calculator (Freyman et al. 2015). Dr. Paul Rothrock of Indiana Univer-

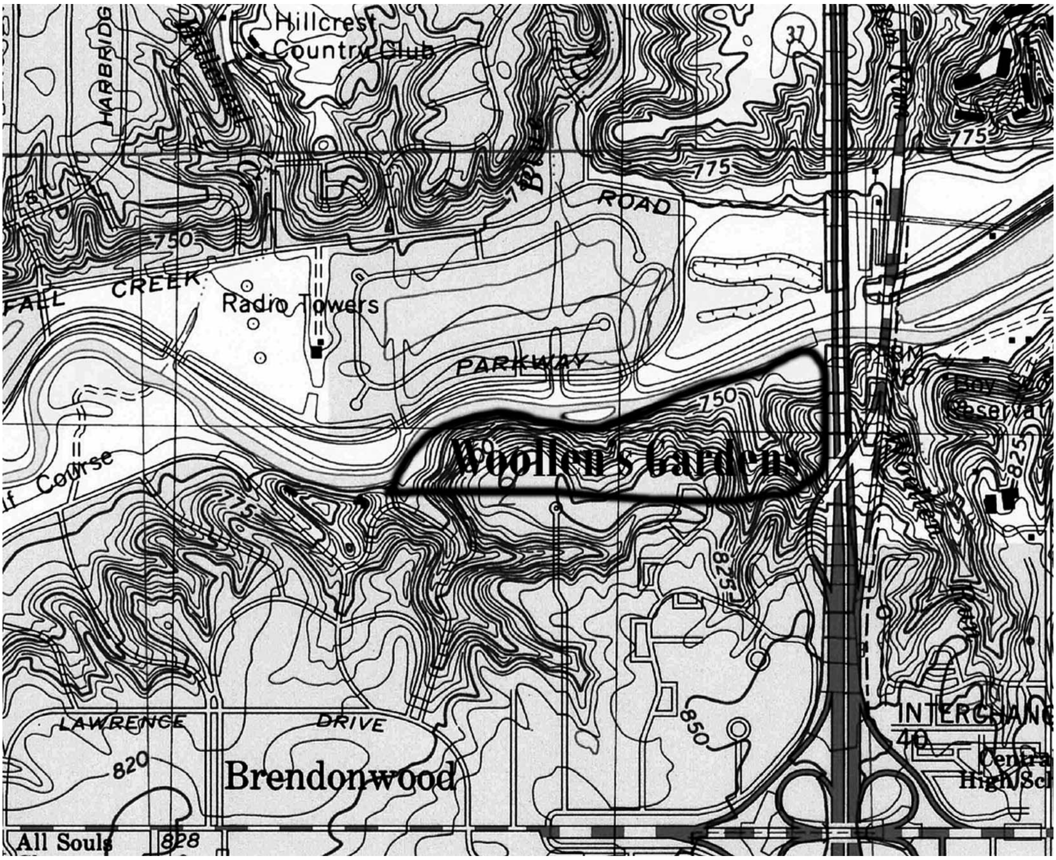

Figure 2.—Woollen's Gardens Nature Preserve topography and location. Note close proximity of major interstate highways and residential development.

sity's Deam Herbarium provided identification of grasses and sedges.

Floristic quality assessment.—Plant lists from both survey years were analyzed separately and combined using the Indiana database (based on Rothrock (2004)) of the Floristic Quality Assessment (FQA) software (Freyman et al. 2015). Mean C, a component of FQA, measures the overall quality of the habitat as indicated by the native species present (Swink & Wilhelm 1994). In this approach, native species have been assigned numbers, coefficients of conservatism (C-values), from 0–10 based on their perceived fidelity to natural plant communities. Higher numbers indicate intolerance of disturbance and restriction to presettlement remnants (Rothrock 2004). The C values are averaged to generate a mean C. In general, mean C of 3.5 and higher indicates that a community retains remnant natural quality. The Floristic Quality Index (FQI) for a site is calculated by multiplying the mean C-value for all native plants at a site by the square root of the number of native species present, thereby weighting the mean C-value by species richness. Higher FQI numbers indicate greater natural habitat integrity. Mean C and FQI with non-natives indicates the influence non-native plants have in reducing habitat quality. Sites with high natural area quality in central Indiana would be expected to have FQI values of 35 or greater (Rothrock & Homoya 2005). When comparing FQI values for a given site over time, the absolute value is not as important as how the number changes through time, with decreasing values indicating site quality decline from an ecological perspective.

Quantitative vegetation analysis.—Seven 100 m transects located throughout the preserve (Fig. 3) were assessed between May and August

Figure 3.—General locations of survey transects in Woollen's Gardens Nature Preserve. GPS coordinates are presented in Appendix 1.

in 2003 and 2016. Transect GPS coordinates and sample dates are presented in Appendix 1. Six of the seven transects were in upland forest habitat; the seventh was located on the floodplain of Fall Creek. Each species in the herb-layer (all herbaceous plants and woody plants smaller than 10 cm dbh) was identified and its aerial coverage in 1 m^2 plots located every 10 m along each transect was characterized. We used a modified Daubenmire cover class scheme (Daubenmire 1959; McCune & Grace 2002) to document cover: 1 = 1–7%, 2 = 8–25%, 3 = 26–50%, 4 = 51–75%, 5 = 76–93%, and 6 = 94–100%. Frequency (the number of plots out of 70 that each species occurred) and average cover class (averaged over all 70 plots) were calculated for herb-layer vegetation. Relative importance values (RIV) were calculated for each species by adding relative frequency and relative cover and dividing by two.

End points of the seven transects for vegetation sampling were marked temporarily in 2003 and their Global Positioning System (GPS) locations recorded. Prior to 2016 work, a professional survey team relocated the end points to within 1.0 cm accuracy using current GPS technology. These points were then marked with rebar pounded into the ground to within 2–5 cm of the soil surface.

RESULTS

A total of 166 taxa was observed during the two study years. Showy stands of declined trillium (*Trillium flexipes*) were present in 2003, along with pink valerian (*Valeriana pauciflora*) and starry campion (*Silene stellata*). In 2016, feathery false Solomon seal (*Maianthemum racemosum*) was especially prominent throughout the preserve. All plants are listed in Appendix 2, along with C-value, physiognomy (tree, fern, perennial forb, etc.), and the year and date first seen. Only 16 of the total taxa (9.6%) were non-native plants (indicated with name in capital letters in Appendix 2). The only rare, threatened, or endangered taxon found at Woollen's Gardens was American ginseng (*Panax quinquefolius*), seen in 2016. It is a state listed Watch List plant (http://www.in.gov/dnr/naturepreserve/files/np-etrplants.pdf). Cigar tree (*Catalpa speciosa)* is state listed in its native range near the Ohio River in southwestern

Table 1.—Floristic quality assessment results for Woollen's Gardens.

	Both years	2003	2016
NATIVE SPECIES	150	128	122
Total Species	166	139	134
% Native	90.4	92.1	91.0
NATIVE MEAN C	4.5	4.5	4.3
W/Non-native	4.0	4.1	3.9
NATIVE FQI	54.2	50.2	47.3
W/Non-Natives	51.5	48.0	45.1

Indiana, but in central Indiana it has escaped from cultivation (Jackson 2004). Downy yellow violet (*Viola pubescens*) is a Watch List plant, but that designation does not apply to the variety occurring in central Indiana (Michael Homoya, Pers. Comm.), and the FQA database for Indiana does not distinguish varieties for this species (Rothrock 2004).

Floristic Quality Assessment for Woollen's Gardens shows the presence of a flora with numerous conservative species that is minimally impacted by non-natives (Table 1). The reduction in mean C and mean FQI when non-natives are included is small for each sample year. Thirty-three species with C-values of 7 or greater were seen in one or both years (Table 2). C-values of 7–10 reflect species representative of high-quality natural areas that have suffered little disturbance (Swink & Wilhelm 1994). Smooth blue aster (*Symphyotrichum laeve*) was the only C-value 10 species. It was seen in 2003 but not 2016. Glade fern (*Diplazium pycnocarpon*), the only plant with a C-value of 9, was found both years. Comparison of plants with low C-values (C = 0–3) shows an increase in 2016 compared with 2003 (Fig. 4).

Herb-layer plot data.—Data on frequency and abundance of individual species collected from surveyed plots reveal additional changes in the flora between survey years (Appendix 3). The most striking difference between years is the RIV of 13.0 for Canada wood nettle (*Laportea canadensis*) in 2016. The species was not among the top ten species for RIV in 2003. RIV of sugar maple (*Acer saccharum* ssp. *saccharum*) almost doubled and RIV of ash seedlings (*Fraxinus* sp.) more than doubled between sample years. Two invasive species were among the top 10 in RIV: Amur honeysuckle (*Lonicera maackii*) in 2003 and wintercreeper (*Euonymus fortunei*) in 2016.

An average of four species was found in each plot in 2003; in 2016 the average was three. These numbers mask a species turnover rate of almost 50%. Forty species were present in plots in both 2003 and 2016. Seventeen were present only in 2003, 14 only in 2016.

Species of concern.—Although total site inventories for the two years documented few non-natives, over half that were present are invasive species of management concern in Indiana (https://www.entm.purdue.edu/iisc/invasiveplants.php). Nine of the 11 invasive species rank as species of high concern in the state (Table 3). Herb-layer data from the sample plots allow comparison of the abundance and location of invasives (Table 4). Transects 4, 6, and 7 harbored the most invasives. Transect 7 is located in the floodplain of Fall Creek (Fig. 3), a location subject to soil disturbance and spread of propagules due to flooding. Transects 4 and 6 are most closely adjacent to neighborhood edges (Fig. 3), points of increased likelihood of introduction and spread of invasives.

DISCUSSION

Data from both 2003 and 2016 document that Woollen's Gardens continues to be a high-quality example of upland forest, as first noted by Brothers (1994). Ninety percent of the species present are native to Indiana. The average for 14 Indianapolis/Marion County parks and natural areas reported by Dolan et al. (2011) is 81%, while the overall average for the flora of Indiana as a whole is estimated to be 70% (Kay Yatskievych, Pers. Comm). FQI values for Woollen's Gardens declined by 2.9 units, calculated based on either natives only or natives with non-natives included, between 2003 and 2016, indicating a slight decline in vegetation quality, even though the percentage of non-natives was similar both years. However, even the reduced FQI of 47.3 for 2016 indicates the flora of Woollen's Gardens is of regional significance from a conservation perspective (Swink & Wilhelm 1994).

FQI can be influenced by the size of an area being inventoried (Rothrock & Homoya 2005), so it is better used to detect changes in quality at a single site through time than to make comparisons between sites. Mean C-values are independent of the area of a site being inventoried, allowing direct comparisons between different sites. Native mean C-values for both years at Woollen's Gardens of greater than 4.0 are comparable to values we have found in the other state dedicated nature preserves in Marion County: Marott Park, Spring Pond,

Table 2.—Plants with C values of 7 or greater present at Woollen's Gardens.

Scientific name	Common name	C-value	Year observed	
			2003	2016
Symphyotrichum laeve	Smooth blue aster	10	x	
Diplazium pycnocarpon	Glade fern	9	x	x
Anemone acutiloba	Sharp-lobed hepatica	8	x	x
Carex amphibola	False gray sedge	8	x	
Carex hitchcockiana	Hairy gray sedge	8		x
Carex oligocarpa	Few-fruited gray sedge	8		x
Carya laciniosa	Big shellbark hickory	8	x	x
Caulophyllum thalictroides	Blue cohosh	8		x
Collinsonia canadensis	Citronella horse balm	8	x	x
Epifagus virginiana	Beech drops	8	x	
Fagus grandifolia	American beech	8	x	x
Hydrophyllum canadense	Canada waterleaf	8	x	x
Symplocarpus foetidus	Skunk cabbage	8	x	
Trillium grandiflorum	Large white trillium	8	x	
Actaea pachypoda	Doll's-eyes	7	x	x
Carex albursina	Blunt-scaled wood sedge	7		x
Carex laxiflora	Beech wood sedge	7	x	x
Dicentra canadensis	Squirrel corn	7		x
Euonymus obovata	Running strawberry bush	7	x	x
Fraxinus quadrangulata	Blue ash	7	x	x
Galium circaezans	Smooth wild licorice	7	x	
Hydrangea arborescens	Wild hydrangea	7	x	x
Hydrophyllum macrophyllum	Large-leaf waterleaf	7	x	x
Packera obovata	Round-leaved ragwort	7	x	
Panax quinquefolius	American ginseng	7		x
Quercus bicolor	Swamp white oak	7		x
Ranunculus hispidus	Rough buttercup	7	x	x
Silene virginica	Fire pink	7	x	x
Solidago caesia	Bluestem goldenrod	7	x	
Stellaria pubera	Great chickweed	7	x	x
Stylophorum diphyllum	Celandine poppy	7	x	x
Uvularia grandiflora	Large-flower bellwort	7	x	x
Valeriana pauciflora	Pink valerian	7	x	x

and Eagle's Crest, with mean native C-values of 3.8, 3.8, and 4.5, respectively (Dolan et al. 2011). These properties all had higher native mean C-values than 10 other parks and natural areas remnants surveyed, which had mean native C-values in the 3.0–3.7 range. Hubini et al. (2017) recently reported mean native C-values of 3.4 for Cooper-Skinner Woods, an urban forest remnant on the Ball State University campus in Delaware County in east central Indiana. Mean native C-values for the best natural sites in the Central Till Plain of central Indiana are in the low 4 range. This is due to a limited number of conservative species, reflecting the historic presence of few specialized habitats (Rothrock & Homoya 2005), likely further influenced by contemporary factors, including small size and isolation from larger tracts of natural habitat and the increased presence of introduced species that accompany habitat conversion for urbanization and agriculture (Hubini et al. 2017 and references therein).

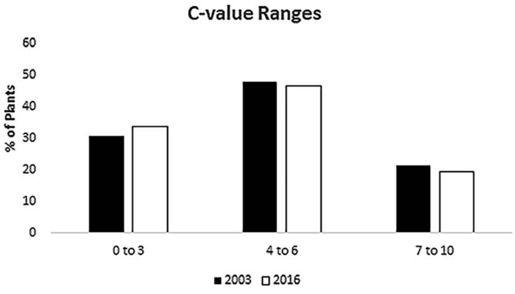

Figure 4.—Distribution of C-values for all native plants seen in 2003 and 2016.

Table 3.—Invasive species at Woollen's Gardens. Rank indicates invasiveness rank in Indiana (https://www.entm.purdue.edu/iisc/invasiveplants.php).

Scientific name	Common name	Year observed 2003	Year observed 2016	Rank
Ailanthus altissima	Tree-of-heaven	x	x	high
Alliaria petiolata	Garlic mustard	x	x	high
Berberis thunbergii	Japanese barberry	x		high
Celastrus orbiculata	Oriental bittersweet	x	x	high
Euonymus fortunei	Wintercreeper	x	x	high
Ligustrum obtusifolium	Border privet	x	x	high
Lonicera japonica	Japanese honeysuckle	x		high
Lonicera maackii	Amur honeysuckle	x	x	high
Ranunculus ficaria	Lesser celandine	x	x	caution
Rhodotypos scandens	Jetbead	x	x	caution
Rosa multiflora	Japanese rose		x	high

Woollen's Gardens vegetation quality is not currently greatly influenced by non-native species, based on FQA. Using data from the 2003 inventory, Dolan et al. (2011) reported Woollen's Gardens had the highest mean C-value with non-natives of 14 natural areas in Indianapolis surveyed between 1996 and 2007. The 2016 mean C-value with non-natives of 3.9 is in line with these findings. Differences between mean C with and without non-natives each year was only 0.4 units. Rothrock & Homoya (2005) have suggested that the natural quality of a site has been compromised when non-native species richness lowers the mean C-value by more than 0.7 units.

Although about the same number of species was documented in sample plots in 2003 and 2016, these numbers mask a species turnover rate of almost 50%. This is a phenomenon seen at other sites in the city (Dolan et al. 2015) and has been attributed to a combination of factors, including disturbance caused by management to remove invasive species, white tail deer (*Odocoileus virginianus* Zimm) browse, and rainfall and other climatological differences between sample years (Dolan et al. 2015). Aspects of this species turnover are reflected in Figure 4 as an increase in species with lower C-values, those with lower fidelity to high-quality habitat.

Between 2003 and 2016, the RIV of sugar maple, ash seedlings, and Canada wood nettle greatly increased in the herb-layer at Woollen's Gardens. Increases in sugar maple over the last 20 years have been recently documented in other mesic forests in central Indiana (Dolan 2015) and were first reported in Indiana as early as 1977 (Abrell & Jackson 1977). This pattern has been seen in many regional oak-hickory forests, perhaps due to reduced frequency of natural disturbance such as fire (Pierce et al. 2006). Increases in the frequency and cover of ash seedlings may reflect natural mast cycles in ash (Boerner & Brinkman 1996) or increased seed produced by trees stressed by the recently introduced emerald ash borer (*Agrilus planipennis* Fairmaire), as has been proposed by BenDor et al. (2006). However, few or no ash seedlings were observed in forests in Ohio and Michigan with high ash mortality due to the borer (Klooster et al.

Table 4.—Invasive species present in herb-layer sample plots. Format = transect number: plot number (cover class). *Ranunculus ficaria* was present elsewhere in the preserve in 2003 but not detected in plots.

Species	2003	2016
Alliaria petiolata	T3:1(2), T3:7(3)	T2:1(1), T2:2(1), T2:4(1)
Euonymous fortunei	T3:7(3)	T3:1(2),T3:2(1),T3:3(2),T3:7(2) T4:4(1) T5:4(1) T6:1(1)
Lonicera maackii	T1:8(1) T3:5(3), T4:1(3),T4:4(2),T4:5(1), T6:4(3)	T1:4(2),T1:6(1),T1:7(2) T3:4(1)
Ranunculus ficaria	–	T3:2(1), T3:10(2)

2014). Canada wood nettles are associated with gaps in forest canopy cover and have been documented to increase in forests where canopies have been opened due to Dutch elm disease (Biederman 2000), likely similar to gaps created when ash trees are killed by the borer. Further, dense patches of nettles are associated with reduced abundance of summer-reproducing forbs and graminoids in Minnesota forests, along with increases in sugar maple (Biederman 2000). Interactions of these disturbance factors with natural succession processes no doubt influence species dynamics at Woollen's Gardens.

The decline in RIV of Amur honeysuckle between survey years likely reflect management success at targeting this plant. However, wintercreeper has greatly increased in frequency and cover, a trend we have seen in many natural areas in Marion County over the last decade following honeysuckle removal. Not much is known about the invasion dynamics of wintercreeper (Bauer & Reynolds 2016; Mattingly et al. 2016), but increases in the presence of non-target invasive species are not uncommon following invasive species control efforts (Kettenring & Adams 2011). Wintercreeper should be a priority species for management action at Woollen's Gardens going forward.

Woollen's Gardens has little foot traffic due to limited parking, few trails, and lack of publicity. These features may contribute to the relatively low numbers of non-native and invasive plant species present, as hikers can introduce and spread non-native seed (Drayton & Primack 1996; Pickering et al. 2011). A large management concern at the site presented itself in September, 2016, however. Strong winds toppled many large trees along a ridge in the center of the preserve, near Transects 5 and 6. On our final visit in 2016, many leaning snapped trees and hanging branches presented hazards. This natural disturbance will open the canopy and potentially change the flora for many years to come. Forest openings are especially vulnerable to invasive species (Hutchinson & Vankat 1997; Pavlovic & Leicht-Young 2011), including wintercreeper (Swearingen & Bargeron 2016), which may then increase in density and/or spread within Woollen's Gardens. Management should focus on controlling invasives throughout the preserve, but especially in these areas. Vegetation should be reinventoried and transects surveyed again within the next few years to monitor changes in order to document the effectiveness of control efforts in maintaining habitat quality in this ecologically significant urban forest remnant.

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Appendix 1.—GPS coordinates for end points of transects and location of memorial plaque at Woollen's Gardens, with dates of sampling in 2003 and 2016.

Transect end point	X1	Y1	2003	2006
1a	-86.04865671640	39.86393599340	24 Jul	8 Aug
1b	-86.04811417650	39.86316989180		
2a	-86.05025729250	39.86363636590	25 May	26 May
2b	-86.05081993290	39.86286426150		
3a	-86.05114790570	39.86350318840	7 Jul	29 Jun
3b	-86.05124470330	39.86263547360		
4a	-86.04948316780	39.86275964190	7 Jul	26 Jun
4b	-86.05033173180	39.86220121890		
5a	-86.05411402700	39.86257418400	13 Aug	23 Aug
5b	-86.05298449660	39.86264173070		
6a	-86.05505816670	39.86273692250	2 Jun	25 May
6b	-86.05623313780	39.86254304350		
7a	-86.05762127820	39.86255656880	2 Jun	25 May
7b	-86.05713143170	39.86334260710		
Rock with plaque	-86.04974553940	39.86255893270		

Appendix 2.—All plants observed at Woollen's Gardens. Non-native species are in capital letters. * = invasive in Indiana. Miller = observed by Don Miller.

Scientific name	Common name	C	Physiognomy	2003	2016
Acer negundo	Boxelder	1	Tree	30 Apr	12 May
Acer rubrum	Red maple	5	Tree	27 May	
Acer saccharinum	Silver maple	1	Tree	12 May	26 May
Acer saccharum s. *nigrum*	Black maple	6	Tree	23 Apr	25 May
Acer saccharum s. *saccharum*	Sugar maple	4	Tree	23 Apr	12 May
Actaea pachypoda	Doll's-eyes	7	Perennial forb	30 Apr	26 May
Aesculus glabra	Ohio buckeye	5	Tree	23 Apr	19 Apr
Ageratina altissima	White snakeroot	2	Perennial forb	12 May	25 May
AILANTHUS ALTISSIMA*	Tree-of-heaven	0	Tree	8 Sep	1 Jun
ALLIARIA PETIOLATA*	Garlic mustard	0	Biennial forb	30 Apr	21 Mar
Allium tricoccum v. *burdickii*	Wild leek	6	Perennial forb	23 Apr	19 Apr
Anemone acutiloba	Sharp-lobed hepatica	8	Perennial forb	30 Apr	21 Mar
Arisaema dracontium	Green dragon	5	Perennial forb		25 May
Arisaema triphyllum	Indian turnip	4	Perennial forb	23 Apr	19 Apr
Arnoglossum atriplicifolium	Pale Indian plantain	6	Perennial forb	24 Jul	
Asarum canadense	Canada wild ginger	5	Perennial forb	23 Apr	19 Apr
Asimina triloba	Pawpaw	6	Tree	23 Apr	12 May
BERBERIS THUNBERGII*	Japanese barberry	0	Shrub	27 May	
Bidens frondosa	Common beggar's ticks	1	Annual forb		23 Aug
Boehmeria cylindrica	False nettle	3	Perennial forb	2 Jun	
Cardamine concatenata	Toothwort	4	Perennial forb	23 Apr	21 Mar
Carex albursina	Blunt-scaled wood sedge	7	Perennial sedge		7 Jul
Carex amphibola	False gray sedge	8	Perennial sedge	12 May	
Carex gracilescens	Slender wood sedge	5	Perennial sedge		7 Jul
Carex grayi	Common bur sedge	5	Perennial sedge	27 May	23 Aug
Carex hitchcockiana	Hairy gray sedge	8	Perennial sedge		14 Jul
Carex jamesii	Grass sedge	4	Perennial sedge		7 Jul
Carex laxiflora	Beech wood sedge	7	Perennial sedge	30 Apr	29 Jun
Carex oligocarpa	Few-fruited gray sedge	8	Perennial sedge		1 Jun
Carpinus caroliniana	Blue beech	5	Tree	30 Apr	
Carya cordiformis	Bitternut hickory	5	Tree	30 Apr	1 Jun
Carya glabra	Pignut hickory	4	Tree	7 Jul	23 Aug
Carya laciniosa	Big shellbark hickory	8	Tree	27 May	1 Jun
Carya ovata	Shagbark hickory	4	Tree	7 Jul	1 Jun
Catalpa speciosa	Cigar tree	0	Tree		1 Jun
Caulophyllum thalictroides	Blue cohosh	8	Perennial forb		12 May
CELASTRUS ORBICULATA*	Oriental bittersweet	0	Woody vine	30 Apr	1 Jun
Celtis occidentalis	Hackberry	3	Tree	30 Apr	25 May
Cercis canadensis	Eastern redbud	3	Tree	23 Apr	19 Apr
Claytonia virginica	Spring beauty	2	Perennial forb	7 Jul	
Circaea lutetiana	Enchanter's nightshade	2	Perennial forb	23 Apr	21 Mar
Collinsonia canadensis	Citronella horse balm	8	Perennial forb	13 Aug	19 May
Cornus florida	Flowering dogwood	4	Tree	23 Apr	
Cornus racemosa	Gray dogwood	2	Shrub	30 Apr	26 May
Crataegus sp.	Hawthorn	?	Tree	30 Apr	
Cryptotaenia canadensis	Honewort	3	Perennial forb	12 May	1 Jun
Cystopteris protrusa	Common fragile fern	4	Fern	30 Apr	19 Apr
Delphinium tricorne	Dwarf larkspur	5	Perennial forb	30 Apr	
Dicentra canadensis	Squirrel corn	7	Perennial forb		12 May
Dicentra cucullaria	Dutchman's breeches	6	Perennial forb	23 Apr	19 Apr
Diplazium pycnocarpon	Glade fern	9	Fern	12 May	12 May
DUCHESNEA INDICA	Indian strawberry	0	Perennial forb	23 Apr	
Elymus villosus	Hairy wild rye	4	Perennial forb	8 Sep	1 Jun
Elymus virginicus	Virginia wild rye	3	Perennial forb	12 May	1 Jun
Enemion biternatum	False rue anemone	5	Perennial forb	30 Apr	21 Mar

Appendix 2.—Continued.

Scientific name	Common name	C	Physiognomy	2003	2016
Epifagus virginiana	Beech drops	8	Perennial forb	8 Sep	
Erigenia bulbosa	Harbinger-of-spring	5	Perennial forb	23 Apr	21 Mar
Erigeron philadelphicus	Marsh fleabane	3	Perennial forb		1 Jun
Erythronium americanum	Yellow adder's tongue	5	Perennial forb	23 Apr	21 Mar
*EUONYMUS FORTUNEI**	Wintercreeper	0	Shrub	27 May	12 May
Euonymus obovata	Running strawberry bush	7	Shrub	12 May	19 May
Fagus grandifolia	American beech	8	Tree	23 Apr	21 Mar
Festuca subverticillata	Nodding fescue	2	Perennial grass		1 Jun
Floerkea proserpinacoides	False mermaid weed	5	Annual forb	30 Apr	
FORSYTHIA SUSPENSA	Weeping forsythia	0	Shrub		21 Mar
Fraxinus americana	White ash	4	Tree	23 Apr	26 May
Fraxinus pennsylvanica	Green ash	3	Tree	30 Apr	25 May
Fraxinus quadrangulata	Blue ash	7	Tree	30 Apr	19 May
Galium aparine	Annual bedstraw	1	Annual forb	30 Apr	19 May
Galium circaezans	Smooth wild licorice	7	Perennial forb	30 Apr	
Geranium maculatum	Wild geranium	4	Perennial forb	23 Apr	19 May
Geum canadense	White avens	1	Perennial forb	12 May	23 Aug
Glyceria striata	Fowl manna grass	4	Perennial forb	8 Sep	Miller
Hybanthus concolor	Green violet	6	Perennial forb	12 May	
Hydrangea arborescens	Wild hydrangea	7	Shrub	12 May	1 Jun
Hydrophyllum appendiculatum	Great waterleaf	6	Perennial forb	23-Apr	12-May
Hydrophyllum canadense	Canada waterleaf	8	Perennial forb	12 May	12 May
Hydrophyllum macrophyllum	Large-leaf waterleaf	7	Perennial forb	30 Apr	21 Apr
Hydrophyllum virginianum	Virginia waterleaf	4	Perennial forb	27 May	
Impatiens pallida	Pale touch-me-not	4	Annual forb	30 Apr	25 May
Iodanthus pinnatifidus	Violet cress	6	Perennial forb	12 May	12 May
Juglans nigra	Black walnut	2	Tree	30 Apr	23 Aug
Laportea canadensis	Canada wood nettle	2	Perennial forb	12 May	12 May
Lepidium virginicum	Common pepper grass	0	Annual forb		1 Jun
*LIGUSTRUM OBTUSIFOLIUM**	Border privet	0	Shrub	23 Apr	21 Mar
Lindera benzoin	Hairy spicebush	5	Shrub	30 Apr	19 Apr
Liriodendron tulipifera	Tulip poplar	4	Tree	30 Apr	12 May
*LONICERA JAPONICA**	Japanese honeysuckle	0	Woody vine	30 Apr	
*LONICERA MAACKII**	Amur honeysuckle	0	Shrub	23 Apr	12 May
Lysimachia ciliata	Fringed loosestrife	4	Perennial forb		23 Aug
LYSIMACHIA NUMMULARIA	Moneywort	0	Perennial forb		23 Aug
Maianthemum racemosum	Feathery false Solomon seal	4	Perennial forb	30 Apr	19 Apr
Maianthemum stellatum	Starry false Solomon seal	6	Perennial forb		12 May
Menispermum canadense	Moonseed	3	Woody vine	30 Apr	
Mertensia virginica	Virginia bluebells	6	Perennial forb	23 Apr	
Mimulus alatus	Winged monkey flower	4	Perennial forb		23 Aug
Nyssa sylvatica	Black gum	5	Tree		25 May
ORNITHOGALUM UMBELLATUM	Star-of-Bethlehem	0	Perennial forb		12 May
Osmorhiza claytonii	Hairy sweet cicely	3	Perennial forb	2 Jun	19 May
Osmorhiza longistylis	Anise root	3	Perennial forb	30 Apr	19 May
Ostrya virginiana	Hop hornbeam	5	Tree	2 Jun	12 May
Packera glabella	Butterweed	0	Annual forb		19 May
Packera obovata	Round-leaved ragwort	7	Perennial forb	30 Apr	
Panax quinquefolius	American ginseng	7	Perennial forb		Miller
Parthenocissus quinquefolia	Virginia creeper	2	Woody vine	30 Apr	12 May
Phlox divaricata	Blue phlox	5	Perennial forb	7 Jul	7 Jul
Phytolacca americana	Pokeweed	0	Perennial forb	23 Apr	19 Apr
Pilea pumila	Canada clearweed	2	Annual forb	12 May	19 May
Platanus occidentalis	Sycamore	3	Tree	30 Apr	25 May
Poa sylvestris	Woodland blue grass	5	Perennial forb	12 May	25 May
Podophyllum peltatum	May apple	3	Perennial forb	23 Apr	12 May

Appendix 2.—Continued.

Scientific name	Common name	C	Physiognomy	2003	2016
Polygonatum biflorum	Small solomon's seal	4	Perennial forb	30 Apr	25 May
Polymnia canadensis	Pale leafcup	3	Perennial forb	30 Apr	23 Aug
Polystichum acrostichoides	Christmas fern	5	Fern	30 Apr	19 May
Populus deltoides	Eastern cottonwood	1	Tree	12 May	25 May
Prenanthes alba	Lion's foot	5	Perennial forb	30 Apr	
Prunus serotina	Wild black cherry	1	Tree	30 Apr	12 May
Ptelea trifoliata	Smooth wafer ash	4	Shrub	8 Sep	1 Jun
Quercus alba	White oak	5	Tree	30 Apr	12 May
Quercus bicolor	Swamp white oak	7	Tree		25 May
Quercus muehlenbergii	Chinquapin oak	4	Tree	7 Jul	1 Jun
Quercus rubra	Northern red oak	4	Tree	30 Apr	19 May
Ranunculus abortivus	Little-leaf buttercup	0	Annual forb	23 Apr	
_RANUNCULUS FICARIA_*	Lesser celandine	0	Perennial forb	23 Apr	21 Mar
Ranunculus hispidus	Rough buttercup	7	Perennial forb	30 Apr	12 May
_RHODOTYPOS SCANDENS_*	Jetbead	0	Shrub	12 May	19 Apr
Ribes cynosbati	Prickly wild gooseberry	4	Shrub	30 Apr	12 May
_ROSA MULTIFLORA_*	Japanese rose	0	Shrub		19 May
Rubus allegheniensis	Common blackberry	2	Shrub	22 Oct	1 Jun
Rudbeckia laciniata	Wild golden glow	3	Perennial forb	2 Jun	1 Jun
Sambucus nigra s. *canadensis*	Common elderberry	2	Shrub	12 May	12 May
Sanguinaria canadensis	Bloodroot	5	Perennial forb	23 Apr	21 Mar
Sanicula odorata	Black snakeroot	2	Perennial forb	23 Apr	21 Mar
Silene stellata	Starry campion	5	Perennial forb	24 Jul	
Silene virginica	Fire pink	7	Perennial forb	30 Apr	Miller
Smilax hispida (= *S. tamnoides*)	Bristly green brier	3	Woody vine	7 Jul	
Smilax herbacea (= *S. lasioneura*)	Cat brier	4	Herbaceous vine	12 May	25 May
Solidago caesia	Bluestem goldenrod	7	Perennial forb	24 Jul	
Solidago canadensis	Canada goldenrod	0	Perennial forb		1 Jun
Solidago flexicaulis	Zig-zag goldenrod	3	Perennial forb	24 Jul	14 Sep
Stachys palustris	Hedge-nettle	4	Perennial forb	27 May	
Stellaria pubera	Great chickweed	7	Perennial forb	23 Apr	19 May
Stylophorum diphyllum	Celandine poppy	7	Perennial forb	23 Apr	19 Apr
Symphyotrichum cordifolium	Heart-leaved aster	5	Perennial forb	27 May	8 Nov
Symphyotrichum laeve	Smooth blue aster	10	Perennial forb	22 Oct	
Symphyotrichum lateriflorum	Side-flowering aster	3	Perennial forb	22 Oct	
Symphyotrichum pilosum	Hairy aster	0	Perennial forb	22 Oct	
Symplocarpus foetidus	Skunk cabbage	8	Perennial forb	22 Oct	
TARAXACUM OFFICINALE	Common dandelion	0	Perennial forb		1 Jun
Tilia americana	American linden	5	Tree	30 Apr	23 Aug
Tovara virginiana	Virginia knotweed	3	Perennial forb	30 Apr	25 May
Toxicodendron radicans	Poison ivy	1	Woody vine	23 Apr	19 May
Tradescantia subaspera	Broad-leaved spiderwort	4	Perennial forb	24 Jul	23 Aug
Trillium flexipes	Declined trillium	5	Perennial forb	23 Apr	12 May
Trillium grandiflorum	Large white trillium	8	Perennial forb	23 Apr	
Trillium recurvatum	Red trillium	4	Perennial forb	30 Apr	21 Mar
Trillium sessile	Sessile trillium	4	Perennial forb	30 Apr	21 Mar
Ulmus americana	American elm	3	Tree	2 Jun	25 May
Ulmus rubra	Slippery elm	3	Tree	30 Apr	25 May
Uvularia grandiflora	Large-flower bellwort	7	Perennial forb	23 Apr	21 Mar
Valeriana pauciflora	Pink valerian	7	Perennial forb	12 May	19 May
Verbena urticifolia	White vervain	3	Perennial forb		14 Sep
Verbesina alternifolia	Wingstem	3	Perennial forb	12 May	
Viola pubescens	Downy yellow violet	5	Perennial forb	30 Apr	19 Apr
Viola sororia	Woolly blue violet	1	Perennial forb	23 Apr	19 Apr
Viola striata	Common white violet	4	Perennial forb	30 Apr	12 May

Appendix 3.—Frequency, average cover class, and relative importance value (RIV) for herb-layer species in transects. RIV was calculated by adding each species' relative frequency and relative cover and dividing by two. Only absolute values for frequency and cover are presented here. Taxa with the ten greatest RIVs each year are in bold.

	2003			2016		
Species	Freq	Ave cover	RIV	Freq	Ave cover	RIV
Acer negundo	-	-	-	3	0.06	1.3
Acer saccharinum	6	0.09	1.8	-	-	-
Acer saccharum s. *nigrum*	-	-	-	1	0.03	0.5
Acer saccharum **s.** ***saccharum***	**15**	**0.31**	**5.4**	**27**	**0.46**	**10.7**
Actaea pachypoda	3	0.06	1.0	1	0.03	0.5
Aesculus glabra	3	0.10	1.4	1	0.03	0.5
Ageratina altissima	-	-	-	1	0.03	0.5
Alliaria petiolata	2	0.04	0.7	3	0.04	1.1
Allium tricoccum v. *burdickii*	7	0.11	2.3	3	0.04	1.1
Anemone acutiloba	5	0.08	1.7	2	0.03	0.8
Arisaema dracontium	-	-	-	2	0.04	0.9
Arisaema triphyllum	5	0.09	1.6	2	0.04	0.9
Asarum canadense	**14**	**0.36**	**5.6**	**13**	**0.37**	**6.7**
Asimina triloba	3	0.10	1.4	1	0.06	0.8
Boehmeria cylindrica	2	0.07	1.0	-	-	-
Cardamine concatenata	-	-	-	3	0.04	1.1
Carex laxiflora	6	0.09	1.8	3	0.06	1.3
Carex sp.	-	-	-	2	0.04	0.9
Carya seedling	5	0.10	1.8	3	0.04	1.1
Celtis occidentalis	2	0.03	0.6	1	0.01	0.4
Cornus seedling	-	-	-	1	0.03	0.5
Cryptotaenia canadensis	1	0.01	0.3	-	-	-
Cystopteris protrusa	2	0.03	0.6	-	-	-
Elymus virginicus	1	0.01	0.3	-	-	-
Enemion biternatum	6	0.10	2.0	2	0.03	0.8
Euonymus fortunei	1	0.04	0.6	**7**	**0.14**	**3.0**
Euonymus obovata	-	-	-	1	0.03	0.5
Fraxinus **seedling**	**8**	**0.24**	**3.5**	**17**	**0.37**	**7.6**
Galium aparine	3	0.04	0.9	1	0.01	0.4
Geum canadense	2	0.03	0.6	1	0.01	0.4
Hydrangea arborescens	1	0.04	0.6	-	-	-
Hydrophyllum appendiculatum	6	0.09	1.8	3	0.06	1.3
Hydrophyllum canadense	**7**	**0.34**	**4.2**	**5**	**0.19**	**3.0**
Hydrophyllum macrophyllum	**9**	**0.20**	**3.3**	1	0.01	0.4
Impatiens pallida	**15**	**0.30**	**5.3**	2	0.03	0.8
Laportea canadensis	3	0.11	1.5	**23**	**0.77**	**13.0**
Lindera benzoin	6	0.17	2.5	1	0.01	0.4
Liriodendron tulipifera	-	-	-	1	0.01	0.4
Lonicera maackii	**6**	**0.19**	**2.7**	4	0.09	1.8
Maianthemum racemosum	**16**	**0.41**	**6.4**	**11**	**0.27**	**5.2**
Osmorhiza claytonii	1	0.01	0.3	-	-	-
Osmorhiza longistylis	1	0.01	0.3	-	-	-
Parthenocissus quinquefolia	**12**	**0.30**	**4.7**	**10**	**0.20**	**4.3**
Phlox divaricata	-	-	-	2	0.03	0.8
Pilea pumila	-	-	-	7	0.10	2.6
Podophyllum peltatum	5	0.14	2.1	3	0.09	1.6
Polygonatum biflorum	**13**	**0.26**	**4.6**	**10**	**0.24**	**4.7**
Polymnia canadensis	-	-	-	1	0.01	0.4
Polystichum acrostichoides	1	0.03	0.5	-	-	-
Prunus serotina	4	0.06	1.2	7	0.10	2.6
Quercus seedling	7	0.10	2.2	2	0.03	0.8

Appendix 3.—Continued.

	2003			2016		
Species	Freq	Ave cover	RIV	Freq	Ave cover	RIV
Ranunculus abortivus	3	0.04	0.9	-	-	-
Ranunculus ficaria	-	-	-	2	0.04	0.9
Ribes cynosbati	1	0.03	0.5	-	-	-
Rudbeckia laciniata	1	0.03	0.5	-	-	-
Sanguinaria canadensis	5	0.10	1.8	5	0.07	1.9
Sanicula odorata	5	0.06	1.7	1	0.03	0.5
Smilax hispida	-	-	-	2	0.03	0.8
Smilax lasioneura	1	0.01	0.3	-	-	-
Solidago caesia	1	0.03	0.5	-	-	-
Solidago flexicaulis	4	0.09	1.5	1	0.01	0.4
Stylophorum diphyllum	3	0.04	0.9	1	0.01	0.4
Symphyotrichum cordifolium	6	0.10	2.0	-	-	-
Tovara virginiana	4	0.07	1.4	2	0.03	0.8
Toxicodendron radicans	5	0.14	2.1	**7**	**0.13**	**2.9**
Tradescantia subaspera	1	0.03	0.5	1	0.01	0.4
Trillium sessile	2	0.03	0.6	-	-	-
Ulmus seedling	3	0.07	1.2	3	0.04	1.1
Uvularia grandiflora	3	0.06	1.0	3	0.04	1.1
Verbesina alternifolia	1	0.01	0.3	-	-	-
Viola sp.	6	0.13	2.2	4	0.06	1.5

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CLUTCH-LEVEL VARIATION IN PREDATOR AVOIDANCE BEHAVIOR IN WOOD FROG (*LITHOBATES SYLVATICUS*) TADPOLES

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ABSTRACT. In nature, genetics and environmental conditions contribute to the abundant variation in morphology, physiology, and behavior. Predator avoidance behavior of Wood Frog (*Lithobates sylvaticus*) tadpoles was tested from six clutches to determine if variability existed between independent clutches reared under the same environmental conditions. Exposing tadpoles to alarm cues from damaged conspecifics and kairomones from a predator (after a learning event) and the corresponding reduction in activity were recorded. While some variation between clutches existed, no significant difference was observed in this behavior. We discuss hypotheses for the lack of variability and suggest our results are due to the critical role of this behavior on the survival and fitness of individuals.

Keywords: Variation, behavioral syndromes, anti-predator, *Lithobates sylvaticus*, Wood Frog, *Rana sylvatica*, tadpole

INTRODUCTION

One of the most important characteristics of any species is the variability found within populations. This variation provides the raw material for evolution by natural selection, and has helped produce the tremendous array of diversity found today (Endler 1986; Grant 1999). Although abundantly evident among morphological characteristics (Berven 1982; Townsend & Hildrew 1994), there also can be great variability in physiology (Prosser 1955; Crespi et al. 2013) and behavior (Bendesky & Bargmann, 2011). Variation in any trait is due to the combined effect of differences in genetics through mutations and heritable variability (Brooker 2012) and environmental conditions that affect the expression of these genes (Hemmer-Henson et al. 2007). A combination of these factors (genes and environment), is primarily responsible for the additive genetic variation found within populations (Cooper & Kaplan 1982; Hemmer-Henson et al. 2007).

The effect of underlying natural variation on the ecology and fitness of organisms is well documented. Differences in environmental conditions can influence the life history of organisms within that environment, such as clutch size (Mitchell & Pague 2014), hormone levels (Harding 1981; Ketterson & Nolan 1999), and the expression of sexually selected traits (Griffith et al. 1999). The effects of environment are also seen among populations from multiple locations. For example, Wood Frog (*Lithobates sylvaticus*) populations exhibit variation in physical characteristics, reproductive characteristics, and development that correspond to differences in altitude (Berven 1982), thus leading to adaptation to local environmental conditions.

One aspect of organismal ecology that is exceedingly variable is behavior, a phenomenon often attributed to behavioral syndromes (Sih et al. 2004). Behavioral syndromes are an array of correlated behaviors that an organism exhibits through differing situations (Sih et al. 2004). These general "temperaments" tend to carry over to multiple events such as mating, parental care, and competition (Sih et al. 2004). For example, an individual that is bold or active in a situation with a mate also may have a similar tendency in situations involving a predator (Bell & Sih 2007; Pruitt et al. 2012). Within a given population, individuals possess different syndromes that occur across a broad spectrum (Huntingford 1976; Bell 2005; Johnson & Sih 2005; Bell & Sih 2007; Dingemanse et al. 2007; Dochtermann & Jenkins 2007; Duckworth & Badyaev 2007; Kortet & Hedrick 2007; Moretz et al. 2007; Reaney & Backwell 2007; Pruitt et al. 2012).

Although the variability in animal behavior is well known, there is little known about clutch-level differences in behavior. Individuals within a clutch should have (at minimum) the same

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maternal genetic background, and are typically reared under similar environmental conditions. Nevertheless, resources are often provisioned differently both within and across clutches (Reed & Vleck 2001), and these differences likely have a dramatic effect on the behavior of those organisms. For example, female birds often provision eggs with varying amounts of androgens that affect multiple life-history characteristics including behavior (e.g., parental care, aggression levels, etc.), physiology (e.g., immune function, hormone levels, etc.), morphology, growth, and even survival (Groothius et al. 2005). In reptiles with temperature dependent sex determination, a single clutch may be exposed to different temperatures (e.g. top vs bottom of the nest), which may produce a mix of each sex. These differences in rearing conditions can have life-long effects, even affecting their mate choice decisions (Putz & Crews 2006).

Within amphibians, studies have documented variation in behavioral syndromes among individuals (Lima & Bednekoff 1998; Laurila et al. 2004; Sih et al. 2004), but an understanding of the differences in clutch-level behavior is less well known. In addition, many studies (e.g. Chivers & Mirza 2001; Mathis et al. 2008; Ferrari & Chivers 2010; Gall & Mathis 2010; Gall et al. 2013; Chapman et al. 2014) use entire egg clutches to test behavioral principles due to the large number of individuals that can be attained and their relative ease of collection. These studies can be based on relatively few clutches (i.e., 2–12). Whether these different clutches exhibit similar patterns of behavior is unknown as clutch is rarely included as a variable in analyses. In addition, it is possible that different responses by individuals from different clutches could mask trends in behavioral patterns.

Wood Frogs were chosen as a model organism to study differences between individual clutches in response to stimuli indicative of predation risk. The predator avoidance behaviors exhibited by tadpoles in response to these cues are well documented, and typically include reduction in activity and spatial avoidance (Kats et al. 1988; Petranka & Hayes 1998; Chivers & Mirza 2001; Relyea 2001). In the first experiment, the variation in predator-avoidance behavior between six clutches of Wood Frog tadpoles before and after exposure to alarm cues from damaged conspecifics was examined. In a second experiment, marbled salamander larvae (*Ambystoma opacum*) were trained via classical conditioning (e.g., a learning event) to fear a natural predator, and the variation in behavior among these clutches in response to exposure to kairomones from that predator alone was then evaluated.

MATERIALS AND METHODS

Wood Frog (*Lithobates sylvaticus*) clutches used in this experiment were collected from three separate water-filled depressions in a flatwoods area in Jefferson County, Indiana on 16 March 2016 (air temperature 22° C). Eggs were transported to Hanover College in plastic containers using water from the collection site. Clutches were housed individually in plastic containers with approximately 8 cm of water per container. Examination of the eggs using an Olympus SZ40 dissecting microscope revealed that they were at Gosner developmental stages 13–19 (Gosner 1960). Based on rainfall patterns, all clutches were likely deposited in the previous 48 hr. To reduce density following hatching, tadpoles from a single clutch were divided into four groups. Each group was placed in a plastic container (60 × 31 × 15 cm) with approximately 6 cm of water (approximately 200 tadpoles per container). The tadpoles were fed algae powder (a mixture of *Spirulina* and *Chlorella*, Saurian Enterprises, St. Louis, MO) every two days. All clutches were housed on a 12:12 light:dark cycle at 16° C. Water was changed twice per week.

Experiment 1: exposure to alarm cue.—The experimental set up consisted of a plastic test chamber (6 × 6 × 9.5 cm) that contained 250 mL of de-ionized (DI) water. To minimize external visual stimuli, blinds were placed around the chamber. Each container had a vertical line drawn down the center (3 cm from either end) that was used to measure tadpole activity. Alarm cues were prepared by macerating tadpoles in a blender (Oster, Sunbeam Products, Inc.) and diluting the solution with DI water to a concentration of 0.003 g tadpole / 1 mL water (Mathis et al. 2008). The alarm cue was prepared at the start of each test day and stored on ice until use.

At the commencement of the experiment, a test tadpole was arbitrarily selected from a randomly chosen clutch and placed in the test chamber to acclimate for 60 min. Following the acclimation period, a four-minute pre-stimulus control period was initiated. During this time, the number of times the tadpole crossed the center line and the number of discrete movements (any movement by the animal separated by a visible period of immobility lasting greater than 1 sec) was recorded. At the conclusion of the control period, 5 mL of alarm cue were added to the test container. The stimulus was injected with a syringe down the side of the test chamber to minimize disturbance. A 4 min post-stimulus period was then initiated immediately following the addition of the alarm cue. At the conclusion of the experiment, the tadpoles were put in separate containers and were never reused. Test containers were rinsed with hot water, then DI water, and the experimental procedure was repeated (n = 98 total; 15–18 from each clutch).

Experiment 2: response to kairomones after learning.—Marbled salamander (*Ambystoma opacum*) larvae were collected (n = 20) from an ephemeral pool in Jefferson County, Indiana. After transporting the larvae in plastic containers using the water from the collection site, the larvae were housed individually in containers (7 × 11 × 11 cm) with 250 mL of DI water for approximately 24 hr. Water from all the marbled salamander larvae was then combined to create a homogenous mixture of the kairomones from all donors and to eliminate variation among individual donor cues. Immediately following preparation of predatory kairomones, each tadpole-holding container was simultaneously exposed to 200 mL of predatory kairomones and 83 mL of freshly prepared alarm cues (0.003 g/mL). This training procedure ensured Wood Frog tadpoles learned to avoid the marbled salamander larvae through classical conditioning, as done previously in numerous studies (e.g., Brown & Smith 1998; Ferrari et al. 2010). Remaining kairomones were frozen for later testing.

The experimental procedure and set-up for the second experiment was identical to that described above, with the exception of the following change: 5 mL of kairomones from marbled salamander larvae was thawed and introduced between the control and post-stimulus observation periods (n = 91; n = 15–16 per clutch).

Statistical Analysis.—Two Two-Way repeated-measures (RM) ANOVAs were used to examine for clutch-level differences in predator avoidance behavior in response to alarm cues from damaged conspecifics and kairomones from predatory salamander larvae. Clutch (6 levels) and treatment (RM component: 2 levels: pre-control exposure, post alarm cue/kairomone exposure) were treated as the two fixed-effect factors, while the number of lines crossed and number of discrete movements were the two response variables. This procedure allowed us to test for interaction effects between clutch and treatment for each of the response variables (i.e., to determine whether different clutches exhibited significantly different responses to the stimuli indicative of predation risk). Assumptions for parametric statistics were assessed using Shapiro-Wilk tests for normality and Levene's test for equal variances, as well as graphical analyses of the residuals. All statistical tests were completed in SAS v9.4 (SAS Institute Inc., Cary, NC). All assumptions were adequately met for all response variables.

RESULTS

A RM ANOVA found a significant main effect of treatment on the number of lines crossed ($F_{[1,92]} = 12.09$, $P < 0.001$, Fig. 1A) and on the number of discrete movements ($F_{[1,92]} = 37.52$, $P < 0.001$, Fig. 1B) by tadpoles in response to alarm cues. These results indicate that all Wood Frog clutches responded to alarm cues with a general reduction in activity (Fig. 1). Although there was variation in the mean response of each clutch (e.g., range: change lines crossed -0.38 to -1.75; change number of moves -3.1 to -6.3), there was no significant main effect of clutch on the number of lines crossed ($F_{[5,92]} = 1.88$, $P = 0.11$, Fig. 1A) or the number of discrete movements ($F_{[5,92]} = 1.06$, $P = 0.39$, Fig. 1B) by the tadpoles after exposure to alarm cues. There was also no interaction effect between clutch and treatment for either response variable (lines crossed: $F_{[5,92]} = 0.51$, $P = 0.77$; moves: $F_{[5,92]} = 0.30$, $P = 0.91$).

After a learning event in which kairomones from marbled salamander larvae were paired with alarm cues, Wood Frog tadpoles reduced activity in response to kairomones alone from these predators [significant main effects of treatment on the number of lines crossed ($F_{[1,85]} = 3.70$, $P = 0.058$, Fig. 2A) and the number of discrete movements ($F_{[1,85]} = 7.22$, $P = 0.009$, Fig. 2B)]. Once again, there was no significant main effect of clutch on the number of lines crossed ($F_{[5,85]} = 0.34$, $P = 0.89$, Fig. 2A) or the number of discrete movements ($F_{[5,85]} = 0.18$, $P = 0.97$, Fig. 2B) by the tadpoles after exposure to predatory kairomones. In addition, there was no significant interaction between clutch and treatment for either response variable (lines crossed: $F_{[5,85]} = 0.33$, $P = 0.89$; moves: $F_{[5,85]} = 0.08$, $P = 0.99$).

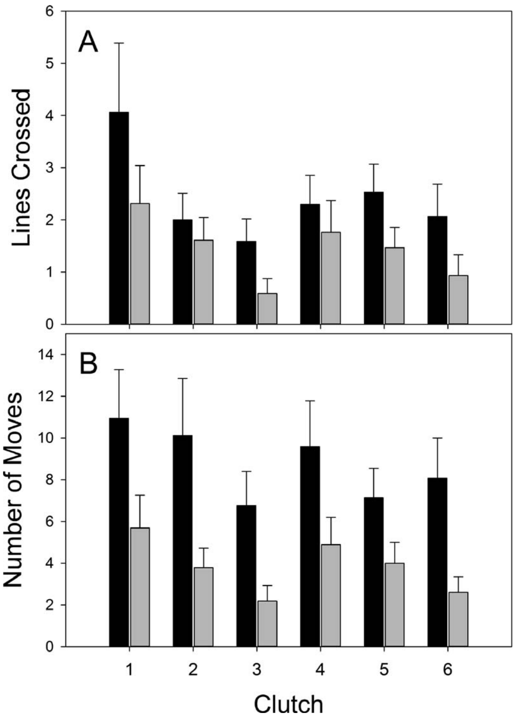

Figure 1.—Mean (± SE) change in lines crossed (A) and number of moves (B) by Wood Frog (*Lithobates sylvaticus*) tadpoles both before (black bars) and after (gray bars) exposure to alarm cues from macerated conspecifics. Wood Frog tadpoles reduced activity in response to alarm cues (lines crossed: $F = 12.1$, $P < 0.001$; moves: $F = 37.5$, $P < 0.001$), but there was no effect of clutch (lines crossed: $F = 1.88$, df = 5, $P = 0.11$; moves: $F = 1.06$, df = 5, $P = 0.39$) and no interaction between clutch and treatment (lines crossed: $F = 0.51$, df = 5, $P = 0.77$; moves: $F = 0.30$, df = 5, $P = 0.91$), indicating each clutch exhibited similar responses to the alarm cues.

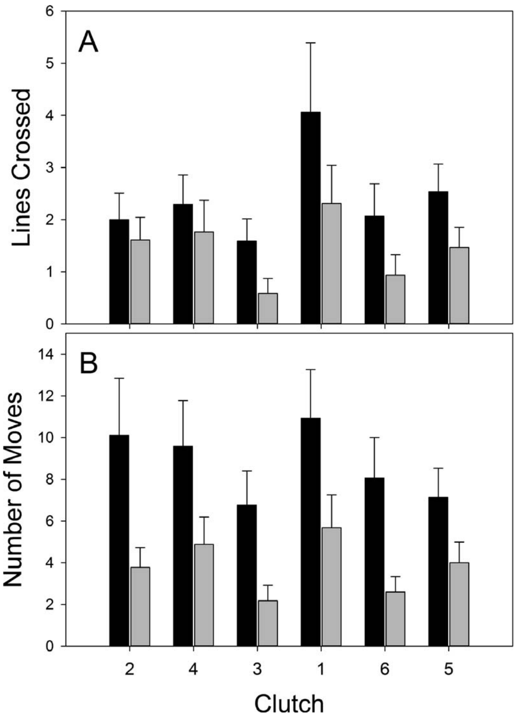

Figure 2.—Mean (± SE) change in lines crossed (A) and number of moves (B) by Wood Frog (*Lithobates sylvaticus*) tadpoles both before (black bars) and after (gray bars) exposure to kairomones from a natural predator, the marbled salamander larvae (*Ambystoma opacum*). Wood Frog tadpoles reduced activity in response to kairomones (lines crossed: $F = 3.7$, $P = 0.058$; moves: $F = 7.2$, $P = 0.009$), but there was no effect of clutch (lines crossed: $F = 0.34$, $P = 0.89$; moves: $F = 0.18$, $P = 0.97$) and no interaction between clutch and treatment (lines crossed: $F = 0.33$, $P = 0.89$; moves: $F = 0.08$, $P = 0.99$), indicating each clutch exhibited similar responses to predator kairomones.

DISCUSSION

Amphibians possess numerous predator avoidance and antipredator behaviors including physical displays (e.g., unken), toxic and distasteful secretions, and numerous behavioral changes including hiding, fleeing, and immobility (Brodie 1977; Brodie et al. 1984; Kats et al. 1988; Williams et al. 2000). Not surprisingly, Wood Frog tadpoles from different clutches were found to significantly decreased the number of lines crossed and the number of discrete movements in response to alarm cues and kairomones from a predator. Behavioral changes by Wood Frog tadpoles in response to these stimuli have been well documented and the reduction in activity observed here is a common predator avoidance behavior in this species (Kats et al. 1988; Petranka & Hayes, 1998; Chivers & Mirza, 2001; Relyea 2001; Ferrari et al. 2010).

Although variation existed in each clutches' mean response to these stimuli, there was no main effect of clutch (and no interaction effect) indicating all clutches exhibited similar predator avoidance responses. The lack of significant variation across clutches in predator avoidance behavior was surprising given studies that have documented highly variable behavioral syndromes among individuals. These correlated behaviors occupy a spectrum from bold/aggressive/active to reclusive/submissive/inactive and may be responsible for the maintenance of the high levels of variability within animal behavior (Sih et al. 2004). These behaviors are presumed to have a genetic basis (Bendesky & Bargmann 2011), and therefore related individuals (i.e., individuals within the same clutch) should exhibit similar patterns along this spectrum, whereas unrelated individuals may not. One possible explanation for a consistent response across clutches as shown in our study may be the relative "importance" of predator avoidance behaviors relative to others. Organisms perform a wide range of activities, and the role in enhancing fitness varies both intrinsically and depending on the general state of the animal. For example, many animals forgo foraging during reproductive periods, likely due to limited life-time reproductive opportunities and the relative need to focus time and energy toward this critical activity (Fleischer et al. 2003). Some behaviors, such as foraging frequency, timing of mating and courtship, and the window of oviposition may not have consistent dramatic fitness consequences from year to year and therefore have more intrinsic variability (Lima & Dill 1990). However, avoiding predators is critical to survival and fitness, and the consistent responses of Wood Frog tadpoles from different clutches in this study may be due to the overwhelming fitness advantage that responding to these cues (as opposed to ignoring them) entails. In this case, the lack of significant variation in the tadpoles' responses to these cues is critical because these stimuli signal the presence of imminent danger (Fraker et al. 2009; Ferrari et al. 2010).

Within predator-prey systems, organisms are exposed to situations and stimuli that are indicative of differing levels of risk (Lima & Bednekoff 1998; Ferrari & Chivers 2010). For example, an organism that detects kairomones from a predator may recognize a risky situation and react accordingly, yet may assign less risk to this situation than if a predator is visually detected in the vicinity-Predation-risk allocation hypothesis. Leopard Frog (*Lithobates pipiens*) tadpoles exposed to a diverse set of predator kairomones (starved, digesting conspecifics) and alarm cues (alone and combined with kairomones) were capable of discriminating among these cues and only responded with a full suite of defenses (both antipredator behavior and morphological changes) in response to the most risky cue (predators chewing and digesting prey) (Schoeppner & Relyea, 2009). While the intensity of predator avoidance behavior varies depending on the situation and level of risk (Lima & Bednekoff 1998; Schoeppner & Relyea, 2009; Ferrari & Chivers 2010), variability in response to a single type of danger (i.e., within a level of risk) may be minimal and may account for the results of our study.

Although there was no significant difference between clutches in response to the chemical threat of predation, the presence of minor variability between clutches is evident (Fig. 1). Some variation was expected, and can be attributed to genetic or environmental factors. To reduce the role of environmental effects in our study, clutches were reared under identical conditions, indicating that any variability present is primarily the result of genetic differences between the clutches (Bendesky & Bargmann 2011).

Variation can arise through genetic differences or the effect of environmental factors on the expression of those genes. By eliminating the possibility of learned experiences by rearing individuals under the same conditions, it allowed this study to focus on the natural variation between clutches in response to predation risk. Rearing these tadpoles under uniform conditions resulted in similar predator avoidance behaviors in response to the same stimuli. Each individual holds genetic variability that results in slight differences in its particular characteristics, including behavior. However, Wood Frog tadpoles do not show significant variation in predator avoidance behaviors across clutches that were reared under the same environment. This suggests tadpoles from different clutches respond to predation risk with similar behavior, therefore studies focusing on behavioral responses toward predators may not need to incorporate clutch as a variable in their analysis.

ACKNOWLEDGMENTS

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132ND ANNUAL ACADEMY MEETING[1]

Presidential Plenary Address by Darrin L. Rubino[2]

"DENDROARCHAEOLOGY: USING BUILDING TIMBERS AND TREE RINGS TO EXPLORE THE PAST"

The following text is a summary of the plenary presentation delivered by Darrin L. Rubino at the 132nd annual meeting of the Indiana Academy of Science. Citations have been added.

INTRODUCTION

Trees deposit a layer of wood, a tree ring, around their circumference each year in temperate regions. Dendrochronology, tree-ring science, focuses on assigning these annual increments of growth to the precise calendar year in which they were formed and on interpreting the short- and long-term growth patterns found in woody plants. Dendrochronological techniques can be used to investigate a wide variety of phenomena. For example, tree-ring science has been used to investigate past climatic conditions, forest fire history, insect outbreaks, and forest stand dynamics. This plenary address focuses on the subfield of dendrochronology known as dendroarchaeology. Dendroarchaeological investigations utilize tree-ring principles to date the construction of historically erected buildings. Dating is accomplished by sampling the timbers found in a building and assigning calendar dates to their tree rings.

Dendroarchaeology, and fundamentally all tree-ring science, relies on the identification of unique growth patterns in trees over time. Tree-ring width varies annually based on resources available to a tree. Ring width, consequently, is an aggregate response to the various biotic and abiotic factors experienced by a tree in a given year (Cook 1987). In years of favorable growth conditions, larger than average rings will be formed, and, likewise, smaller than average rings will be formed under stressful annual growing conditions (e.g., drought). Since temperature and precipitation have a large influence on growth, climatic conditions impart a common growth pattern or signal on tree growth over a large geographic region. Once unique growth patterns have been identified in samples of known age (living trees, for example), one can look for these patterns in samples of unknown age.

The goals of this long-term and on-going project are to date and document the construction of historically erected structures in Indiana and to tap the tree-ring data found within their timbers. With European settlement of the state, much of Indiana's forests were lost. A.W. Butler (1896) commented on the loss of the archetypical old-growth or virgin forests of the state in his presidential address to the Indiana Academy of Science in 1895. In his address titled "Indiana: A Century of Changes in the Aspects of Nature," Butler comments on the loss of "tall trees" and "heavy timber" especially in the southern portion of the state. With the loss of nearly all of the old trees, studying past forest growth using tree rings is greatly hampered. However, dendroarchaeology offers a unique opportunity to simultaneously utilize the cultural and natural heritage of the state to study the past. The numerous eighteenth century buildings that dot the Hoosier landscape are made of local timber, the trees that original settlers and explorers found when they arrived in the region. By studying these buildings and the tree-ring patterns found in their timbers much information about the dynamics, composition, and architecture of the pre-European settlement forest can be studied. For the past 15 years I have worked with numerous colleagues and students to explore the cultural legacy left by early Hoosiers.

CONDUCTING DENDROARCHAEOLOGICAL STUDIES

Determining the construction date of a historical building is a multistep process. First samples need to be extracted from the buildings' timbers. This can be accomplished by harvesting salvaged logs made available during renovation or repair.

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[1] J.W. Marriott, Indianapolis, IN, 25 March 2017.

[2] Professor of Biology, Hanover College, Biology Department, 517 Ball Drive, Hanover, IN 47243; 812-866-7247 (phone); rubino@hanover.edu.

Most commonly, samples are obtained by coring timbers with a boring bit chucked into a power drill (Figs. 1 & 2). Coring permits sample acquisition without negatively affecting the structural integrity of a building.

To date a building's construction it is necessary to determine the year in which a tree died and was subsequently used as a building timber. Death dates can be determined by dating the last year a tree formed a ring—a ring adjacent to the bark or a ring taken from the waney surface of a timber. Wane can be identified by noting a uniform, rounded outer surface of a timber that is free of any tool marks (e.g., those created by hatchet, ax, adze, chisel, or saw). If wane is present but bark is not, the outermost ring of the timber represents the last ring formed by a tree, and the bark most likely sloughed off or was removed. When numerous timbers from a structure have similar or comparable death (cutting) dates, identifying the construction date of a building is possible. Sampling, therefore, is routinely focused on bark- and wane-bearing timbers.

Next, samples must be sanded, using progressively finer grits of sandpaper, so that the tree-ring structure in a sample can be observed under a microscope. Individual rings of a sample are then assigned years, not calendar dates, since the year of formation of rings is not known in dendroarchaeological investigations. The innermost (oldest) ring in each sample is assigned "year 1", the next "year 2", and so on until each of the rings in the sample is assigned a year. The tree rings in these samples are considered floating in time since years, not dates, were assigned to the individual tree rings.

Assigning actual calendar dates to the floating series is accomplished by crossdating (Stokes & Smiley 1968). Crossdating has proven to be a highly reliable method for dating wood of unknown age. Crossdating is a method of pattern matching that utilizes regional chronologies (series of accurately dated tree rings from living trees or other historically erected buildings; Fig. 3). The samples of unknown age are crossdated with the dated chronologies using skeleton plots. Skeleton plots are graphical representations of the widths of individual tree rings in a sample. These plots allow for the identification and matching of unique growth patterns in the timbers of unknown age and verified chronologies. Crossdating also is performed using ring-width measurements. The tree-ring widths in the samples of unknown age are measured and correlated with the ring widths in dated chronologies. When skeleton plots and measured ring-width analyses suggest similar dates of ring formation, a sample is considered to be dated (see Rubino & Baas' 2014 article in *The Proceedings* for a more complete description of field and laboratory methodologies used in the region).

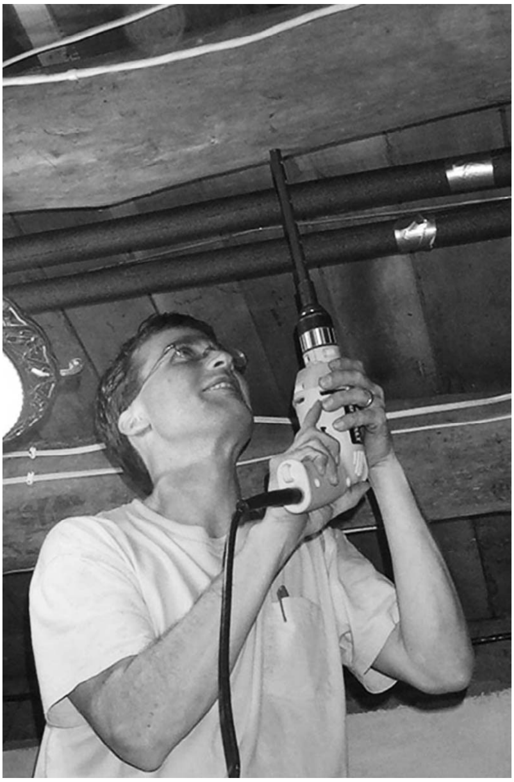
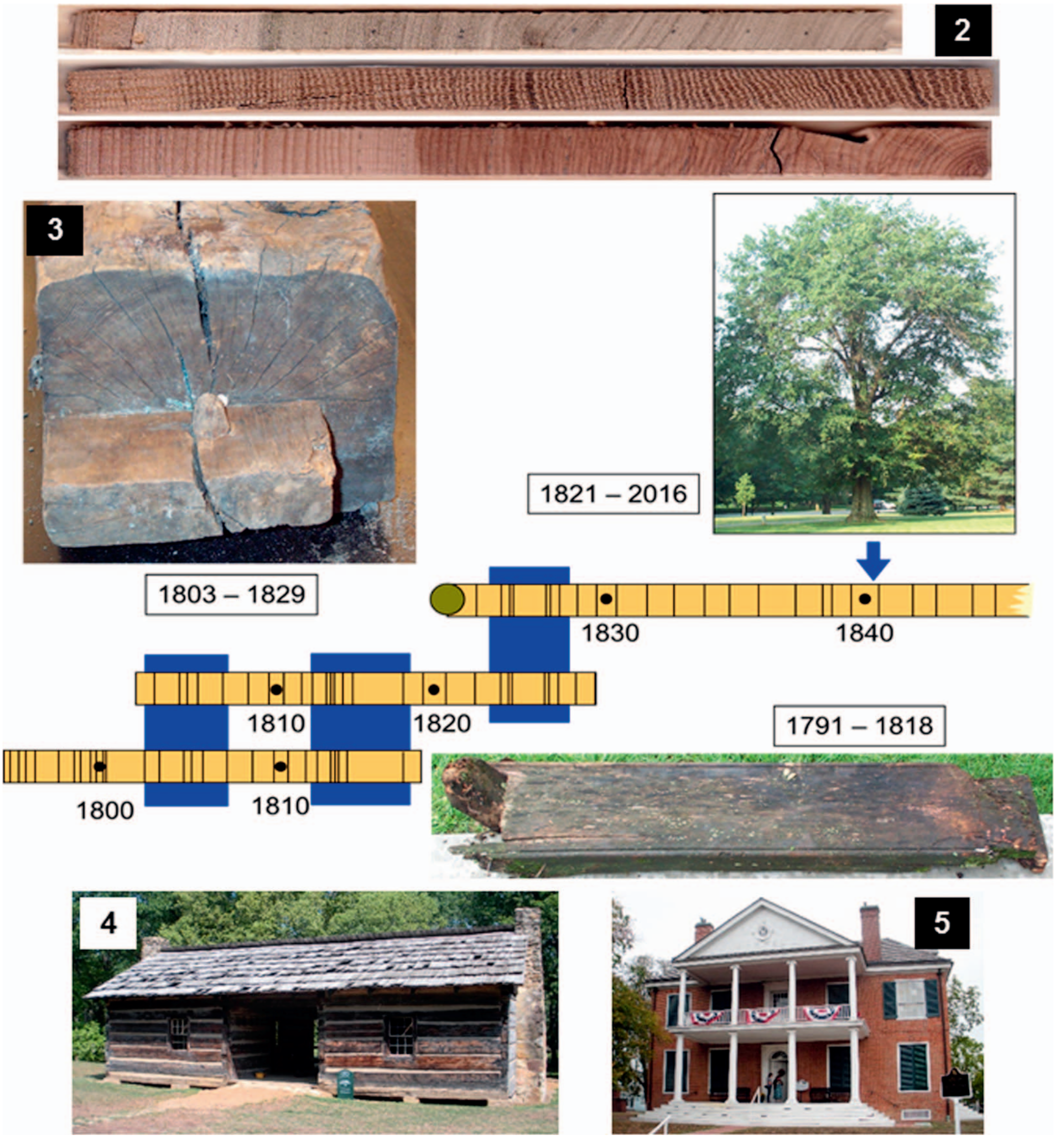


Figure 1.—Obtaining a core from a floor joist using a boring bit and drill. Note the waney surface of the log. If the outer ring of this timber can be dated, its death date can be verified.

APPLICATION OF DENDROARCHAEOLOGY

To date, my collaborators and I have been able to sample scores of buildings from the region. We have successfully crossdated churches, smokehouses, forts, barns, houses, factory buildings, and mills. When scant historical evidence is available, tree rings offer an excellent method to determine the age of buildings. We have used tree-ring analysis to verify the construction of many buildings throughout the state. Tree rings also



Figures 2–5.—Dendroarchaeological methodology and findings. (2) Cores obtained from timbers used in the construction of a historically erected building. From top to bottom: tulip poplar, white oak, American beech; the wane or bark edge is to the left. (3) Dating timbers of unknown age (a beam [upper left)] and floor joist [lower right]) is performed by crossdating their tree-ring growth patterns with chronologies consisting of dated tree rings. Blue areas represent unique growth patterns or signatures that make pattern matching and crossdating possible. Note: the sample lengths used in this demonstration illustration are much shorter than those that are needed to perform an actual analysis. Modified from Rubino (2014). (4) The Grayson dogtrot house (Posey County, IN). This building was reportedly built in 1775. Tree-ring analysis suggests a construction date of 1853. Photo courtesy of C. Baas. (5) Grouseland, the home of William Henry Harrison when he served as the Territorial Governor of the Indiana Territory in the early 1800s. Photo courtesy of C. Baas.

have been useful in providing construction dates when dubious historical information was available. For example, the Grayson House, a dogtrot house in Posey County, has been attributed a construction date of 1775 (Fig. 4). This date seemed suspect in light of regional settlement patterns. Through tree-ring analysis we were able to determine that the structure was built sometime

Figures 6–7.—Tulip poplar tree-ring samples. (6) Sample TRC01A (1561–1803). This tulip poplar sample was obtained from the attic of the Territorial Capitol (Vincennes) during renovation. Since dating the ring adjacent to the bark was possible for this sample, we were able to determine when the tree was cut and used in construction (1803). Numbers on the sample indicate individual decades of growth. (7) Sample KEL69A, a wall stud obtained from the Kellems House. The tree rings in the sample date from 1564 to 1836. The growth in this sample is extremely compact, and mean ring width is a mere 0.56 mm (± 0.24 SD).

after the initiation of the 1852 growing season (Rubino & Baas 2014). In situations such as this, tree rings enhance our cultural interpretation of unique structures found throughout the state.

Several of the buildings we have had the pleasure to date are important pieces of the cultural and historic fabric of our state. For instance, we were able to confirm the construction date of Grouseland, the Home of William Henry Harrison when he served as the Territorial Governor of the Indiana Territory (Fig. 5). Samples taken from the basement warming kitchen had a bark date of 1802. Dating also was performed on the Territorial Capitol (Vincennes); we found two samples with bark dates of 1803 (Fig. 6). We were able to verify construction dates of several buildings from New Harmony including Community House No. 2 (1822) and Thrall's Opera House (1823).

IMPORTANCE OF DENDROARCHAEOLOGY

Most of our dendroarchaeological investigations, however, have focused on the dating of vernacular structures that belonged to every-day Hoosiers. Their buildings, which have survived for well over a century, have provided us with thousands of samples that have enabled us to create long, well-replicated regional chronologies. With these chronologies we can date other buildings, gain a better understanding of how regions were settled, determine how buildings were constructed based on cultural differences, and understand the composition and growth of historic regional forests.

One such building is the Kellems House located in Canaan, Indiana (Jefferson County). During the renovation of this building we were able to extract fascia boards, floor boards, wall studs, and

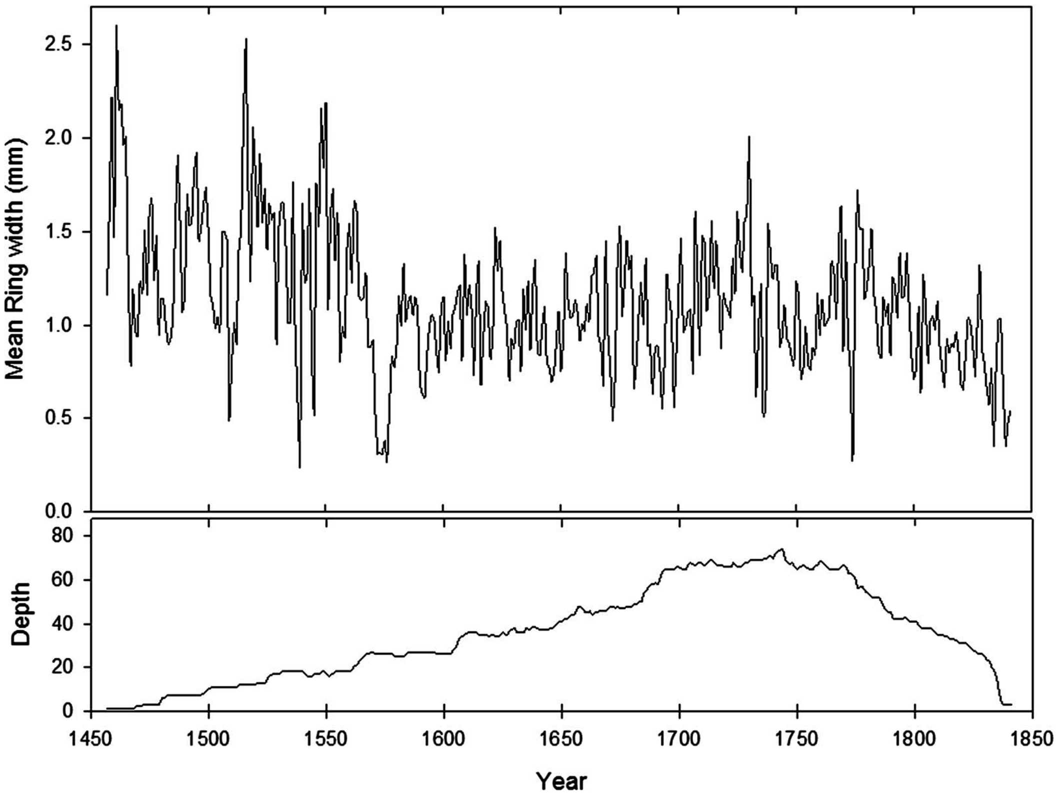


Figure 8.—Mean tree-ring chronology of tulip poplar timbers obtained from the Kellems House. This chronology was prepared by combining all tulip poplar timbers into one aggregate sample. Depth is the sample depth or number of tree rings dated and measured for a particular year.

joists and to date the construction of the building to 1836. Dating this structure was notable for several reasons. First, we were able to obtain several hundred timbers, data for creating a robust regional chronology. Secondly, we sampled several different timber types including white oak, beech, ash, and tulip poplar. Most regional dendroarchaeological work focuses on white oaks. Sampling this structure enabled us to create new species chronologies—a necessity when trying to understand past forest growth and dynamics since analyses of different species help to paint a more complete picture of how trees and forests grow in the past. We completed an ash chronology (135 samples; 11,321 rings) that spanned from 1654 to 1836. Most notably, we obtained and accurately crossdated 153 tulip poplar timbers. From these samples we developed a chronology spanning from 1457 to 1836; the final chronology consisted of 14,596 tree rings. Creation of this chronology has proven pivotal in dating many regional structures that contain tulip poplar timbers. Additionally, we were able to gain a better appreciation of how tulip poplar, our state tree, grew in old-growth forest conditions (Figs. 7 & 8).

Dendroarchaeological investigations also may give insight into cultural practices of early Hoosier settlers. For example, tree-ring analysis of numerous barns throughout the region elucidated how particular agricultural systems developed in the state. In 1843 Samuel Hewitt invented a hay press, a unique device designed to create compressed hay bales (2 × 3 × 4 foot; 0.6 × 0.9 × 1.2 m) that weighed 400 pounds (180 kg). By compressing hay, growers and shippers were afforded ease in handling, storing, and shipping hay to markets on the East Coast. The timber-built hay press was incorporated into a three story barn and compressed hay by dropping a large wooden block into a hay-filled box. Our dendroarchaeological analysis has documented 19 of these unique barns (it is thought that hundreds dotted the mid-Ohio River Valley in the mid- to late-1800s). Timbers

Figure 9.—Floor joists from a hay press barn located in Braytown, Indiana (Switzerland County). Note the author straddling a floor joist that is constructed from an entire tree bole.

used in the construction of these barns are often oversized to sustain the strains associated with the pressing process. Thus, large, entire trees are often used as floor joists (Fig. 9). From these large timbers one may generate remarkably long tree-ring series. For example, a white elm floor joist from a hay press barn in Braytown, Indiana (Switzerland County) yielded the oldest tree-ring sample we have collected to date, 1436–1863 (Fig. 10).

IN CONCLUSION

Through dendroarchaeological analysis of historically erected buildings in the region, we may better understand short and long-term growth patterns of the dense forests that once characterized Indiana. It is my hope that we continue, into the distant future, to sample buildings throughout the state and region. By adding new buildings from different areas and by analyzing new timber species, a clearer picture of the history of our forests and the settlement of

Figure 10.—Sample BRB02A, a floor joist obtained from a hay press barn in Braytown, Indiana. This white elm sample spans from 1436 to 1863 and represents the oldest crossdated sample we have collected to date.

Indiana will be possible. Ultimately, chronologies prepared from historically constructed buildings can be joined with chronologies prepared from living trees to provide a record of growth that extends, without interruption, from the present to several centuries in the past; we currently have a tulip poplar chronology spanning from 1457 to 2016. Future sampling will likely enable us to create similar chronologies for red and white oaks, beech, elm, and ash. This additional sampling will help us to understand growth of some of the most common and important species that flourished in pre-European settlement forests.

In closing, the timbers of historically erected buildings have given us a unique opportunity to look into the past. Future research can put the chronologies prepared from these building timbers to work. Research can focus on a wide variety of topics such as historic climate patterns and forest disturbance regimes. Additional work in the region will help contribute to our knowledge of how the vast forests that once covered Indiana functioned. Thank you.

ACKNOWLEDGMENTS

This work would not have been possible without the numerous land owners and property managers that permitted me and my co-researchers to obtain samples from their historic buildings. Funding for much of this research was provided by the Hanover College Faculty Development Committee and the various Hanover College grants that support summer student research opportunities. I thank the many Hanover College students that have helped make this research possible. I am greatly indebted to Chris Baas of Ball State University. His long-term friendship and collaboration have been pivotal in creating research opportunities and moving our understanding of historical buildings forward.

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Dr. Darrin Rubino is a Professor of Biology at Hanover College. He joined the Hanover Faculty in 2002. He is a graduate of Thiel College (1995) and earned his Masters from Clarion University of Pennsylvania (1997) and Ph.D. from Ohio University (2002). He has been a member of the Indiana Academy of Science since 2002. In addition to serving as the President of the Academy, Darrin served as Chair and Vice Chair of the Academy's Botany Section on several occasions. He became a Fellow of the Academy in 2013. Darrin is a forest ecologist and studies wood decay, vascular plant community composition, non-native plants, and woody debris (dead and down trees). His main research interest is dendrochronology, the study of tree-rings. He uses patterns of tree rings to understand the influence of historic human impacts and natural processes on forest structure, function, and composition. Currently, Darrin mainly uses tree rings to date the construction and modification of historic buildings (mainly in the mid-Ohio River Valley). He and his students and colleagues have dated scores of buildings in the region. Additionally, he and his students have created accurately dated series of tree-rings from living and recently dead trees from forests throughout the regions. By combining the tree-ring studies from buildings and forests, he has been able to create tree-ring series stretching from the present to the mid-fifteenth century. In 2007 and 2012 Darrin was awarded the Arthur and Ilene Baynham Award for Outstanding Teaching at Hanover College, and he won the College's Daryl R. Karns Award for Scholarly and Creative Activity in 2014.

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INDIANA ACADEMY OF SCIENCE
2017 Year End Financial Report

	Balance 1-Jan-17	Revenues	Expenses	Balance 31-Dec-17
OPERATING FUND				
Membership Dues		32,795.00		
Interest		14.91		
Misc. Income		547.65		
Foundation Support		175,386.23		
Officer's Expenses			151,447.14	
Operating Expenses			27,104.74	
Financial Expenses			3,250.97	
Newsletter Expenses			0.00	
Annual Meeting		72,385.00	73,152.01	
Academy Store		443.00	181.40	
Web Site Expenses			17,467.64	
Operating Funds Total	**22,695.55**	**281,571.79**	**272,603.90**	**31,663.44**
RESTRICTED FUNDS				
Proceedings	26,439.41	22,675.24	21,580.99	27,533.66
Publications	(50,952.06)	180,867.04	161,772.47	(31,857.49)
Research Grants*	9,215.31	71,271.67	71,821.66	8,665.32
Lilly Library	6,756.47	0.00	0.00	6,756.47
Welch Fund	6,108.56	0.00	0.00	6,108.56
Life Member's Fund	14,343.61	0.00	0.00	14,343.61
Past President's Fund	8,599.17	0.00	0.00	8,599.17
Special Projects	6,640.55	6,900.00	10,400.00	3,140.55
Total Restricted Funds	**27,151.02**	**281,713.95**	**265,575.12**	**43,289.85**
TOTAL FUNDS	**49,846.57**	**563,285.74**	**538,179.02**	**74,953.29**
FUNDS ON DEPOSIT				
Checking Account	61,916.48	640,383.15	665,730.93	36,568.70
Money Market Savings Account	3,069.06	110,858.58	59,089.00	54,838.64
Cert. of Deposit	13,554.82	33.93		13,588.75
TOTAL FUNDS DEPOSITED	**78,540.36**			**104,996.09**

*** Provided support for 20 senior member grants and 6 high school grants**

ACADEMY FOUNDATION FUNDS				
TOTAL ACADEMY FOUNDATION FUNDS	**$8,715,040.31**			**$9,615,750.04**

Foundation Funding Used For	
Operating Fund	165,206.23
Proceedings	22,675.24
Publications	91,976.31
Grants	67,868.53
Special Projects	7,400.00
Total	**355,126.31**

Michael S. Finkler
Treasurer

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