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Cover: *Lepidophora lutea* Painter, 1962 (Insecta: Diptera: Bombyliidae: Ecliminae). This individual was found frequently visiting cultivated *Coreopsis verticillata* Linnaeus, 1753 (Asterales: Asteraceae) in New Bellsville, Brown County, Indiana, on the sunny afternoon of 11 July 2015. The species, known as the hunchback bee fly, was last seen in Indiana in 1914, in Lafayette, Tippecanoe County (Rodrigues & Lamas, 2013. Zootaxa 3682(1): 1–44). Outside Indiana, the species is found from Ontario south to Louisiana and Florida. The hunchback bee fly is a fairly large fly that is an important native pollinator. Species of this genus, the Scaly Bee Flies, are cleptoparasites in solitary wasp nests; the female fly will follow a wasp in order to oviposit in the wasp's nest, which the wasp then stocks with food for its own larva. The bee fly larva feeds on the host's provisions, causing the host larva to starve. Bee flies are bee mimics, having a similar furry appearance and coloration, but they do not sting or bite. Photograph by Luke M. Jacobus; Greg Curler assisted with identification.

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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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HYPOBRANCHING INDUCED BY BOTH ENVIRONMENTAL ANTIOXIDANTS AND ROS METABOLISM GENE KNOCKOUTS IN *NEUROSPORA CRASSA*

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ABSTRACT. Previous work suggested a role of reactive oxygen species (ROS) metabolism on branch density, the statistical distribution of physical distances between branch points along a growing hypha in *Neurospora*. Here we report the results of experiments designed to ask more generally about the relationship between ROS and branch density by examining the branching effects of selected ROS metabolism gene knockout mutants as well as the impact on branching of exogenously added antioxidants. In all ROS metabolism mutants tested, growth was shown to branch less densely (hypobranching) when grown at lower temperatures, a shift not observed in the wild-type. Interestingly, this holds true for knockouts of genes expected to reduce ROS as well as those expected to produce them. In addition, in tests on wild type *Neurospora*, added ascorbic acid produced unusual branching patterns. Hypha exposed to exogenous antioxidants display dose dependent hypobranching with hypha becoming more hypobranched as doses increase. At higher doses, however, the branch distribution becomes bimodal with one maximum continuing to shift toward hypobranching and the second maximum representing a spike of very closely spaced branch points.

Keywords: *Neurospora*, morphology, branching, hypha, reactive oxygen species

INTRODUCTION

Growth in filamentous fungi proceeds via the continuously extending tip of a hypha which sends off periodic branches which are capable of extension and branching. Tip growth results from the polarized flow and exocytosis of 'tip growth' vesicles at the apex of the growing tip (Heath et al. 1971; Katz et al. 1972; Trinci 1974; Steinberg 2007; Riquelme et al. 2011); however, the role of these vesicles in the control of branching is unclear. The genetic system underlying tip growth and branching is complex. Studies on the epistasis of morphological mutants have revealed a complex range of interactions (Gavric & Griffiths 2003). Previous studies of tip growth and branching have included statistical/mathematical modeling studies of branching patterns (Prosser 1995; Watters et al. 2000b; Davidson 2007) and visualization of system components (Riquelme & Bartnicki-Garcia 2004; Mouriño-Pérez et al. 2006; Riquelme et al. 2007). Genetic approaches to understanding tip growth and branching have proven fruitful, including the analysis of suppressors of classical mutations (Plamann et al. 1994; Minke et al. 1999), broad screens for new mutants (Seiler & Plamann 2003), making use of established paradigms from yeast budding (Momany 2002; Harris & Momany 2003; Knechtle et al. 2003; Harris et al. 2005), and the cloning and characterization of classical morphological mutations.

It has been suggested that branching is induced when the concentration of tip-growth vesicles reaches a critical density at the apex (Trinci 1974). Although several studies have presented results that are consistent with this hypothesis (Katz et al. 1972; Trinci 1974; Watters & Griffiths 2001), none demonstrate it definitively. The results presented by these previous studies, in fact, are entirely consistent with the possibility that branching is triggered by the accumulation of some other undefined factor (other than tip-growth vesicles) associated with tip growth. The experiments described below were designed to begin to explore the possibility that the triggering factor was the accumulation of reactive oxygen in the hypha.

The observation of a temporary response to growth rate shifts followed by a return to normal branch density (Watters et al. 2000a; Watters & Griffiths 2001; Watters 2013) supported the

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Table 1.—ROS control mutants result in growth rate sensitive branching not seen in wild-type *Neurospora*. N values for the comparison varied between samples. Typical N values were roughly 200 branch lengths at each of the two temperatures. Reported are the means ± standard deviation of the distribution of distances between branch points for each strain under the two temperatures tested. Also reported are P values for a T-test comparing branching at the two temperatures. As with previous studies, wild-type shows no significant difference in branching between the two conditions. All tested ROS metabolism mutants however show significant differences (below p = 1%) between branching under the two conditions. The ROS metabolism mutants' branching, while typically close to wild-type at 33° C, show a strong shift toward much longer than normal branching when grown at 10° C.

Accession #	Disrupted gene	Branching (µm) at 33° C (Mean ± SD)	Branching (µm) at 10° C (Mean ± SD)	P value 33° C vs 10° C
	Wild-type	155 ± 104	169 ± 136	0.21
NCU08791	catalase-1	140 ± 87	239 ± 132	5.1×10^{-12}
NCU05770	catalase-2	155 ± 134	254 ± 174	1.5×10^{-11}
NCU00355	catalase-3	159 ± 109	257 ± 135	1.7×10^{-9}
NCU05169	catalase-4	169 ± 109	268 ± 175	4.2×10^{-13}
NCU02110	NADPH oxidase-1	197 ± 132	239 ± 149	2×10^{-3}
NCU10775	NADPH oxidase-2	169 ± 131	239 ± 154	3.6×10^{-7}
NCU07850	NADP oxidase regulator-1	140 ± 89	239 ± 156	4×10^{-17}
NCU02133	superoxide dismutase-1	154 ± 136	211 ± 112	5.1×10^{-7}
NCU01213	superoxide dismutase-2	155 ± 140	211 ± 123	2.4×10^{-7}
NCU07386	Fe superoxide dismutase	155 ± 117	254 ± 142	5.8×10^{-14}
NCU07851	superoxide dismutase 1 copper chaperone	113 ± 62	211 ± 134	1.3×10^{-28}
NCU09560	superoxide dismutase	183 ± 112	225 ± 148	4.6×10^{-5}

hypothesis that tip growth and branching are connected, but that this connection is compensated for in the wild-type, resulting in a consistent branch density. Thus, it was proposed (Watters & Griffiths 2001) that *Neurospora* morphology was controlled, in part, by a homeostatic system responsible for branch initiation. This system compensates for growth rate and is responsible for the maintenance of a constant branch density under a wide range of growth conditions (Watters & Griffiths 2001).

Mutations which appear to affect the proposed growth rate/branch density compensation system have been identified among both older *Neurospora* mutants (Watters et al. 2008) as well as among the current knockout library (Watters et al. 2011). Among the gene knockouts seen to affect the previously proposed growth rate/branch density compensation system were two (catalases) involved in the metabolism of reactive oxygen species (ROS). ROS are highly reactive molecules, commonly generated in biological organisms as a byproduct of normal oxygen metabolism. ROS production typically increases in fungi due to various stresses (reviewed by Gessler et al. 2007). Reactive oxygen species have been found to play a role in sexual and asexual development as well as hyphal growth in fungi (Cano-Dominguez et al. 2008; Semighini & Harris 2008). Reactive oxygen species have also been linked to developmental determination in a broad range of organisms (Finkel 2003; Foreman et al. 2003; Lambeth 2004; Aguirre et al. 2005; Carol & Dolan 2006). The relationship between cold stress and ROS has been studied extensively in plants, where there appears to be a multi-step response to exposure to cold where the plant initially experiences an increase in the production of ROS, and damage associated with that increase, followed by an increase in the production of antioxidants which counter that initial increase allowing the plant to better acclimatize to the cold (Beck et al. 2007, Airaki et al. 2012, Miura et al. 2012). The observation that ROS control was playing a role in branching, suggests the possibility that the accumulation of ROS could be the trigger for branch initiation. The experiments reported here were designed to test that hypothesis.

We report here on an expansion of our earlier study (Watters et al. 2011) that examined the *Neurospora* knockout library (Colot et al. 2006) for mutants with defects in the maintenance of

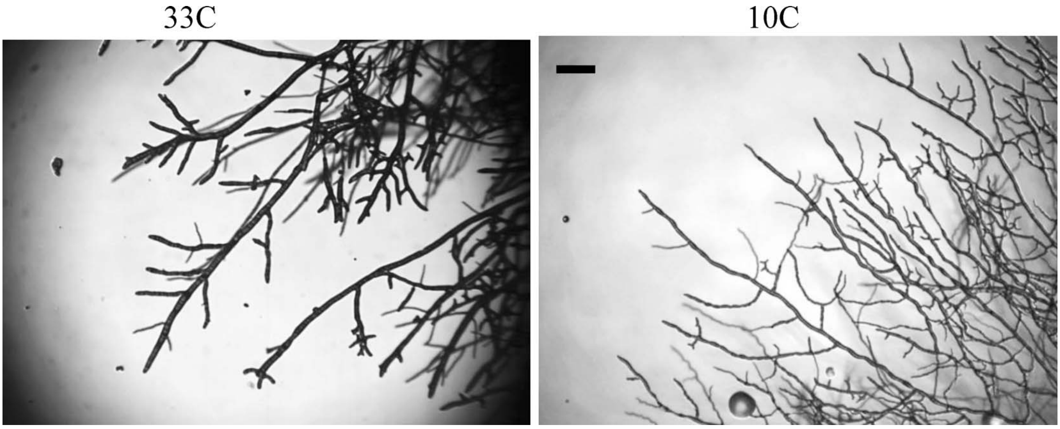

Figure 1.—Wild-Type at 33° C and 10° C. In wild-type *Neurospora*, branch density is kept constant during a wide range of growth conditions, including temperature variation. Scale bar = 100 μm.

branch density at different rates of growth. We expanded on the previous study by closely examining mutations in a wide variety of genes known to be important to ROS metabolism for their effects on branch density homeostasis. In addition, the effect on branching of exposure to the water soluble antioxidants ascorbic acid and glutathione were examined. Both lines of study point to a relationship between ROS control and branching in *Neurospora*. These also represent the first report of sustained hypobranching in *Neurospora*.

MATERIALS AND METHODS

Strains and media.—A library of knockout strains containing disruptions in presumptive genes has been constructed (Colot et al. 2006). Strains from this library are available from the Fungal Genetics Stock Center (McCluskey 2003). Our attention for this study was focused on a group of selected strains with knockouts in genes (listed in Table 1) related to the metabolism of reactive oxygen species. Vogel's media and culturing procedures were those described in Davis & deSerres (1970). Water soluble antioxidants ascorbic acid and glutathione as well as lipid soluble antioxidants beta-carotene and alpha-tocopherol were independently added to media.

The accession numbers listed in Table 1 represent the locus number of the gene subject to inactivation in the knockout strain under test.

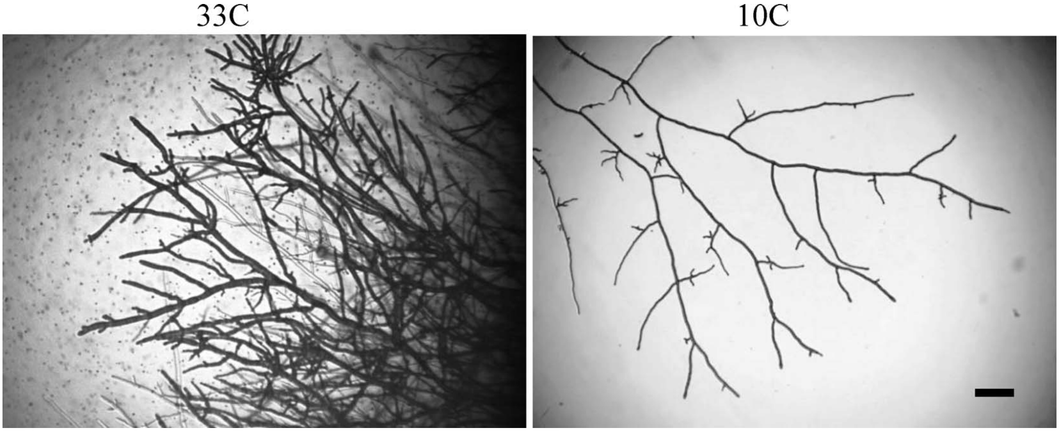

Figure 2.—Cat-4 at 33° C and 10° C. The ROS metabolism mutants tested (cat-4 shown, others similar) responded to differences in incubation temperature. In all cases, the branch density at reduced incubation temperatures (10° C) was significantly hypobranched relative to growth at 33° C. Scale bar = 100 μm.

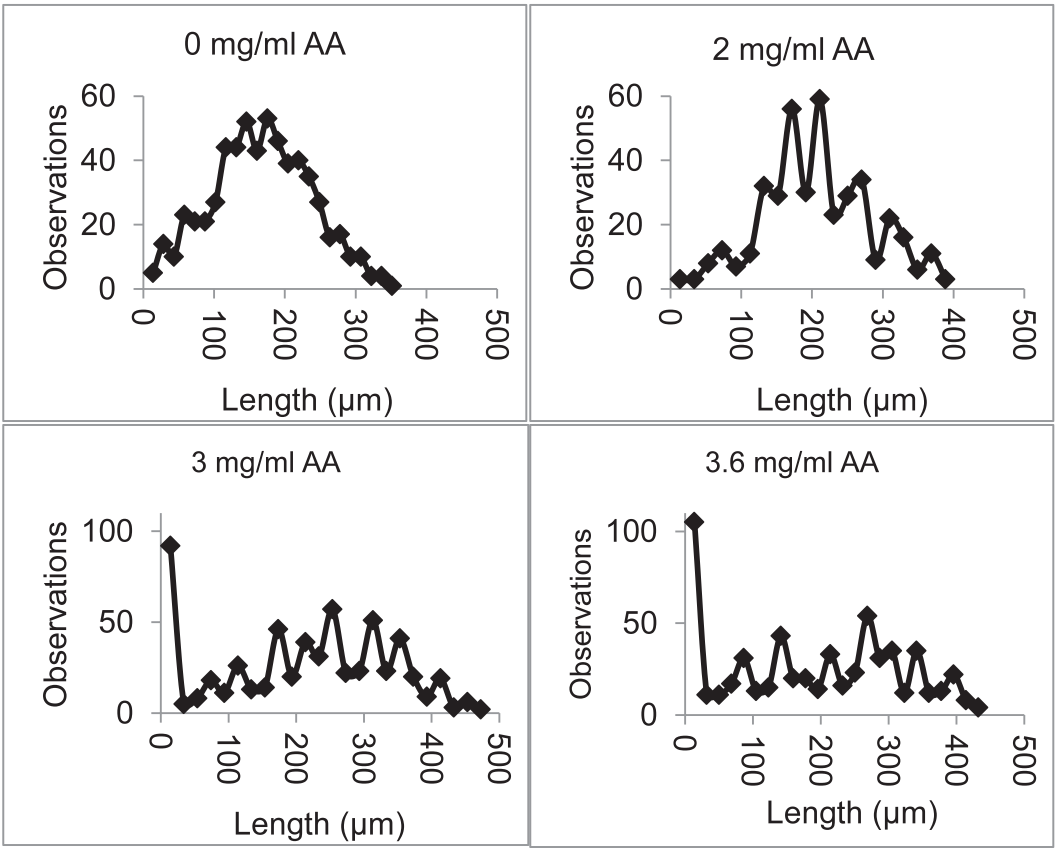

Figure 3.—Influence of ascorbic acid on branch density. Exposure to ascorbic acid at 33° C causes a dose dependent shift to hypobranching. At sufficiently high concentrations, however, a shift to frequent, very tight branching with some wider spaced branching is observed. Shown are curves of frequencies of branch interval lengths at 0, 2, 3 and 3.6 mg/ml ascorbic acid (AA). Sample sizes are 608, 413, 606 and 602 branch intervals, respectively.

Every annotated gene in *Neurospora crassa* has been assigned a locus number of the form NCU#### by the Broad Institute. The gene functions associated with the knockout strains reported in Table 1 are based solely on the annotations currently associated with those strains and have not been independently confirmed by the authors of this study. The functions reported are those associated with the genes as annotated on the Broad Institute's *Neurospora crassa* database: http://www.broadinstitute.org/annotation/genome/neurospora/MultiHome.html.

Photomicroscopy.—Growing cultures were examined and photographed using a Diagnostic Instruments, Inc. SPOT RTke digital camera attached to an Olympus BH-2 microscope. Photographs were taken of well separated, leading hyphae in order to determine the branch density (distances between branch points along hyphae as they extend). Photos were used to measure distances between branch points. Measurements of distances between branch points were collected into databases of several hundred individual distances for statistical comparison of branching at different growth conditions. Growth at 33° C was photographed after 24 hrs growth. Growth at 10° C was photographed after seven days growth in order to allow sufficient growth to measure. This is the same procedure used previously (Watters et al. 2011)

Statistical comparison of branch density.—Comparison of branch density followed the procedure used previously (Watters et al. 2000a; Watters & Griffiths 2001; Watters et al. 2011).

Figure 4.—Altered morphology induced by high doses of antioxidants. Branching variation induced in wild type *Neurospora* by exposure to 3 mg/ml ascorbic acid. The altered branching displays a combination of regions of very tightly spaced lateral branches separated by regions of longer than normally spaced branches. Scale bar = 100 μm.

Measurements of the distance between branch points were made by measuring directly off photographs of growth and converting these lengths to distances on the plate. These measurements were then used to build a dataset of lengths between branch points. N values for the comparison varied between samples. Typical N values were roughly 200 branch lengths at each of the two temperatures. The resulting distributions were compared and analyzed using the Student's t-test.

RESULTS

Wild strains and strains with knockouts of selected genes involved in the metabolism of ROS in *Neurospora* were grown on minimal media at both 33° C and 10° C. As with previous studies (Watters et al. 2000a; Watters and Griffiths 2001; Watters 2013), wild-type strains showed no significant difference in branching between the two temperatures (Fig. 1; Table 1). All tested ROS metabolism mutants, however, showed significant differences (below $p = 1\%$) between branching under the two conditions (Fig. 2; Table 1). The ROS metabolism mutants' branching, while typically close to wild-type at 33° C, show a strong shift toward much longer than normal branching when grown at 10° C. In fact, statistically longer inter-branch distances (i.e., hypobranching) were seen in every ROS mutant tested compared with wild-types. For every ROS metabolism mutant tested however, the results were similar, regardless of the mutant's predicted impact on ROS levels.

In addition to the tests of the influence of ROS on branching, we examined the effect of the addition of reducing agents (antioxidants) to the media. At modest concentrations (0.04 to 2.0 mg/ml) of added ascorbic acid, the distribution of inter-branch intervals shifted toward

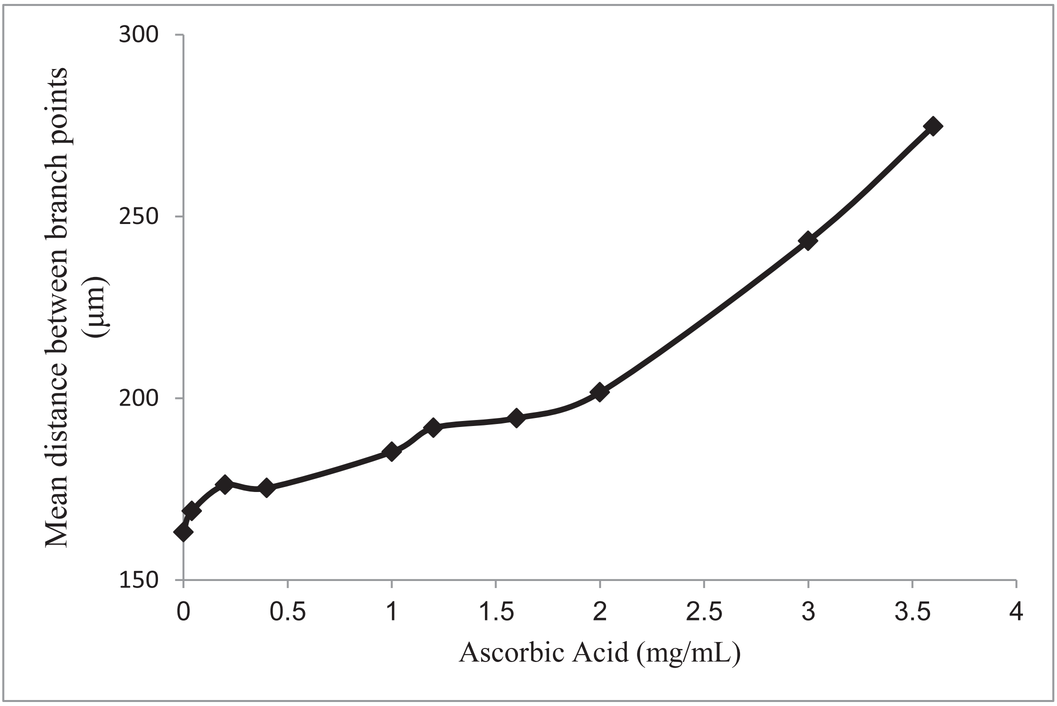

Figure 5.—Progressive shift toward hypobranching induced by increasing ascorbic acid concentration in media. Hypobranching induced by antioxidants is dose dependent. Increasing ascorbic acid in the medium leads to stronger hypobranching until the critical concentration, causing more serious disruptions, is reached. Each point on the curve is the mean of a branch distribution curve (as above) and represents the mean of between 400 and 650 branch intervals. For this curve, the smallest branch intervals have been eliminated in order to remove the impact of the spike of tightly spaced lateral branches and focus solely on the behavior of the more substantial portion of the branch distribution curves. Displayed is the response of wild-type *Neurospora* grown at 33° C.

longer distances (Fig. 3). At larger concentrations (>3.0 mg/ml), however, a new effect was observed. A “spike” of very short (10–20 μm) inter-branch distances begins to be observed. Past 3.0 mg/ml ascorbic acid, the frequency of the very short branches which form the spike increased with increasing dose of ascorbic acid. A representative photograph showing the morphology resulting from high-dose antioxidant exposure is shown in Fig. 4. In order to track the impact of antioxidant exposure beyond the high-dose spike, we deleted the shortest branches from each dataset, calculated the mean of the remaining inter-branch distance measurements and plotted these means against the concentration of ascorbic acid they were subjected to, resulting in Fig. 5. This shows a clear dose-dependent shift toward longer inter-branch distances as the dose of ascorbic acid in the media was increased.

DISCUSSION

Reactive Oxygen Species (ROS) have been linked to developmental determination in a broad range of organisms (Finkel 2003; Lambeth 2004; Aguirre et al. 2005; Carol & Dolan 2006). In *Neurospora*, reactive oxygen species play a role in sexual and asexual development as well as hyphal growth (Cano-Dominguez et al. 2008). This current study further explored a relationship between ROS metabolism, growth rate, and branch density previously suggested in *Neurospora* (Watters et al. 2011). This relationship remained masked in the wild-type and under standard growth conditions due to a homeostatic system which compensates for diverse growth rates to produce a consistent branch density. The mutants thus identified in this study may prove useful in the further exploration of the branch density homeostasis system as well as the general relationship between tip growth and branching.

The observation that branching responds to exogenous antioxidant (ascorbic acid) exposure provides additional evidence of the role of ROS in branching control. The added ascorbic acid resulted in a dose-dependent shift toward hypobranching. This response becomes complex at higher concentrations, however, as more extreme hypobranching is induced as well as a spike of hyperbranched growth. Similar results were seen with glutathione (data not shown). Exposure to lipid-soluble antioxidants (beta-carotene and alpha-tocopherol) had no detectable impact on branching (data not shown).

Mutations or certain environmental conditions which result in hypobranching are rare. Hypha from germinating ascospores or conidia in the mutant *ipa* are reported (Perkins et al. 2001) to branch less frequently, but quickly revert to normal branch density. The morphological response to cold shock (Watters et al. 2000a) includes a brief hypobranched phase, but that is followed by tightly spaced apical branching and a subsequent return to normal branch density. The response of growing tips to hyphal damage (Watters & Griffiths 2001) likewise includes a hypobranching component, but the response is transient, and branch density rapidly returns to normal. In *Aspergillus*, the temperature sensitive *ahbA1* mutant was reported (Lin & Momany 2004) to result in hypobranching at the restrictive temperature, but continued incubation of the mutant under those conditions proved lethal. In contrast to hyperbranching, hypobranching appears to be rare and unstable. This report marks the first observation of sustained hypobranching.

The results observed are difficult to interpret in the context of the proposed hypothesis that ROS concentration at the tip serves as the appropriate trigger for branch formation. This hypothesis would have predicted that mutants that result in decreased ROS concentrations (NADPH oxidase-1, -2, and NADP oxidase regulator-1 in Table 1) would display hypobranching while those which cause increased ROS concentrations (remaining mutants tested) would display hyperbranching. What is observed is that both cause hypobranching under slow growth conditions. Furthermore, the hypothesis would predict that exogenous antioxidants would also cause hypobranching. While this is observed to be the case, in some extreme concentrations they also cause hyperbranching at the same time. These interesting and seemingly contradictory results suggest that the relationship between ROS and branching is complex. This relationship could be explored further in future using ROS sensitive dyes in actively growing and branching hypha.

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CERULEAN WARBLER TERRITORY SIZE IS INFLUENCED BY PREY–RICH TREE ABUNDANCE

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ABSTRACT. Food availability has far-reaching implications for the breeding success of birds and may be a limiting resource affecting populations. Many birds, such as the Cerulean Warbler (*Setophaga cerulea*), defend territories for foraging purposes, and the size of their territory is likely to vary with an area's potential for foraging. This study investigated the abundance of prey in various trees (white oak group [*Quercus alba* L. and *Q. prinus* L.], hickories [*Carya* spp.], and sugar maples [*Acer saccharum* Marshall]) to understand the relationship between prey availability, tree species, and territory size. Relative prey abundance using caterpillar frass (droppings) was calculated. Estimated basal area of the various tree groups within each territory was used to determine whether Cerulean Warbler territory size is predicted by prey-rich trees. The white oak group and hickory group dropped almost double the amount of frass compared to sugar maples, suggesting that the former groups may provide more prey to foraging Cerulean Warblers. Territory size ($n = 51$) was negatively correlated with the basal area of trees in the white oak group, positively correlated to the basal area of the sugar maple group, yet no relationship to hickory or total tree basal area (combined tree types) was found. Therefore, Cerulean Warblers may adjust territory size based on an awareness of the prey-productivity of different tree taxa.

Keywords: Avian, foraging habitat, frass collection, prey, *Setophaga cerulea*, territory size

INTRODUCTION

Food availability has far-reaching implications for the breeding success of avian species, as it affects egg production (Drent & Daan 1980; Perrins 1996), ultimate clutch size (Perrins & McCleery 1989; Aparicio 1994; Robertson 2009), number of broods (Nagy & Holmes 2005), the condition of nestlings (Herring et al. 2011), and the survival of fledglings (Martin 1987). Although some have argued that prey is a superabundant resource (Fretwell 1972; Wiens 1977) and has not contributed to the decline of Neotropical migrants (Rappole & McDonald 1994), there are hundreds of studies, both theoretical and experimental, that have demonstrated the limitations in prey during the avian breeding season (reviewed in Martin 1987) and the importance of vegetative structure in supporting ample prey resources (e.g., van Balen 1973).

Many birds defend territories during the breeding season to maximize foraging capacity (Hinde 1956; Brown 1969) and, therefore, territory size should maximize resource exploitation while minimizing defense-related energy expenditure (Hixon 1980). Territorial birds may use environmental cues that enable the selection of quality habitat (Brown 1964; Fretwell & Lucas 1970; Wiens 1977; Davies 1980; Chalfoun & Martin 2007). For example, food availability has been found to influence territory selection (Stenger 1958; Myers et al. 1979; Smith & Shugart 1987; Marshall & Cooper 2004) and breeding performance (Seki & Takano 1998; Nagy & Holmes 2005).

Because food is crucial to successful reproduction, we sought to understand its importance to the rapidly declining Cerulean Warbler (*Setophaga cerulea*) (Robbins et al. 1992; Hamel 2000; Sauer et al. 2008). Cerulean Warblers primarily forage in hickories (*Carya* spp.; Gabbe et al. 2002), chestnut and white oaks (*Quercus prinus* L. and *Q. alba* L.; George 2009; MacNeil 2010), and sugar maples (*Acer saccharum* Marshall; George 2009). Cerulean Warblers glean insects from foliage (Buehler

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et al. 2013) and their adult diet consists primarily of lepidopteran larvae and homopterans (Sample et al. 1993; Buehler et al. 2013). Although little is known about the nestling diet (Wagner 2012, Auer et al. In Press), Lepidoptera larvae (caterpillars), in particular, are a large and energetically profitable food source for nestlings as they have little chitin, making them highly digestible to birds (Bernays 1986; Bell 1990). Additionally, the majority of caterpillars are defoliators, making them readily available to gleaners like the Cerulean Warbler (MacArthur 1959; Holmes & Schultz 1988).

Due to the importance of caterpillars as an excellent food source, hatching of insectivorous birds is synchronized with a peak in insect prey abundance (Lack 1968; Visser et al. 2006; García-Navas & Sanz 2011). The importance is exemplified by recent work from the Netherlands; climatic cues have been associated with asynchrony in peak caterpillar abundance of the winter moth (*Operophtera brumata* L.) and energy demands of the Great Tit (*Parus major* L.), which has contributed to a decline in fledgling number and weight (Visser et al. 2006). Therefore, synchronizing reproduction and/or raising offspring in areas with ample resources are imperative.

No study has yet investigated Cerulean Warbler territory selection in relation to prey availability. The objective of this study was twofold. First, to determine which tree groups (categories described below) contain the greatest amount of caterpillars, an optimal prey item, during the avian breeding season. This was measured through caterpillar frass (droppings), which is highly correlated to caterpillar abundance (Seki & Takano 1998) and, therefore, is useful for comparing relative prey abundances (van Balen 1973; Zandt 1994). Second, tree surveys were conducted throughout all territories and post-hoc analyses were performed to determine if basal area of prey-rich trees (i.e., those with the greatest frass drop) was a useful predictor of territory size. We hypothesized that areas with a greater abundance of prey-rich trees would be deemed of higher quality by the Cerulean Warbler males and, therefore, would necessitate the defense of a smaller area for the territory compared with males in areas with a lower abundance of prey–rich trees.

METHODS

Study area.—This study was conducted from May to July 2011, in Morgan–Monroe (~9,700 ha; 39° 19′ N, 86° 24′ W) and Yellowwood (~9,500 ha; 39° 11′ N, 86° 19′ W) State Forests in Morgan, Monroe, and Brown counties, Indiana. Both forests are within the Brown County Hills region (Homoya et al. 1984), with wet-mesic bottomlands dominated by sugar maple, American sycamore (*Platanus occidentalis* L.), and American beech (*Fagus grandifolia* Ehrh.) and mesic slopes dominated by sugar maple, tulip poplar (*Liriodendron tulipifera* L.), American beech, and northern red oak (*Quercus rubra* L.). Dry mesic slopes are dominated by white oak (*Quercus alba* L.) (Jenkins et al. 2004). The research was conducted on nine study sites, selected by the Hardwood Ecosystem Experiment (HEE) to study faunal response to silviculture (Swihart et al. 2013). For testing the questions in this study, vegetation was sampled at the scale of the territory, and thus we consider the landscape-scale silvicultural practices to be reflected in the analysis of basal area.

Avian territory delineation and vegetation sampling.—Male Cerulean Warblers were located using point count surveys in May 2011 conducted between 0600 to 1030 hr Eastern Standard Time at each of the nine HEE study sites (Jones & Islam 2006; Wagner & Islam 2014). We conducted 1–3 site revisits at areas where Cerulean Warblers were detected and demarcated territories. If a male was not apparent on a revisit, playback was used to elicit a territorial song (Falls 1981). We located singing males and recorded GPS locations of perch trees (range = 5–17 per male). Territories were typically demarcated during a single visit. However, if a bird was minimally active on the first visit, we revisited it a second time to demarcate the minimum number of trees. GPS coordinates were used to produce minimum convex polygons in ArcMap (ArcGIS 10.0, ESRI 2010).

To determine basal area (BA) of mature trees in each territory, we identified the centroid of the territory as the cross point of the two longest distances across each territory (in ArcGIS 10.0). At the centroid, an 11.3 m radius vegetation plot (0.04 ha, James & Shugart 1970) was established. Species and diameter at breast height (DBH) of all trees >10 cm DBH were determined. BA of each tree was calculated as BA = 0.00007854 × DBH^2. To calculate BA for each tree group, the BA was summed across all trees in the plot. This total basal area was then divided by 0.04 ha (vegetation plot size) to determine the BA in m^2/ha.

Frass collection.—Mass of caterpillar frass (droppings) was used as a proxy for prey abundance. Frass was collected during two sample periods using funnel traps placed below trees within Cerulean Warbler territories. We used low density polyethylene plastic (thickness of 0.05 cm) to form funnels with an overall collection surface of 0.2 m^2 (diameter = 0.5 m). The bottom of the funnel was sealed during the sample period and affixed to a 0.91 m wooden stake (adapted from Liebhold & Elkinton 1988). Two traps were placed below each tree to determine precision of sampling methodology, producing a total collection area of 0.4 m^2 per tree. The first trap was placed at the part of the tree where there was the greatest distance between crown foliage edge and trunk (as estimated visually by J. Wagner). The second trap was placed as close to 180° from this location as possible and both traps were equidistant from the trunk and outer extremities of the crown.

Frass was sampled from 23 trees within a subset of Cerulean Warbler territories, selected because these territories were demarcated early enough within the season to ensure sampling during the period of interest. Four to six randomly selected trees (within the categories of white oak, hickory, or sugar maple) in six territories with two traps per tree were sampled. A stratified random sampling method was used to ensure even sampling of points within territory polygons. Briefly, the territory was divided into concentric circles and a random point was generated within each area to ensure that sampling was distributed throughout the territory. At each random point, the nearest tree of at least 15 cm DBH in any cardinal direction was used as the random tree. This tree size minimum allowed us to sample the vertical stratification of all vegetative strata (midstory and lower- to upper-canopy) because although Cerulean Warblers are high canopy nesters and singers, they do spend time in relatively lower strata during foraging (Barg et al. 2006; Wood & Perkins 2012). The species, height, DBH, and coordinates of the 23 sampled trees were noted.

Frass was collected with a Ziploc bag during a four day period in early June and an eight day period in late June/early July. In the field, large plant matter was removed from the trap. In the laboratory, reduced mm paper was used to sort only frass pellets larger than 0.6 mm, since smaller pellets have a negligible influence on frass mass (Tinbergen 1960) and reduce efficiency. Samples were dried in an oven at 85° C for 24 hr (Tinbergen 1960) and weighed to 0.001 g on an OHAUS Precision Standard TS00D microbalance (Parsippany, New Jersey). The collected masses were summed across both sample periods for each tree to produce a total frass mass. No attempt to identify collected frass to associated Lepidoptera species was made.

Data analysis.—To determine which trees had the greatest prey abundance, we used the sample periods of 6 June to 9 June and 28 June to 6 July 2011. Although we attempted to sample across a wider temporal scale, many rainy days prohibited the collecting of frass samples from all trees during the same dates. We therefore only included dates for which all trees were sampled and during which breeding (nestling and/or fledgling period) was still occurring. We compared total frass mass (mg) from prey-host trees of the categories: hickory spp. (Shagbark [*Carya ovata* (Mill.) K. Koch], pignut [*C. glabra* (Mill.) Sweet], and bitternut [*C. cordiformis* (Wangenh.) K. Koch]; $n = 5$), white oak group (white oak and chestnut oak; $n = 14$), and sugar maple ($n = 4$). Daily frass mass for individual trees was summed across the aforementioned dates, producing a total frass mass for each tree. Data were checked for normality and raw data were used for analyses. Neither height nor DBH significantly affected frass drop and therefore were not used in analyses. A one–way analysis of variance (ANOVA) was used to compare total frass mass between tree groups (Minitab Statistical Software 2013). Fisher's post hoc analysis was used to compare individual group means.

The hypothesis that territory size is influenced by density of prey-rich or prey-poor trees within the territory was tested using linear regressions with territory size as the dependent variable and basal area of the tree category as the independent variable (white oak group, hickory spp., or sugar maples). To meet normality assumptions, territory sizes were log10-transformed (Minitab Statistical Software 2013).

The efficiency and precision of using constructed frass traps was tested by determining whether two traps under the same tree produced unified results. The amount of frass per trap per day was used to test for differences in frass collection between the two traps of the same tree. Instances where one trap fell over (15/100 samples) were not used in the analysis. We used 75 paired samples, collected from 60 traps under 30 trees (some sampled trees were not used in analyses). The collection of two time periods during 28 June to 6 July 2011 allowed the addition of samples to this test. A paired *t*-test was used to test for differences in frass mass collected per trap (Minitab Statistical Software 2013). All statistical tests were conducted using an α-level of 0.05, however marginal significance (α-level = 0.05–0.10) was considered with post-hoc analysis due to small sample sizes.

RESULTS

The total frass drop (mg; mean ± SE) produced by each tree category during the sample periods combined was: white oak group (50.9 ± 5.1), hickory spp. (47.7 ± 4.7), and sugar maple (27.2 ± 5.1) (Fig. 1). There was a marginally significant difference in total frass drop during our sample period among the three tree categories ($F_{2,20} = 3.23$, $p = 0.061$; Fig. 1). Trees in the white oak group produced more frass than sugar maples (Fisher's LSD: $p = 0.020$) and hickories tended to produce more frass than sugar maples (Fisher's LSD: $p = 0.080$).

Average size of the 51 territories analyzed was 2145 ± 298 m^2 [mean ± SE] (range 108–10225 m^2) and when analyzed for a relationship to basal area of particular trees, several relationships were found (Table 1). Territory size was negatively correlated to the basal area of trees in the white oak group ($F_{1,49} = 5.93$, $r^2 = 0.108$, $p = 0.019$; Fig. 2) and positively correlated to the basal area of sugar maples ($F_{1,49} = 5.43$, $r^2 = 0.099$, $p = 0.024$; Fig. 3). There was no relationship between territory size and the basal area of hickories or all trees together ($p > 0.05$). These data suggest that territory size is influenced specifically by the density of trees in the white oak group; smaller territories tend to have higher densities of these trees than larger territories. Conversely, larger territories tended to have a greater density of sugar maples.

No difference was found between frass mass collected from traps A and B of the same tree ($t_{74} = 0.48$, $p = 0.63$). Thus, one trap per tree may be sufficient for sampling of relative frass drop from tree crowns.

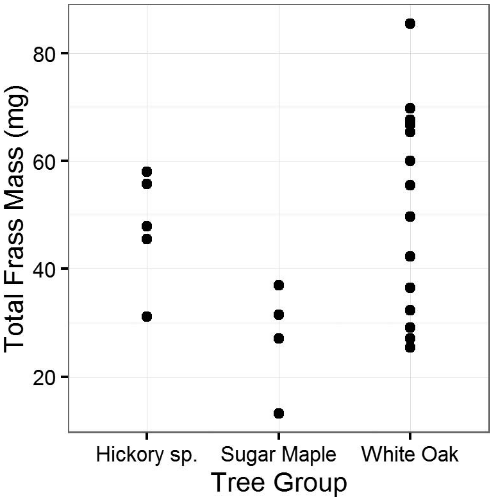


Figure 1.—Amounts of insect frass collected under three taxonomic tree groups, i.e., white oak group, hickories, and sugar maples. Trees were sampled from 6 June to 9 June and 28 June to 6 July 2011.

DISCUSSION

Trees in the white oak group and hickories dropped nearly double the amount of frass compared to sugar maples. The finding that oaks in particular contain a high abundance of insects (specifically Lepidoptera) is consistent with findings from other locations in the eastern deciduous forest (Wagner et al. 1995; Butler & Strazanac 2000a; Summerville et al. 2003) and in Europe (Southwood 1961; Veen et al. 2010). A tree fogging study in Ohio found that oaks tend to support greater species richness and abundance of Lepidoptera than beeches (Summerville et al. 2003). In the Baltic Islands of Sweden, frass biomass was highest (nearly double the mass) from oak species compared with three other deciduous taxa and two coniferous taxa (Veen et al. 2010). In Appalachia, research involving branch clippings produced similar results: white oaks contained ~25% of caterpillar species abundance, whereas maples contained 15% (Butler & Strazanac 2000b). Butler & Strazanac (2000b) also reported caterpillar abundance on hickory and chestnut oak and found that they supported 18% and 17%, respectively. This is somewhat comparable to our finding, as hickories dropped more frass than maples, yet less than trees in the white oak group. Interestingly, Butler & Strazanac (2000b) reported ~25% of caterpillar abundance on trees

Table 1.—Basal area results of each tree group throughout Cerulean Warbler territories in 2011. The "All Trees" category includes the three prior tree groups and any other trees with a diameter at breast height (DBH) >10 cm.

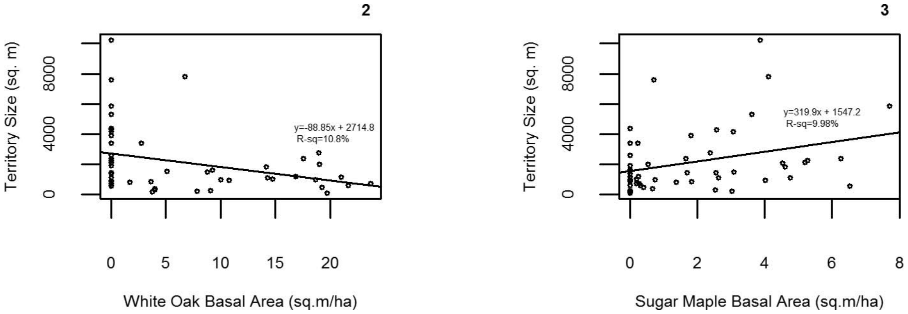
	Basal area (m^2/ha)			
Territory size (m^2)	White oak group	Hickory spp.	Sugar maples	All trees
108	19.72	4.23	0.00	33.92
189	3.77	0.00	0.00	11.81
238	7.88	2.50	3.02	28.74
268	9.10	0.44	0.00	34.77
333	4.01	0.00	2.53	17.81
384	4.02	2.06	0.68	14.59
508	19.28	0.30	0.40	27.10
578	0.00	2.96	6.52	15.98
617	21.69	0.22	0.00	32.52
621	0.00	1.37	0.31	8.31
734	23.73	2.91	0.20	38.19
755	0.00	9.08	0.28	13.81
827	1.71	3.96	1.37	15.85
871	3.63	14.44	1.82	23.27
881	0.00	0.00	0.00	22.69
929	0.00	9.21	0.00	20.15
973	10.78	2.43	4.02	31.04
975	10.02	11.28	0.00	38.14
980	18.70	2.14	0.75	28.74
1050	14.74	0.00	0.20	23.51
1124	0.00	0.00	4.75	18.66
1134	14.28	1.25	2.63	21.70
1185	21.02	0.72	0.00	21.74
1219	16.89	2.00	0.25	21.24
1363	0.00	0.00	0.00	11.98
1475	0.00	0.00	2.55	15.28
1475	0.00	0.00	1.70	15.85
1507	8.77	1.34	3.09	33.99
1540	5.11	3.84	0.00	39.75
1626	9.25	8.20	0.00	17.45
1840	14.19	0.28	4.60	23.77
1938	0.00	3.67	0.00	19.36
2006	19.02	0.00	0.54	29.32
2076	0.00	0.00	4.53	19.69
2144	0.00	0.00	5.19	18.57
2286	0.00	11.11	5.27	21.38
2379	0.00	0.00	6.26	32.45
2385	17.58	0.00	1.65	19.23
2607	0.00	0.00	0.00	30.01
2760	18.95	0.00	2.37	21.33
3413	2.79	5.66	0.23	10.18
3421	0.00	7.93	0.00	12.60
3923	0.00	4.83	1.81	22.01
4189	0.00	0.00	3.06	22.07
4318	0.00	7.48	2.58	22.11
4369	0.00	0.00	0.00	33.47
5335	0.00	0.00	3.62	3.62
5882	0.00	0.00	7.71	35.16
7592	0.00	14.03	0.71	15.40
7826	6.72	2.85	4.11	20.23
10225	0.00	2.84	3.87	20.32

Table 1.—Continued.

in the red oak group, suggesting that they may support just as high of a food source for insectivorous warblers as the trees in the white oak group, although we did not sample enough trees in that group to make frass comparisons.

We associate the greater frass drop in white oak trees to two non-mutually exclusive mechanisms. Prey was more numerous and/or prey was larger during the collected time periods in trees in the white oak and hickory groups than in sugar maples. Both of these explanations would account for the greater mass of frass drop and contribute to large quantities or individually-large prey items. We excluded frass smaller than 0.6 mm in diameter, and thus excluded the smallest larvae from our samples. Large quantities of small caterpillars may be a substantial food source, particularly if they are clumped together, alleviating foraging effort on the bird (e.g., Naef-Daenzer & Keller 1999). These small frass particles were negligible (~1% of most samples) and the exclusion of the smallest frass was performed uniformly across all sampled trees; however, future studies may consider including this size of frass.

When we analyzed how territory size related to the basal area of tree type within the territory, we found that territory sizes of the Cerulean Warbler had a negative relationship to BA of trees in the white oak group (the most prey-rich trees group) within their territory. Yet, there was no relationship between territory size and the hickory tree group (the next highest prey-rich group). There was a positive relationship with sugar maple BA, and no relationship to total tree BA. To our knowledge, this is the first study to document the finding that trees in the white oak group may have a relationship to Cerulean Warbler territory size, allowing Cerulean Warblers to maintain smaller territories. This finding corroborates field observations, as the Cerulean Warbler is found in high abundance in oak and hickories at our field sites (Barnes et al. 2016) and in other parts of their range (e.g., the Appalachian Mountains, Boves



Figures 2 & 3.—The relationship between basal area of white oak and sugar maple trees and the territory size of Cerulean Warblers. 2. Territory size tended to be negatively related to the basal area of trees in the white oak group; 3. Territory size tended to be positively related to the basal area of sugar maples. There was no relationship between territory size and the basal area of hickories or all trees (not shown).

et al. 2013; Wood et al. 2013), while also preferentially selecting oak (and other large trees) as song perches (Jones & Islam 2006). However, when oak is not readily available, Cerulean Warblers will use other tree species for daily activities, such as black cherry (*Prunus serotina* Ehrh.) and black locust (*Robinia pseudoacacia* L.) in West Virginia, American elm (*Ulmus americana* L.) and sycamore in Ohio (Wood et al. 2013), and sugar maple in Ontario, Canada (Oliarnyk & Roberton 1996). However, as discussed above, there may be vast differences in the extent to which these other tree species are able to support an abundant food supply for Cerulean Warblers.

In this study, territory size was used as a proxy for energy expenditure; territory defense is an energetically-demanding task (Walsberg 1983) and adults (especially males) must simultaneously forage for nestlings and provide predation defense. Given the evidence provided here and the foraging selectivity found in other studies (Gabbe et al. 2002; George 2009; MacNeil 2010), it is likely that white oak and hickory-dominated stands may alleviate energetic pressures and support a greater abundance of Cerulean Warblers compared with areas dominated with other trees species (e.g., Barnes et al. 2016). Further, it is plausible that they may have higher reproductive success in oak/hickory-dominated stands compared with areas dominated with other tree species because of the differences in foraging potential necessary for self-maintenance and provisioning of nestlings (e.g., Varble 2006); however, this needs to be studied.

Although it can be beneficial to select territories with a high density of foraging trees, there are at least two mechanisms which may act to reverse the presumed positive impacts of increases in prey. First, due to the quality of prey available in specific tree stands, these areas may be deemed more valuable by conspecifics and thus, male Cerulean Warblers may expend more energy defending their territories. For example, clustering of Cerulean Warbler territories (Roth & Islam 2007; Dibala 2012) has resulted in close territory boundaries and may require ample energy to defend. Second, predator abundance may be influenced by forest tree composition (e.g., Auer et al. 2013). For example, at our project sites, small mammal populations were correlated with mast production of oaks (Kellner et al. 2013) and Eastern chipmunks have caused forced-fledging of nestling Cerulean Warblers in the Appalachian Mountains (Boves 2011).

This study provides the first evidence that Cerulean Warblers seek prey-rich trees, specifically trees in the white oak group, for establishing territory size. Other studies have noted the importance of prey-rich areas, such as an increase in territory number in a black locust grove after a lepidopteran outbreak (Rosenberg et al. 2000) and an apparent increase in successful nests during a cicada outbreak year compared with non-outbreak years (Varble 2006). Future studies with larger sample sizes of prey abundance are warranted to further establish the importance of specific tree stands to this bird species. When compared to trees in the white oak group, we under-sampled maples and hickories for frass. Yet, even with these limited, unbalanced data on frass drop, there is an important suggested difference in prey productivity across the three tree types. Furthermore, the inverse relationship between oak BA and territory size when we used a large sample of territories suggests that warblers recognize the difference in tree type and adjust territories appropriately. However, this apparent pattern needs further testing with a large, balanced data set which aims to collect frass from the three main tree types within territories during the breeding season.

This study adds to the mounting evidence that the Cerulean Warbler has specific habitat associations and, therefore, may rely on specific tree taxa for their continued existence. This may be important for conservation efforts because studies of eastern deciduous forest structure indicate that mature oak and hickory forests may be succeeded by maple and beech forests (e.g., Saunders & Arseneault 2013). At our project sites, the oak and hickory group comprised older individuals with multiple younger cohorts of other tree species (Saunders and Arseneault 2013). At Kieweg Woods in west-central Indiana, the same trend in tree succession was found whereby sugar maple, American beech, and slippery elm (*Ulmus rubra* Muhl.) dominate the young age classes (Cowell & Hayes 2007). It is understood that human disturbance is the primary cause of forest structure changes, either through the use of specific harvest regimes or forest suppression (Cowell & Hayes 2007; Jenkins 2013). In the future, it will be important to monitor and identify specific forest areas that are crucial to declining insectivorous birds, such as the Cerulean Warbler.

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RIPARIAN WIDTH AND NEOTROPICAL AVIAN SPECIES RICHNESS IN THE AGRICULTURAL MIDWEST

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ABSTRACT. Neotropical migratory birds have declined in recent decades in the agricultural Midwest and a conservation need is to determine the minimum size of riparian buffer areas needed to support diverse populations of Neotropical migrants during the breeding season. Thirty-six sites were surveyed along the west side of a 17 km stretch of the Mississinewa River in east-central Indiana, each adjacent to an area with agriculture as the primary land use. Sites were divided into three categories based on the width of the riparian buffer (< 25 m, 25–75 m, and > 75 m) and surveyed three times each during the breeding season. In total, 56 species of birds were identified, including 25 species of Neotropical migrants. A positive correlation was noted between Neotropical species richness and riparian buffer width, however no difference in species richness was noted between medium and wide sites suggesting that widening riparian buffers to 75 m in the agricultural Midwest would be a practical conservation target and help protect all but the most area-sensitive species such as Acadian Flycatcher (*Empidonax virescens*) and Wood Thrush (*Hylocichla mustelina*). Vegetative characteristics had little impact on species richness in our study likely because our sites were generally homogeneous and unmanaged.

Keywords: Agriculture, avian conservation, Midwest, Neotropical migrants, riparian width

INTRODUCTION

Many Neotropical migrants utilize riparian areas for nesting during the breeding season, however due to increased agricultural activity, many of these nesting areas have been pushed closer and closer to rivers (Peak & Thompson 2006). These riparian buffer zones are typically areas that are either of too poor quality to be utilized for agricultural purposes or areas that are maintained to reduce nutrient and sediment run-off and stabilize river banks (Frimpong et al. 2006). There are a number of problems associated with narrower riparian buffer zones, particularly for birds. Narrow buffer zones increase the amount of edge habitat, which often increases egg parasitism, especially by species such as Brown-headed Cowbird (*Molothrus ater*; Gates & Giffen 1991; Bohning-Gaese et al. 1993) that utilizes agricultural lands for foraging and nearby wooded habitat for egg-laying (Saab 1999). Narrow riparian buffer areas also increase the risk of predation to songbirds posed by larger predators and competitors (e.g., raccoons, fox, and feral cats, as well as other birds) that prefer edge habitats (Bohning-Gaese et al. 1993; Peak et al. 2004; Shake et al. 2011). In addition, area-sensitive species, such as Wood Thrush (*Hylocichla mustelina*) are often absent in places with narrow riparian areas. Wood Thrush, which prefer mature, interior wooded habitat near water, has experienced an annual population decrease of 2.1% since 1966 (USGS 2012).

Previous studies have indicated that a minimum riparian width is needed to maintain a high degree of avian diversity. Darveau et al. (1995) assessed species richness in riparian buffer strips of the boreal forest that were 20 m, 40 m, 60 m, and > 300 m from recent clear-cuts and concluded that a minimum of 60 m buffer strips were necessary to support the majority of forest-dwelling birds. Hodges & Krementz (1996) surveyed six focal species in different-width corridors in Georgia adjacent to pine plantations and suggested that 100 m was necessary to support the majority of Neotropical

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migrants. Kilgo et al. (1998) conducted a study in the South Carolina hardwoods with three different habitat types (forest, pine forest, and field-scrub) surrounding riparian buffer zones, and suggested that 500 m or more was needed to support the complete avian community. Hagar (1999) studied widths of logged versus unlogged sites in Oregon and suggested that riparian buffer areas ≥ 40 m were most beneficial to forest-dwelling species. In Missouri, Peak & Thompson (2006) observed more bird species in wider forested-riparian habitat and suggested that riparian buffers should be > 400 m in width where possible. The broad range of recommendations reported in previous studies are likely related to regional differences in climate and land-use history and illustrate the need for careful regional-level recommendations to be provided in places where studies have not yet been conducted.

Some studies have also assessed the impact of vegetative quality and/or successional stage on the usefulness of riparian buffer areas for birds. Saab (1999) evaluated the impact of vegetation on avian species richness at three spatial scales (i.e., macrohabitat, landscape, and microhabitat) and found that microhabitat variables correlated most with species richness. At this scale, the greatest predictor of species richness was canopy cover; species richness was greater in habitats with a more open canopy. Peak & Thompson (2006) reported that grassland-shrub buffer strips increase avian species richness in narrow habitats. Berges et al. (2010) revealed that avian species richness was dependent on both the successional stage of the riparian buffer strips (2, 9, and 14 year plots) and on the dominant vegetation present (i.e., tree, shrub, or native grass/forb). Studies such as these provide landowners with important recommendations on how to improve the composition of buffer areas for birds in cases where increasing buffer area is not feasible.

Prior to European settlement, much of the agricultural Midwest, including as much as 85% of Indiana, was covered by forest (Tormoehlen et al. 2000). Settlers began clearing the land for agriculture, particularly during the 1950s when technology and farming techniques improved. Subsequently, farms became both larger and more intensively cultivated, leading to increased soil erosion, stream degradation, and a decline in native biodiversity, especially of Neotropical migrant birds (USGS 2012). By 2005, only 20% of the original forest cover remained, and this was scattered and fragmented across the landscape (Hewitt 2005). In response to these changes, Partners in Flight (PIF), a prominent partnership committed to promoting bird conservation, recognized the importance of providing "conservation recommendations regarding minimum patch sizes and landscape attributes that will sustain populations of PIF priority species especially for regions where grasslands, shrublands, savanna, and forest once were naturally interdigitated" (Donovan et al. 2002). Therefore, the objective of this study is to assess Neotropical migrant species richness in relation to riparian buffer width and vegetative quality in an area of Indiana that is representative of much of the agricultural Midwest.

METHODS

Study area.—This study was conducted along an approximately 17 km (10 mi) stretch of the Mississinewa River in Grant and Delaware Counties, Indiana (between 40° 28′ 10.55″ N, 85° 36′ 33.12″ W and 40° 15′ 57.24″ N and 85° 26′ 17.16″ W). The Mississinewa River begins in western Ohio and runs northwest, emptying into the Wabash River near Peru, Indiana. The riparian zone of the Mississinewa River between Jonesboro and Eaton, Indiana, is dominated by bottomland forest (US Fish and Wildlife Service 2014). It mainly consists of a mix of mature tree species often > 6 m in height, including box elder (*Acer negundo*), American elm (*Ulmus americana*), and sycamore (*Platanus occidentalis*) in the lowlands, and hackberry (*Celtis occidentalis*), as well as a number of oak (*Quercus*) and maple (*Acer*) species in the upland habitat. Wood-nettle (*Laportea canadensis*) is often dominant in the floodplain. In the upland habitat mutiflora rose (*Rosa multiflora*) is dominant. The majority of adjacent land-use is agricultural (i.e., row crops such as corn and soybeans), with fragmented forests scattered throughout the watershed, and riparian buffer strips of varying widths. Based on these characteristics, the Mississinewa resembles many of the streams in Indiana, as well as in the broader Midwest.

Site selection.—Potential sites along the west side of the river with agriculture as the adjacent land-use were identified using ArcGIS 10.1 (ESRI 2012 – Redlands, CA). Assessing one side of the river and considering one type of adjacent land-use minimized potential variability associated with avian habitat preferences. Upon identification of potential sites, permission to access sites was requested from landowners by mail. Based on the number of returned permission forms, 45 possible site locations were identified and categorized as 'small,' 'medium' or 'large' based on the width of the riparian buffer. 'Small' sites were between 0–25 m in width, 'medium' sites were 26–75 m in width, and 'large' sites were $>$ 75 m in width; these designations were based on typical buffer sizes found in this region of Indiana. The riparian buffer zone was the distance from the edge of the river to the edge of the forest/agricultural demarcation.

Two feature-class polygons were created (one with a width of 25 m and one with a width of 75 m; each were 100 m in length) and superimposed over base maps of Grant and Delaware Counties that were downloaded from the Geographic Information System (GIS) map database from Indiana University (http://gis.iu.edu/). If the whole width of the site fit within the 25 m polygon, it was considered a small site. If the site was wider than the 25 m polygon, but fit within the 75 m polygon, it was considered a medium site. If the site was wider than 75 m polygon, it was considered a large site. Of the 45 total sites, 18 were classified as small sites, 14 as medium sites, and 13 as large sites. Each potential site was utilized except those that, upon visiting, were found to be inaccessible or too close to the interstate highway, and therefore too noisy, to allow for reliable detection of birds by sound ($n = 9$). This resulted in 12 usable sites in each of our 3 width categories. A poly-line was created to measure the distance between sites to make sure they were $\geq$ 250 m apart to reduce the likelihood that an observer would count the same bird twice (Ralph et al. 1995). At each of the sites ($n = 36$), flagging was put up at the point of observation, as well as 50 m upstream and downstream to demarcate the observation area. Every bird seen or heard within the flags was identified in each trial.

Point counts.—Each site was visited three times throughout the breeding season to increase the likelihood that all species utilizing the site were recorded. Even though Neotropical migrants were the focus of our study, all birds detected were recorded, including "year-round residents" (i.e., those found in the Midwest throughout the year or those that likely wintered somewhere in the United States; Butler 2003). Surveys were conducted from sunrise until no more than four hours after sunrise (i.e., between 0600–1000 hrs EST), a period of high bird activity. Point counts were conducted from 3 June 2013 to 28 June 2013, a period when most transient migrants had likely passed and most breeding birds were maintaining territories or raising young. Small and medium sites were surveyed from the geometric center of each site and large sites were surveyed at a fixed width of 50 m from the river to increase detection probability (Forcey & Anderson 2002). During each trial, MC waited one min for birds to become acclimated to her presence and then recorded every bird seen or heard for 10 min. Individuals heard or seen outside the site or flying overhead (and obviously not utilizing the site) were not counted.

Vegetation survey.—The vegetative type and structure at each site was assessed during the last point count survey (21 June 2013 to 28 June 2013) by MC when vegetation was at its peak growth and easy to identify. Five random circular plots to sample were selected within each site, by latitude and longitude, using a random number table. The centroid of each circular plot was located using a handheld GPS unit and a 5 m sampling radius was flagged. The percentage aerial cover of canopy, understory, and shrubs in each circular plot was estimated by the observer. The canopy (vegetation $>$ 6 m tall) consisted of the tallest trees as well as vines that reached the same height. The understories were mainly trees that were not yet mature (i.e., between 2 and 6 m tall). The shrub layer was $<$ 2 m tall and usually consisted of brambles and other short growing plants. A site average was calculated by dividing the sum of each variable by five. The number of trees, tree species, and snags in each plot were counted and shrub and groundcover species were identified. Trees were defined as being $\geq$ 2.54 cm (1 in.) dbh (diameter at breast height) and $>$ 2 m tall (note: most trees were $>$ 6 m in height), snags consisted of standing dead trees, shrubs included species $<$ 2 m in height, and groundcover species included emerging saplings and herbaceous vegetation not included in the shrub layer such as wood nettle (*Laportea canadensis*) which reached 1.5 m in some places. The number of tree, shrub, and groundcover species were added together across the five plots to determine the cumulative number of species at each site. The total number of trees, snags, and shrub and groundcover individuals were also averaged across the five plots to determine a mean density value at each site for each variable and expressed as the number of individuals per 78.5 m^2.

Data analysis.—Analysis of variance (ANOVA) and linear regression were used to analyze the relationship between riparian width and avian species richness for Neotropical migrants, for year-round residents, and for all birds combined (Keller et al. 1993). Each of the analyses met normality assumptions. Multiple regression was then used to identify the impact of each vegetation parameter on avian species richness; since preliminary analyses indicated that riparian width was strongly correlated with avian species richness, it was included in each of the regression equations. Logistic regression was used to analyze the presence/absence probability of each of the 56 species at different riparian widths and significance was assessed at an α-level of 0.05.

RESULTS

Across all sites (n = 36), 56 species of birds were identified, including 25 species of Neotropical migrants (Table 1). Overall species richness at each site ranged from 6 to 33 species. Collectively, 38 species were observed at small sites, and richness ranged from 6–22 species per site ($\bar{x}$ = 8.6 species per visit, SD = 3.3). Medium sites had a total of 50 species and richness ranged from 15–26 species per site ($\bar{x}$ = 14.9 species per visit, SD = 3.1). Large sites had a total of 49 species and richness ranged from 14–33 species per site ($\bar{x}$ = 15.4 species per visit, SD = 5.2). No temporal trends were noted in number of birds observed in subsequent sampling periods. Using width class as a categorical variable, ANOVA indicated differences in Neotropical species richness among riparian buffer widths when plots were averaged ($P < 0.001$; Fig. 1). Post-hoc tests indicated that small and medium sites differed in mean species richness, as well as small and large sites; however no differences were found between medium and large sites (Fig. 1). Comparable results were noted when year-round residents species were analyzed and when Neotropical and year-round residents were combined (Fig. 1). Using width class as a continuous variable, linear regression also showed that as riparian buffer width increased, Neotropical species richness increased (P = 0.033; Fig. 2).

Based on logistic regression, there were positive correlations between buffer width and presence of Wood Thrush and Acadian Flycatcher (*Empidonax virescens*) (P = 0.048, P = 0.045, respectively). Acadian Flycatcher was observed at ten of the thirty-six sites; however, only one individual was observed at a small site and all others were observed at sites that were ≥ 50 m wide. Similarly, Wood Thrush was observed at eight of the thirty-six sites, with the narrowest being 75 m wide. There was a 50% probability of observing Acadian Flycatcher and Wood Thrush in areas of buffer width of 370 m and 455 m, respectively (Fig. 3). A positive correlation with width that approached significance ($P < 0.1$) was noted for Cerulean Warbler (*Setophaga cerulea*), Baltimore Oriole (*Icterus galbula*), Blue-gray Gnatcatcher (*Polioptila caerulea*), and Louisiana Waterthrush (*Parkesia motacilla*).

No relationships were detected between species richness and individual vegetation variables when combined with riparian width, although the number of shrub species approached significance (P = 0.094). When comparing each vegetation variable by width class using ANOVA, only the total and average number of shrub species differed between treatments, with smaller sites having a greater mean number of shrub species. In addition, the percent shrub cover approached significance (P = 0.052) with smaller sites tending to have a greater percent shrub cover.

DISCUSSION

Our results indicate that increasing riparian width increases Neotropical bird species richness (Fig. 2). Most notably, however, no difference in species richness were observed between medium and wide sites which suggest that medium sites, with widths of 25–75 m, may be sufficient to support the majority of avian diversity in this region (Fig. 1). While it is possible that medium sites contain both species that prefer edge habitat and species that prefer forest-interior habitat, the overall similarity in species noted between width categories suggest that these potential differences in species richness may be negligible.

In the North-Central region of Indiana, there is limited suitable habitat for bird populations due to intense land use associated with agriculture, making it likely that Neotropical species

Table 1.—All bird encountered during our study along the Mississinewa River (east-central Indiana) in early summer 2013, categorized as Neotropical migrants (*a*) and year-round residents (*b*) according to Butler (2003). Values indicate the percentage of sites in each riparian width class where species were observed. Species arranged taxonomically according the American Ornithologists' Union 7th Checklist of North and Middle American Birds.

a)

Bird species *Neotropical species:*	% of sites occupied per riparian band width category		
	Small (n = 12)	Medium (n = 12)	Large (n = 12)
Yellow-billed Cuckoo	8	33	25
Ruby-throated Hummingbird	8	8	17
Eastern Wood-Pewee	17	83	92
Acadian Flycatcher	8	33	42
Least Flycatcher	0	8	0
Great Crested Flycatcher	50	67	75
Yellow-throated Vireo	0	25	17
Warbling Vireo	58	50	58
Red-eyed Vireo	8	25	25
House Wren	42	33	42
Blue-gray Gnatcatcher	25	50	83
Wood Thrush	0	8	58
Gray Catbird	58	50	33
Cedar Waxwing	17	42	25
Ovenbird	0	0	17
Louisiana Waterthrush	0	33	33
Common Yellowthroat	25	75	33
Cerulean Warbler	0	0	17
Northern Parula	58	67	75
Yellow-throated Warbler	0	25	25
Yellow-breasted Chat	8	0	8
Scarlet Tanager	0	0	8
Rose-breasted Grosbeak	0	8	0
Indigo Bunting	92	92	67
Baltimore Oriole	17	58	58

b)

Bird species *Local species*	% of sites occupied per riparian band width category		
	Small (n = 12)	Medium (n = 12)	Large (n = 12)
Wild Turkey	0	8	0
Turkey Vulture	0	8	0
Red-tailed Hawk	0	17	0
Mourning Dove	67	67	67
Barred Owl	0	0	8
Red-bellied Woodpecker	58	92	92
Downy Woodpecker	50	75	92
Northern Flicker	17	42	50
Pileated Woodpecker	8	8	8
Blue Jay	67	58	75
Eastern Phoebe	0	25	8
American Crow	25	42	50
Carolina Chickadee	83	92	100
Tufted Titmouse	58	92	92
White-breasted Nuthatch	50	58	83
Carolina Wren	17	58	58
Eastern Bluebird	17	17	17
American Robin	75	67	75

Table 1.—Continued.

Bird species *Local species*	% of sites occupied per riparian band width category		
	Small (n = 12)	Medium (n = 12)	Large (n = 12)
Brown Thrasher	0	8	8
Northern Mockingbird	0	8	0
Pine Warbler	8	0	0
Eastern Towhee	0	8	25
Chipping Sparrow	42	25	25
Field Sparrow	17	8	33
Song Sparrow	50	75	58
Northern Cardinal	58	83	92
Red-winged Blackbird	17	8	0
Common Grackle	8	25	25
Brown-headed Cowbird	58	58	42
House Finch	0	8	0
American Goldfinch	58	67	50

utilize similar habitats for nesting and food as year-round residents. The similarities between Neotropical species richness and year-round resident species richness (Fig. 1) suggest that year-round species richness could be used as an indicator of Neotropical richness if surveying the entire avian community in an area is not feasible.

As expected, certain birds, such as Acadian Flycatcher and wood thrush, showed correlations with buffer width (Fig. 3), similar to what Keller et al. (1993) reported in Maryland and Delaware. While basing management recommendations on the habitat needs of area sensitive species (i.e., suggesting that the buffer widths should be ≥ 450 m; Fig. 3) may be optimal from a conservation standpoint, this width is not feasible for most private landowners in the agricultural Midwest who use their land for cash crops. Acadian Flycatcher and Wood Thrush, not withstanding, riparian buffers of ≥ 75 m could be a more realistic target if managing for Neotropical migrants in the Midwest is a conservation objective (Figs. 1 & 2).

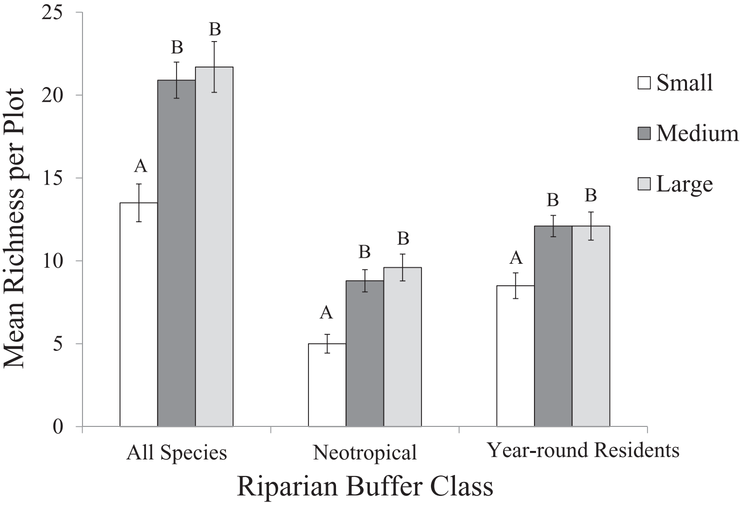

Figure 1.—Mean number of species observed per site during three visits to small, medium, and large sites. Analysis of variance (ANOVA) indicated differences in mean species richness by riparian buffer class for all species combined, Neotropical species, and year-round residents. Inset letters indicate differences between mean species richness at small and medium, and at small and large sites. Error bars represent standard error.

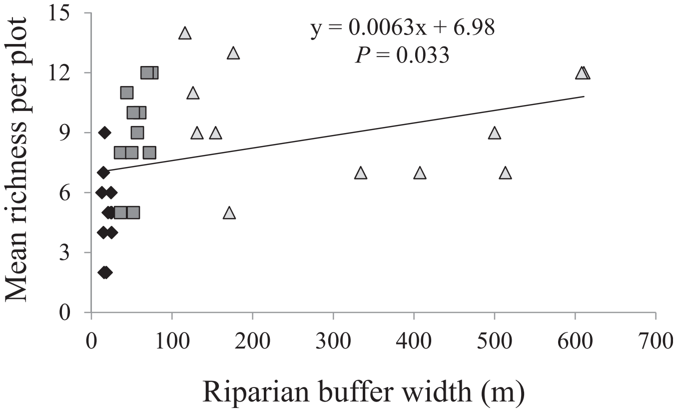

Figure 2.—Linear regression comparing the width of small (diamonds), medium (squares), and large (triangles) sites and mean Neotropical species richness during three visits ($P = 0.033$).

There were no correlations between vegetation variables and Neotropical species richness. There was, however, variability in the number of shrub species among width categories ($P = 0.01$), as well as a weak correlation with the percent shrub cover ($P = 0.052$), which may explain the weak negative correlation between cumulative Neotropical species richness and the number of shrub species ($P = 0.094$). This result is somewhat counterintuitive as it would seem that a greater number of shrub species would provide more nesting habitat and food for Neotropical migrants. It is possible that year-round species may be more aggressive in claiming and occupying territories in shrubby habitats (Kokko 1999), or that Neotropical birds observed in this study simply did not prefer to utilize this specific type of habitat. Taken together, the vegetative characteristics of all field sites were largely homogeneous which is often the case in many areas of the Midwest (Asbjornsen et al. 2014) and may have prevented us from detecting relationships between vegetative variables and avian species richness that have been reported in previous studies (Stauffer & Best 1980; Saab 1999; Schultz et al. 2004; Berges et al. 2010; Bennett et al. 2014; Holoubek & Jensen 2015). In many cases, regional guidelines and incentives are in place (e.g., through the Indiana Department of Natural Resources http://www.in.gov/dnr/fishwild/2352.htm) for landowners who wish to improve riparian buffer composition for wildlife species.

Management implications.—Population sizes of neotropical migrants have declined at a greater rate than non-migrants in recent years, and

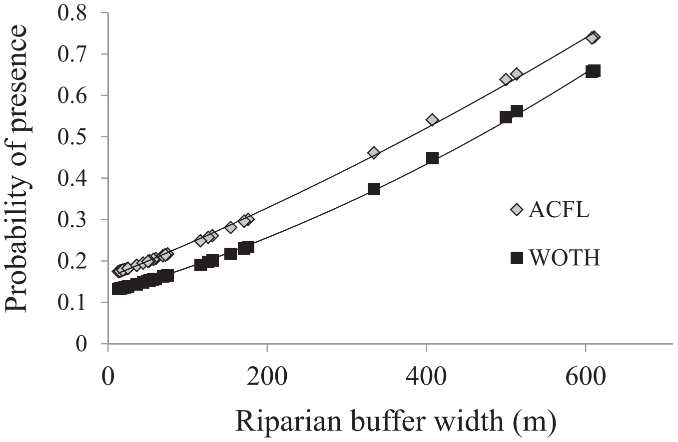

Figure 3.—Logistic regression indicated a positive correlation between the presence of Acadian Flycatcher (ACFL; $P = 0.045$) and Wood Thrush (WOTH; $P = 0.048$) and increasing riparian buffer widths.

while many factors may contribute, habitat loss on the breeding grounds is often a primary contributor (Sillet & Holmes 2002). Based on our results, programs designed to protect habitat for the majority of Neotropical migrants in the agricultural Midwest should encourage landowners to increase the width of riparian buffer areas to a target width of 75 m and follow regional guidelines for improving the quality of existing buffer areas, which may include managing the shrub layer. In addition, larger areas of public land, such as state parks or fish and wildlife areas, may still be needed at the regional level to support the most area-sensitive species.

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DOCTOR ELIAS FRANCIS SHIPMAN AND THE HOOSIER FROG

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ABSTRACT. The holotype of the Hoosier frog (*Rana circulosa*), now the northern crawfish frog (*Lithobates areolatus circulosus*), is an important museum specimen with minimal documentation. Its exact collection locality and date are unknown. The specimen is the earliest and northernmost Indiana record, and the sole known individual from Benton County. Our investigation of Elias Francis Shipman, the man who collected the holotype, provides some resolution on the holotype's provenance. Shipman was a native Hoosier with family ties to Benton County. He attended Northwestern University, graduated with a medical degree, and set up medical practice in Remington, Indiana. As an undergraduate he collected both zoological and botanical specimens, but mostly botanical. A sufficient number of his botanical specimens exist in herbaria databases to reveal a collecting pattern. Biographical and botanical data indicate that the frog was collected in summer or fall 1876. While unable to determine an exact collection locality within Benton County, areas near Shipman family farms in Grant and Gilboa townships are strong possibilities. These conclusions may change if a different collecting pattern emerges when more of Shipman's herbarium becomes available for analysis. The biographical information on Shipman suggests a date range of 1872–1885 for his undated plant specimens and provides an opportunity to update plant collector databases. Shipman's previously unrecognized contributions to Indiana natural history are worthy of note.

Keywords: *Lithobates areolatus circulosus*, Hoosier frog, northern crawfish frog, Benton County Indiana, E.F. Shipman

INTRODUCTION

Museum specimens are critical to the study and understanding of biodiversity. However, specimens with limited documentation leave gaps in our knowledge. The holotype of the Hoosier frog (*Rana circulosa*), now the northern crawfish frog (*Lithobates areolatus circulosus*) (Fig. 1), is one such specimen – historically and currently important, but with minimal documentation. Its collection locality is documented only to the county level and its collection date is currently estimated at pre-1879 (Engbrecht & Lannoo 2010). *Lithobates areolatus* is an Indiana endangered species, with isolated populations in the southern half of Indiana (Engbrecht et al. 2013). Shipman's specimen is the northernmost and earliest record for the species in Indiana, and the sole Benton County record (Engbrecht 2010; Engbrecht & Lannoo 2010). Our goal was to learn more about the provenance of the holotype by learning more about its collector, E.F. Shipman (Fig. 2).

Using historical and genealogical research methods and sources, and herbarium records, we have constructed the story of a Hoosier naturalist whose legacy is more than a significant frog specimen. During his short life, Shipman assembled an herbarium of over 2,000 plants (Northwestern University Museum of the College of Liberal Arts 1893). Some of Shipman's botanical specimens are extant in museum collections and have contributed to botanical research, even though many of his plant specimens are as cryptically documented as his frog. Understanding Shipman's Benton County ties, his pattern of Indiana collecting, and the natural history, topography and settlement of Benton County in the late 1870s, offer useful clues on the provenance of the Hoosier frog holotype. Evidence supporting a collection year and possible collection localities are presented. A year range is offered that can be used to date undated Shipman herbarium specimens to enhance their scientific value.

EARLY DOCUMENTATION FOR THE 'HOOSIER FROG' HOLOTYPE

Shipman deposited his frog specimen in the collection of the Northwestern University Museum

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Figure 1.—Holotype of *Lithobates areolatus circulosus*, Chicago Academy of Sciences (CA 160). (Photo by Alan Resetar.)

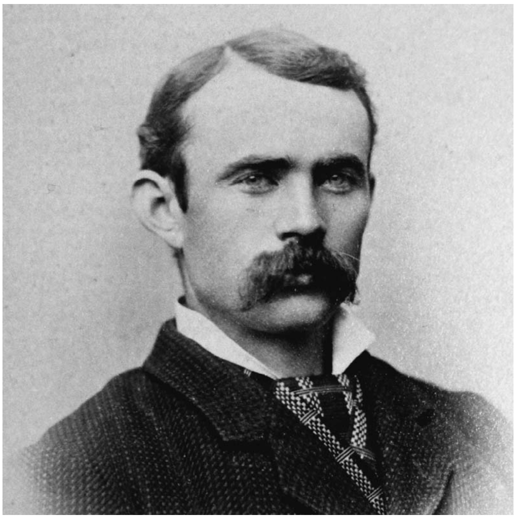


Figure 2.—Elias Francis Shipman, circa 1880. (Original photo attributed to Alexander Hesler. Courtesy of Northwestern University Archives.)

of Natural History in Evanston, Illinois (Northwestern University Museum of Natural History 1883). In February 1931, the specimen was transferred to the Chicago Academy of Sciences and is currently listed in their catalog as CA 160. The original Academy catalog and the current jar label with the preserved frog have "northern Indiana" as the locality, but the Academy database indicates Benton County, Indiana, as the locality. The original specimen tag that read "Benton County, Indiana" (Minton 1972, p. 119) no longer exists. The Academy catalog record indicates Shipman as the collector.

Frank Leon Rice and Nathan Smith Davis, Jr. (Figs. 3 & 4) first described Shipman's specimen as the Hoosier frog (*Rana circulosa*). Their original description appears in the addendum to the second edition of David Starr Jordan's *Manual of the Vertebrates of the Northern United States* (1878). Jordan's text concerning *R. circulosa* is "abridged from Mr. Rice's Notes" (p. 355). Unfortunately, Rice's notes have not been found in the Jordan archival collections at Indiana University or Stanford University, or in the archives at Butler University, where Jordan was teaching when he wrote the second edition. A few years after the original description was published, Davis & Rice (1883a) designated it as *Rana areolata circulosa*, a subspecies of the crawfish frog.

Jordan (1878) credits Rice and Davis for the original description and acknowledges Shipman as the "discoverer" but not necessarily the collector. However, Davis & Rice (1883a) do specifically acknowledge "Mr. E.F. Shipman" as the collector. Minton (1972) makes a simple mistake when he credits Rice and Davis as the collectors. This error was not repeated in Minton's second edition (2001).

Authors are careful to note 1878 as the year of description, but not as the collection date. Altig & Lohoefener (1983) give the collection date as "unknown." Engbrecht & Lannoo (2010) give pre-1879 for a collection year and 1878 as an estimated date for the most recent county record. The original Northwestern University Museum of Natural History catalog is missing. Museum reports remain, but none were generated after June 1874 until 1883. The June 1874 Museum report lists only a water bug (*Belostoma haldimani*) donated by E.F. Shipman (Marcy 1874). This suggests that Shipman was just beginning to engage in natural history collecting, and had not yet collected the frog. The 1883 Museum report lists donors since 1874, with this entry on page 16, "Shipman, E.F. Ethnological specimens, A large collection of plants (deposited), *Rana circulosa*, R. and D. (type, see Jordan's Manual of Vertebrates, p. 355) (deposited), Other zoological specimens" (Northwestern University Museum of Natural History 1883). This entry narrows the collection time window

Figures 3 & 4.—The original description of the Hoosier frog was written by Shipman's classmates, Frank Leon Rice and Nathan Smith Davis, Junior. 3. Left. Rice, circa 1881. 4. Right. Davis, circa 1880. (Original photos attributed to Alexander Hesler. Courtesy of Northwestern University Archives.)

for CA 160 to between July 1874 and 1878, the year it was described.

HISTORY OF THE TYPE LOCALITY CONTROVERSY

Shipman's specimen, as the only Benton County record and the northernmost Indiana record (Engbrecht 2010), gave rise to a controversy surrounding the validity of the type locality (Stejneger & Barbour 1943; Mittleman 1947; Schmidt 1953; Minton 1972; Harding 1983). Minton (2001, p. 135) alludes to the question surrounding the Benton County locality when he writes, "This frog was described from Benton County, Indiana, in 1883. While it has not been recorded from there since, the record is probably valid. I have taken specimens within thirty miles of the southern boundary of the county." Minton is referencing specimens from Vermillion and Fountain counties (Minton 1998; Engbrecht & Lannoo 2010) to support the validity of Benton County as the type locality. Minton's reference to the 1883 date is curious, since he does not include an 1883 publication in his bibliography, but he is likely referencing Davis' and Rice's enhanced description of the frog (1883a).

Confusion over the type locality begins with Stejneger & Barbour (1943) who give "northern" Illinois as the type locality without explanation. Mittleman (1947) points out Stejneger's and Barbour's error in rejecting Benton County as the type locality. Nevertheless, Schmidt (1953, p. 78) restricts the type locality to the "vicinity of Olney, Richland County, Illinois." Smith (1956) follows Schmidt. Neill (1957, p. 140) criticizes Schmidt for revising "numerous type localities and overlooking previous and different revisions," although he does not specify the northern crawfish frog holotype in his critique. As noted above, Minton (1972) corrects Schmidt and cites the original specimen tag. Harding (1983) repeats the Illinois type locality error, in the same year that Altig & Lohoefener (1983) summarize the debate and support Benton County, Indiana, as the valid type locality, and E.F. Shipman as the collector. Frost (2014) and Fouquette & Dubois (2014) also note the errors and provide summaries of the type locality issue.

WHO WAS E.F. SHIPMAN?

Family and early life.—Elias Francis Shipman was a rural Indiana boy from humble beginnings. He was born in Indiana in 1851 or 1852 (U.S. Census 1860. Indiana, Montgomery Co.), the eighth child of Joseph and Mary Ann Wine Shipman. Joseph Shipman was a farmer and a carpenter (U.S. Census 1850. Indiana, Cass Co.; Iowa State Census 1856. Davis Co.). Elias's

Table 1.—Location of Elias Francis Shipman's adult relations in the 1870 and 1880 U.S. Censuses, the time period critical to the collection of the holotype of *Lithobates areolatus circulosus.* Some relatives are missing from one or both censuses.

Name	Relationship to E.F. Shipman	1870 U.S. Census	1880 U.S. Census
Sara Johnson Hayes	Half-sister	Benton Co., Grant Twp.	Warren Co., Pine Twp.
Elizabeth Johnson Baldwin	Half-sister	Benton Co., Grant Twp.	Moved to Illinois in Feb 1880
James Scott Shipman	Brother	Benton Co., Gilboa Twp.	Benton Co., Gilboa Twp.
Daniel Shipman	Brother	Benton Co., Gilboa Twp.	Deceased (Died July 1879)
Abigail Shipman Steffey	Sister	Newton Co., Iroquois Twp.	Benton Co., Center Twp.
George C. Shipman	Brother	Newton Co., Iroquois Twp.	Montgomery Co., Wayne Twp.
Henry Milton Shipman	Brother	Newton Co., Iroquois Twp.	Jasper Co., Newton Twp.
William Marshall Shipman	Brother	Unknown	Unknown
Nancy Shipman Ogburn	Sister	Unknown	Warren Co., Pine Twp.
Sara Baldwin Royalty	Niece	Benton Co., Grant Twp.	Deceased

extended family included Mary Ann's three children by her first husband. The ninth Shipman child was born in October 1853, and both mother and infant died in December of that year. Two months after the death of his mother and infant brother, the oldest child, Elias's half-brother, died at age twenty-five (Brown n.d.).

By 1856, most of the remaining extended family, except Elias, were living in Davis County, Iowa (Iowa State Census 1856. Davis Co.). The family oral history handed down to Shipman genealogist Marvin Ogburn (Pers. Comm.), is that the wagons were full and everyone had to walk to Iowa. Elias was left behind, presumably because there was no one who could care for him on the journey. His two married half-sisters had to carry their own toddlers. If the adolescent Shipman boys had to help with the wagons and stock, only one teenage daughter was available to care for the three younger children who did make the trip. Elias was left with a neighboring farm family in Coal Creek Township, Montgomery County. There he lived and attended school (U.S. Census 1860. Indiana, Montgomery Co.). His father enlisted in the Union Army and died of disease in 1864 at the age of fifty-seven (Iowa Adjutant General 1910). By the time he was thirteen, Elias was an orphan.

Around 1861, Elias's half-sister Elizabeth Johnson Baldwin returned to Montgomery County. The family story (Ogburn, Pers. Comm.) is that she retrieved Elias upon her return to Indiana and raised him along with her two daughters, who were about his age. In 1862, Elizabeth Baldwin's husband bought a tract of land in the northeast corner of Benton County in Gilboa Township (Indiana. Benton County. 1862. "Deed Books"). Between 1867 and 1870, the Baldwins sold their Gilboa Township land, purchased land in southern Benton County in Grant Township along the border of Warren County, and moved there (Indiana. Benton County. 1867, 1868. "Deed Books"; U.S. Census 1870. Indiana, Benton Co.).

Although Elias's very early childhood was spent in Montgomery County, he had a number of family ties to Benton County and the surrounding area. In 1870 and 1880, Elias's siblings were living in the Indiana counties of Benton, Jasper, Montgomery, Newton, and Warren (U.S. Census 1870. Indiana; U.S. Census 1880. Indiana). The known whereabouts of Elias's adult relations in the 1870 and 1880 censuses (Table 1) may be relevant to the collection of the frog and Shipman's Indiana herbarium specimens.

Elias is missing from the 1870 census index; his precise whereabouts that year are unknown. While there is no reason to doubt the oral tradition that Elias lived with the Baldwins in Benton County (Ogburn, Pers. Comm.), no records have been found to verify this. Elias's undergraduate student records at Northwestern University, Evanston, Illinois, list his hometown as Zionsville, Boone County, Indiana (Northwestern University 1873, 1874, 1876, 1877, 1878, 1879, 1880 Catalogue). Elias must have lived in Zionsville sometime before attending Northwestern to consider it his hometown,

Table 2.—Number of Shipman plant records by year, month, and locality. The records show that Shipman did most of his collecting in Illinois, except for the summer and fall of 1876, when he collected in Indiana.

Year	Month	State/Province	Localities	Number of plant records
1872	*unknown*	IN	Newton Co.	1
1875	May-Aug	IL	Cook Co.	34
1875	Sep-Oct	IL	Cook Co.	16
1876	Apr-May	IL	Cook Co.	7
1876	June	ONT	Niagara Falls	1
1876	June	IN	*unknown*	1
1876	June	IN	Hamilton, Marion Cos.	3
1876	July	PA	Elm Station	2
1876	July	IN	*unknown*	1
1876	July	IN	Boone, Clinton, Hamilton, Jasper, Newton Cos.	9
1876	Aug	IN	Benton, Warren Cos.	6
1876	Sep	IN	Jasper, Newton, Warren, White Cos.	10
1876	*unknown*	IN	Hamilton Co.	1
1876	*unknown*	IN	W. Ind.	1
1876	*unknown*	MI	*unknown*	1
1877	May-July	IL	Cook Co.	4
1878	May-Aug	IL	Cook Co.	9
1878	*unknown*	IL	Cook Co.	3
1879	July-Sep	IL	Cook Co.	6
1880	*unknown*	TN	Franklin Co.	2
n.d.	*unknown*	IL	Cook Co.	20
n.d.	*unknown*	IN	Hamilton Co.	1
n.d.	*unknown*	IN	Marion Co.	2
n.d.	*unknown*	IN	White Co.	2

but his living situation and activities there remain a mystery.

Undergraduate years and plant collecting.—When Elias Francis Shipman left Northwestern University, he donated "a large herbarium" to their Museum of Natural History (Northwestern University Museum of Natural History 1886, p. 21). In a later report, his herbarium was described as "a collection of at least two-thousand specimens" assembled when he was a student (Northwestern University Museum of the College of Liberal Arts 1893, p. 6). He also donated zoological and ethnological specimens (Northwestern University Museum of Natural History 1883). Between 1930 and 1933, Northwestern dispersed its museum collection (Northwestern Daily 1930 May 30; Turner 1954). No museum de-accession records are available at Northwestern. Shipman's frog went to the Chicago Academy of Sciences, but the Academy has no other Shipman specimens listed in their database (Roberts, Pers. Comm.). About five percent of Shipman's herbarium can be accounted for in current museum collections or through the literature, but not his zoological or ethnological specimens. It is possible that more Shipman specimens will be revealed as museums database their collections but, for now, information regarding his collecting habits must be determined from the preserved plants available and from the details of his life. The available records (summarized in Table 2) indicate that Shipman's collecting was done while he was associated with Northwestern. We can narrow the collection date window for the frog by knowing exactly when Shipman was away from the Evanston campus and free to collect in Indiana.

In the fall of 1872, around the age of twenty-one, Shipman began his studies at Northwestern in the Preparatory School "Selected Studies" program (Tripod 1872 Oct 21; Northwestern University 1873. Catalogue). The purpose of the Preparatory School was to groom students for college level work. The "Selected Studies" option was designed for persons who did not plan on seeking a degree, although the entrance qualifications and academic rigor were the same as for students who intended to seek a degree

(Northwestern University 1876. Catalogue). Preparatory School completion normally took three years, but students who had already completed some of the required studies were allowed to finish earlier. Shipman finished his preparatory course in two years and matriculated to the undergraduate program in the fall of 1874 (Northwestern University 1874. Catalogue).

Northwestern was a good fit for Shipman. The University's expanding natural history museum, curated by Professor Oliver Marcy, supported Shipman's affinity for botany. The original Northwestern museum collection began with donations from noted naturalist Robert Kennicott, but it was Marcy who transformed the collection into a proper natural history museum (Turner 1954; Pridmore 2000). Marcy was an active, published scientist who believed in "the importance of firsthand observation" (Pridmore 2000, p. 50). For Marcy, the museum was important to scientific pedagogy. Shipman was one of many students who contributed specimens to the museum collection during their undergraduate years.

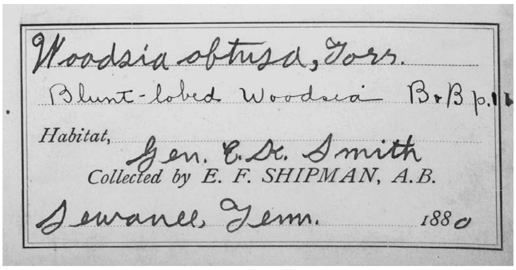
Frank L. Rice and Nathan S. Davis Jr. were Shipman's undergraduate classmates when they wrote the initial description of the Hoosier frog. However, their backgrounds were very different than Shipman's. Rice was the son of an Evanston businessman and had an older brother who also attended Northwestern (U.S. Census 1870. Illinois, Cook. Co.; Northwestern University 1878. Catalogue). Davis was the son of Dr. Nathan S. Davis, Sr., a prominent physician, founder of the American Medical Association, and dean of the Medical College of Chicago (later the Northwestern University Medical School) (Bonner 1957). Rice and Davis were in preparatory school at the same time as Shipman (Northwestern University 1874. Catalogue), although they were about seven years younger (U.S. Census 1880. Illinois, Cook Co.). Davis matriculated to the undergraduate program with Shipman in the fall of 1874 (Tripod 1874 Oct 22). Rice matriculated in the fall of 1876 (Northwestern University 1877. Catalogue). Both Rice and Davis lived at home with their families during their college years, while Shipman first lived in Dempster Hall and later in an Evanston boarding house (Northwestern University Registrar 1877; 1878. Index Register).

The financial data in the available Registrar's records (Northwestern University Registrar 1876–1879. Index Register) support our understanding that Shipman was a man of limited means. Undergraduate tuition was $15 per term, with an additional $7 per term for incidentals. Davis, as the son of a Northwestern faculty member, paid only the incidental fee. Rice and his brother paid a reduced total when both were enrolled, and later when Rice's father became disabled, but for at least one term, Rice paid the full cost. Shipman never paid more than the incidental fee, and for at least one term he paid nothing. How he qualified for his financial aid is unknown.

As undergraduates, Shipman and Davis were students in the "Classical Curriculum", which meant two years of study in Greek and Latin. Rice started out in the "Scientific and Latin Curriculum", which meant he did not have to study Greek. He eventually switched to the "Scientific Curriculum", which meant he could study a modern language instead of a classical one (Northwestern University Registrar 1874–1880. Class Roster). Other than the language requirements, the courses among these three curricula were very similar. Botany and zoology were requirements for all three (Northwestern University 1877, 1878, 1879, 1880. Catalogue).

Shipman's transition to the undergraduate degree-granting program did not go smoothly. At the beginning of the 1874/75 academic year he is listed as an incoming freshman in the class of '78 (Tripod 1874 Oct 22). In the 1875/76 catalog, published at the end of the academic year, he is listed as a sophomore but a dagger next to his name indicates that he was not on campus (Northwestern University 1876. Catalogue). He is also absent from the Registrar's record for 1876 (Northwestern University Registrar 1876–1879. Index Register). There is no mention of Shipman in the campus newspapers for 1875 or 1876. Early in 1877, he is mentioned in the campus newspaper Freshman Brevia column (Tripod 1877a Jan 25) and again in the Personals column as joining the class of '80 (Tripod 1877 Feb 22). At the end of the 1876/77 academic year, he is listed in the catalog as a freshman again (Northwestern University 1877. Catalogue). The Registrar's records confirm his return to campus in January 1877 (Northwestern University Registrar 1876–1879. Index Register). His undergraduate career proceeded without interruption after January 1877, and he earned his A.B. degree in June 1880 (Vidette 1880 Jun 24).

The 1875/76 break in Shipman's undergraduate career is significant to possible collection dates for the frog. Based on Shipman's available



Woodsia obtusa, Torr.

Blunt-lobed Woodsia B&B p.1

Habitat, Gen. E. K. Smith

Collected by E. F. SHIPMAN, A.B.

Sewanee, Tenn. 1880

Figure 5.—Shipman's personal herbarium label used after earning his A.B. degree in June 1880. This label is on FMNH 1430010. (Courtesy of the Field Museum of Natural History.)

herbarium records, he was collecting plants in Evanston during the fall of 1875 and the spring of 1876, even though he was "not on campus." His plant records make it clear that he spent at least part of the summers of 1875, 1877, 1878 and 1879 in Evanston, even though there were no summer classes. The only time he did extensive plant collecting in Indiana was during the summer and fall of 1876. Later in the paper, we strengthen our argument that this is when he collected the frog.

Rice and Davis also had breaks in their undergraduate programs. Davis left campus for a trip to South America from January to June 1877 (Tripod 1877b Jan 25; 1877 Jun 28). Like Shipman, missing two terms put Davis back. Instead of graduating in 1878, he graduated in 1880 with Shipman (Vidette 1880 Jun 24). While Rice was on campus every term, he changed his curriculum and had to return to the preparatory school coursework his sophomore year (Northwestern University 1879. Catalogue). He earned his undergraduate degree in 1881, a year after Shipman and Davis (Northwestern Daily 1881 Jul 8).

While Shipman's natural history interest was botany, Rice and Davis focused on zoology. This may explain why Rice and Davis wrote the description of the Hoosier frog instead of Shipman. The specimens Rice donated to the Northwestern Museum included insects, bird eggs, and bird and mammal skins (Marcy 1874; Northwestern University Museum of Natural History 1883). Davis donated specimens of insects, crabs, fish, lizards and snakes, many of which were collected on his South American trip (Northwestern University Museum of Natural History 1883; Northwestern University Museum of the College of Liberal Arts 1893).

As an undergraduate, Shipman put his botanical skills to work on behalf of his fellow students. He worked with a local merchant to print a standardized set of botanical labels that students could purchase to help them complete their herbarium assignment (Tripod 1879 May 16). As a senior, he tutored the sophomore botany students and the student newspaper acknowledged his expertise, "The botanists have kept Shipman well occupied the past week. 'Shippy' is a necessity to the students, and should be given the chair of Botany." (Tripod 1880 Jun 18, p. 106). Whether he wanted the job or not is unknown, but Shipman did not become the chair of botany.

Life after 1880.—After graduating, Shipman had new personal herbarium labels printed with his degree (Fig. 5), suggesting that he intended to continue plant collecting. Thus far only two specimens have been found using this label, so we cannot determine any post June 1880 plant collecting pattern. There are only two public records that describe Shipman's activities between receiving his undergraduate degree and entering medical school. In the fall of 1880, Shipman is listed in the *Evanston Directory* for 1880–1881 as a janitor for a local church (Evanston Directory 1880). A December 1880 note in the campus newspaper suggests that he may have taught school in Illinois but outside of the Evanston area (Tripod 1880 Dec 17).

In the fall of 1882, around the age of thirty, Shipman enrolled in the Chicago Medical College, which was a department within Northwestern University. Although he had listed Zionsville, Indiana, as his undergraduate hometown, he considered Rensselaer, Jasper County, Indiana, his hometown during medical school (Northwestern University 1883, 1884, 1885. Catalogue). His brother Henry had a farm in the Rensselaer area (U.S. Census 1880, Indiana, Jasper Co.), which explains Shipman's connection to Rensselaer, although we have yet to find evidence that Shipman actually lived in either Zionsville or Rensselaer.

Many of Shipman's medical school classmates had preceptors who were physicians. Shipman, as a rural Indiana man without prestigious connections, had no individual preceptor; he was mentored by the entire medical school faculty (Northwestern University 1883, 1884, 1885. Catalogue). While in medical school, he worked as a laboratory assistant (Northwestern Daily 1882 Nov 16). Shipman earned an A.M.

from Northwestern in 1884 and his medical degree in the spring of 1885 (Northwestern University 1885, 1886. Catalogue).

In August 1885, Dr. Elias Francis Shipman applied for his license to practice medicine in Jasper County, Indiana (Rennselear Republican Weekly 1885 Aug 13). By December 1885, he had set up medical practice in Remington, Jasper County, Indiana (Remington News 1885 Dec 25). This was a logical place for him to locate if he wanted to stay in Indiana and be close to family. His sisters no longer lived in Benton County, but Remington lies almost halfway between his brother Henry's farm near Rensselaer and his brother James Scott's farm in Gilboa Township, Benton County (U.S. Census 1880. Indiana, Benton Co., Gilboa Twp.).

Rice went into business after graduating (Northwestern University College of Liberal Arts 1903). He collaborated with Davis on two publications (Davis & Rice 1883a, 1883b) but did no published science after that. Davis followed in his father's footsteps. He enrolled in medical school and earned both an A.M. and M.D. in 1883. His research interests turned from zoology to the field of human medicine (Northwestern University College of Liberal Arts 1903).

While Rice and Davis prospered in their chosen fields of business and medicine, Shipman simply disappears from the public record. Shipman is listed as a Remington physician in the *Annual Report of the State Board of Health for the Year ending October 31, 1885*, but he is not listed in the reports ending in October 1886 or 1887 (Indiana State Board of Health 1886, 1887, 1888). He is listed as a Remington physician in the 1886 *Medical and Surgical Directory of the United States*, but not in the 1887 *Indiana State Gazetteer and Business Directory*. He is not listed among registered physicians in Illinois (Illinois State Board of Health 1886; 1890). The *Remington News* for 1886–1890 has not been preserved, and there is no mention of Shipman in the *Rensselaer Republican* for those years. He is not mentioned in the *History of the Town of Remington and Vicinity, Jasper County, Indiana* (Royalty 1894) even though the author had been connected to the Shipman family through marriage and business interests. Shipman's residence is listed as unknown in the 1903 Northwestern alumni publication and he is listed as deceased in the 1909 publication (Northwestern University College of Liberal Arts 1903; 1909). Shipman is not listed in any online census records after 1860, nor in any online city directory.

Inaccurate tombstone.—When, where and how Shipman died remains unknown. No death record has been found for him. He is buried in the Jordan Chapel Cemetery, Jefferson County, Illinois, next to his half-sister, Elizabeth Johnson Baldwin, but this cemetery has no early burial records or corresponding church records. His tombstone (Find-A-Grave 2012) displays his dates as 1857–1884. Clearly both dates are wrong. His mother died in 1854, so Shipman could not have been born in 1857. He was in medical practice in December 1885, so he could not have died in 1884. Charles Deam, in his list of Indiana plant collectors (1940), gives Shipman's dates as 1861 to pre-1902, but Deam's source for this information is unknown. The 1861 birthdate may be a typographical error for 1851.

WHEN COULD SHIPMAN HAVE COLLECTED THE FROG?

We have already narrowed the collection time window to between 1874 and 1878. The first date in this range is based on the Northwestern University Museum of Natural History report (1883), which lists the frog as a specimen added to their collection after June 1874. The end date, 1878, is the year the frog's description was published by Jordan. To better determine the collection year, we need to look at the frog's period of activity and compare it to Shipman's opportunities to return to Indiana from Evanston, Illinois.

It has been noted often that the northern crawfish frog is difficult to find in Indiana due to both its rarity and its secretive, burrowing habits (Blatchley 1900; Myers 1925, 1926; Smith 1956; Minton 2001; Heemeyer & Lannoo 2012; Heemeyer et al. 2012). Individual crawfish frogs show exclusive fidelity to specific burrows and typically overwinter in their primary burrows (Heemeyer & Lannoo 2012; Heemeyer et al. 2012.) The frogs are easier to locate during their March to early April breeding season, when their loud distinctive calls can be heard from a distance (Minton 2001; Karns 2003; Heemeyer & Lannoo 2012; Williams et al. 2013; Palis 2014). Shipman's only opportunity to collect the frog during any breeding season between 1874 and 1878 would have been during Northwestern's one-week "spring break" between the second and third terms. The plant collecting data (Table 2) indicate that Shipman spent most of his time in Evanston, even in summers when classes were not in session. A brief spring break trip back to Indiana neither fits his pattern nor our knowledge that he was a man of limited means.

Eighteen seventy-eight can also be eliminated as the collecting year based the short time frame between possible collection dates and when Jordan published the description. Jordan's second edition was reviewed in July 1878 (American Naturalist 1878). It is clear from the review that the second edition had been published, so it was published sometime between January and June 1878. This eliminates summer or fall as possible collection times for that year. In 1878, Northwestern's spring break was March 27 to April 3, a few days later than in previous years (Northwestern University 1878. Catalogue, p. 91). This greatly reduces the time in 1878 for Shipman to collect the frog, for Rice and Davis to complete their description, send it to Jordan, and for Jordan to summarize and submit it to his publisher.

As explained previously, the plant collecting evidence indicates that Shipman was not actively collecting anything in 1874, and that he was in Evanston during the summers and autumns of 1875 and 1877. Jordon's comment (1878, p. 355) that the frog was "lately discovered" suggests 1876 or 1877 as the more likely collection years over anything earlier. The only time Shipman collected extensively in Indiana was the summer and fall of 1876, when the Northwestern documentation indicates he was not on campus (Northwestern University 1876. Catalogue; Northwestern University Registrar 1876. Index Register).

Could Shipman have caught the frog after the breeding season, despite the difficulty in finding them then? History and biography suggest an answer. Wright & Wright (1949, p. 410) describe their conversation with an Illinois farmer who "has plowed them up and cut them in plowing." In 1876, Shipman had relatives actively farming in Benton County. If he was on their farms during that summer or fall, he could have found a frog disturbed by plowing.

Another possibility is that the frog was discovered during the extensive ditching of Benton County. Ditching began in Benton County in the 1850s near Oxford (Birch 1928) and some tile drainage was used in the early 1870s near Raub. However, use of the prairie ditching plow, starting in 1875 or 1876, allowed extensive county-wide ditching to begin in earnest (Barce 1925). This plow was a formidable ditching machine, as described below. The Biblical language at the end of the quote emphasizes the reverence with which farmland was regarded over wetlands.

> "Twelve yoke of oxen were strung out in a long line. ... Following behind was a large plow equipped with a lever, cutting a V shaped ditch from two to three feet deep, from two to three feet wide on the bottom, and from four to six feet in width at the top. The dirt was pushed out on the banks by two wooden mould-boards about four feet in height and attached to the body of the plow by frames of steel. Rude as was this contrivance, it spelled the work of progress. The waters under the heavens were gathered together unto one place and the dry land appeared." (Barce 1925, p. 91–92)

If Shipman collected the frog in 1876 and brought the frog with him when he returned to campus in January 1877, it would have been in the Northwestern Museum collection and available to Davis when he returned from South America in June 1877. Davis and Rice would have had the summer and fall of 1877 to write the description and send it to Jordan in time for the early 1878 publication.

We suggest that future date references to the collection of the frog be given as "circa 1876." This is based on the evidence that 1) Shipman was not enrolled at Northwestern during the summer and fall of 1876, 2) this is when he was actively collecting plants in Benton and surrounding counties, 3) there is no evidence to date that he did major collecting in Indiana at any other time, 4) he could have found the frog outside the breeding season during plowing or ditching, and 5) this date allows sufficient time for Rice and Davis to write the description and send it to Jordan, even though Davis was out of the country for the first six months of 1877.

WHERE IN BENTON COUNTY COULD SHIPMAN HAVE COLLECTED THE FROG?

Shipman's biography in general and his plant collecting activity in particular narrow the

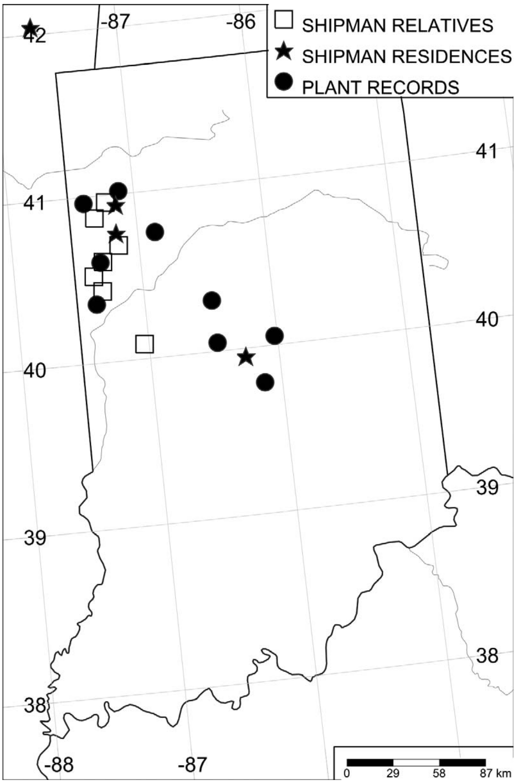


Figure 6.—Map showing Indiana localities where Shipman collected plants (Table 2), his stated hometowns, and the general areas where his relatives lived between 1870 and 1880 (Table 1). Symbols for relatives indicate township center and not exact location. Symbols for plants indicate county center, and not exact plant collection sites, which are unknown.

collection time window for the frog, but do not help in determining a more precise Benton County collection locality. His plant collecting in Indiana included the county of his undergraduate residence (Boone), nearby counties (Clinton, Hamilton, and Marion), and counties near and where his siblings lived (Benton, Jasper, Newton, Warren, and White) (Fig. 6). This distribution of the plant localities suggests that he was willing to travel to collect specimens.

The habitat requirements of northern crawfish frogs include fishless bodies of water in which to breed, abandoned crayfish burrows to shelter the adults, and "large, grassland complexes" (Engbrecht et al. 2013, p. 154). Prior to ditching, Benton County offered an ideal habitat for the northern crawfish frog. Although it was dotted with several forest groves of oak, hickory, and walnut, Benton County was a land of tallgrass prairie. Water was not limited to the major streams or the many ponds large and small. The prairie itself was wet—very wet.

> " ... up to the early 70's little had been done to render the fertile plains of Benton County fit for the plow. Sloughs and ponds abounded, filled with miasma and croaking frogs—fever and ague and malarial fevers prevailed—greenhead flies swarmed in the lowlands and in the tall bull-grass, tormenting the horses and cattle—roads wound around the bogs and marshes, and for weeks at a time, were wholly impassable—crops were precarious—often a failure. ... there was scarcely a field of twenty acres that did not border on a slough. There was no under-drainage whatever. Only the higher lands along the ridges were under a state of cultivation. Even these were seepy and wet. ... The fields, on account of the many ponds and sloughs, consisted of small patches of irregular shape. ... The ground, having but little power of absorption, could not drink up the great rains, and frequently the farmer could not get into his fields for a week." (Barce 1925, p. 88–89)

Once railroads were built in the early 1870s, solving the problem of getting farm products to market, there was incentive to ditch and farm the prairie. Towns were platted along railroad lines and the population grew from 5,615 in 1870 to 11,108 in 1880 (Birch 1928). As noted above, ditching began in earnest around 1875 or 1876, draining the sloughs and marshes, and permanently lowering the water table (Barce 1925). The prairie ditching plow described previously was first used to ditch land in Gilboa Township just south of land owned by Shipman relatives (Barce 1925). Even large ponds were drained. Hickory Grove Lake near Fowler, one of the largest ponds at 200 acres, was drained around 1880 (Barce 1925). Most of the ponds visible on one 1876 county map no longer exist (Andreas 1968).

Biogeographical evidence that *L. areolatus* is native to Benton County is its occurrence in the watershed of the Wabash River. It appears that the Wabash River tributaries are important in the distribution of *L. areolatus* at its northern limits in Illinois and Indiana. It occurs in the watersheds of the Embarrass and Little Wabash Rivers in Illinois, west of the main stem of the Wabash. The two northernmost Indiana records from Benton and Vermillion counties are from north and west of the main stem respectively (Engbrecht & Lannoo 2010).

The plots of Shipman land (Gilboa Township) and Baldwin land (Grant Township) are within or adjacent to the Wabash River watershed, albeit possibly in two different subwatersheds. In the 1870s, Shipman's brothers, Daniel and James Scott, lived together in Gilboa Township on land in Section 29, T26N R6W (U.S. Census 1870. Indiana, Benton Co.; Indiana. Benton Co. 1871. "Deed Books"). Section 29 is immediately north of a major drainage divide (Blue Ridge) between Big Pine Creek which flows directly into the Wabash and the Tippecanoe River watershed (Gorby 1886). From 1867 to 1880, the Baldwins (Shipman's half-sister and brother-in-law) owned land in Section 35, T24N R9W in Grant Township (Indiana. Benton Co. 1867. "Deed Books"; 1880. "Deed Books"). This land is either in the watershed of Mud Pine Creek (a tributary of Big Pine Creek) or in the watershed of the Vermilion River, which trends west into Illinois and then south to join the Wabash River in Vermillion County, Indiana.

Given Benton County's extensive network of sloughs and marshes, Shipman's propensity to travel as indicated by his plant collections, and that he had relatives with farms at opposite county boundaries, he could have found the northern crawfish frog anywhere within the 407 square miles of the county.

Researchers generally agree that the northern crawfish frog is extinct in Benton County (Minton 2001; Engbrecht et al. 2013). Robert Brodman, Michael Redmer, and St. Joseph College students surveyed Benton County for it in 1998 without success (Brodman, Pers. Comm.).

THE VALUE OF SHIPMAN'S HERBARIUM

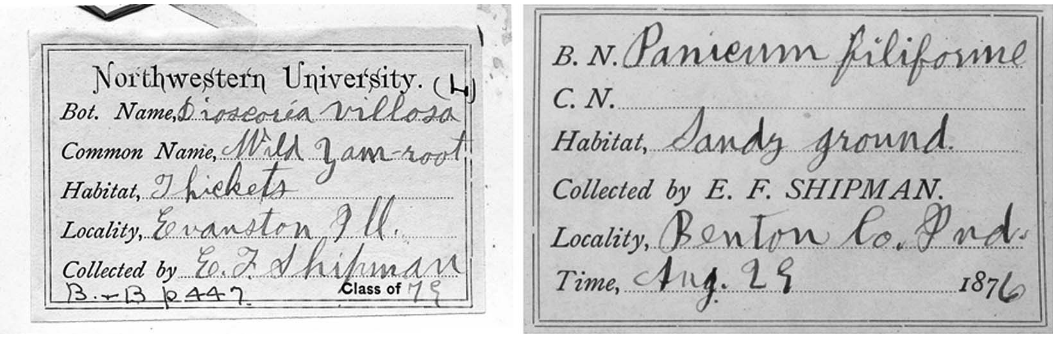
Museum specimens illustrate what our world was like at a given point in time. Like the Hoosier frog, some of Shipman's Indiana plants are now rare, threatened, endangered, or extirpated, including the spoon-leaved sundew (*Drosera intermedia* Hayne), Carolina bugbane (*Trautvetteria caroliniensis* (Walter) Vail), running buffalo clover (*Trifolium stoloniferum* Muhl. ex Eaton), and the prairie white fringed orchid (*Platanthera leucophaea* (Nutt.) Lindl.) (Yatskievych 2000). Shipman's collecting provides valuable information on the former landscape of the Indiana Grand Prairie Region.

By modern standards, many Shipman plant specimens are not well documented. While most of his Illinois specimens have locality information to the city level, and occasionally more detail (e.g., Calvary Cemetery or Lincoln Park), his Indiana specimens have only county level localities. While this is unfortunate for our understanding of Indiana natural history, it is understandable. At the time Shipman was collecting, the Indiana prairie areas were largely featureless. Some township lines were still in flux. Benton County had few roads, only two railroad lines, and only eleven towns, all located along the railroad lines (Andreas 1968). Even today, Gilboa Township is traversed by only county roads; it has no railroad line and no federal or state highway.

Many Shipman plant specimens lack collection dates. This appears to be a factor of which label he used. The Northwestern branded labels (Fig. 7) had no space for the date. Shipman's personal labels bearing his printed name had a place for a date (Fig. 8). Fortunately, we can narrow the range of collection years for all Shipman specimens to the years he was associated with Northwestern University, 1872 to 1885. Specimens collected after June 1880 have the printed label indicating his undergraduate degree (Fig. 5). Herbarium collection managers may find one other clue on Shipman's undated labels. On one Field Museum specimen (FMNH 1430383) Shipman noted on the label that he was in the Class of '78 (Fig. 7). This specimen must have been collected in 1874 or 1875, when he was a member of that class.

In 1893, Oliver Marcy broke up a number of Northwestern student herbaria, including Shipman's, incorporating them into one large systematic herbarium (Northwestern University Museum of the College of Liberal Arts 1893; Northwestern Daily 1893 Mar 3). Duplicates were removed from the main collection, put into storage, or exchanged with other herbaria for more "desirable additions" (Northwestern University Museum of the College of Liberal Arts 1893). This explains how some of Shipman's plants ended up in other collections.

As noted earlier, we can account for only about five percent of Shipman's original



Northwestern University. (L)
Bot. Name, Dioscorea villosa
Common Name, Wild Yam-root
Habitat, Thickets
Locality, Evanston Ill.
Collected by E. F. Shipman
B.-B. p447. Class of 78

B. N. Panicum filiforme
C. N.
Habitat, Sandy ground.
Collected by E. F. SHIPMAN.
Locality, Benton Co. Ind.
Time, Aug. 29 1876

Figures 7 & 8. —Additional examples of labels on Shipman herbarium specimens. 7. Left. Northwestern University printed plant label. Shipman specimens with this label often are undated. This label on FMNH 1430383 is unusual in that Shipman noted that he was in the class of '78. This plant must have been collected in 1874 or 1875, when he was a member of that class. 8. Right. E.F. Shipman personal printed label on FMNH 1386158. Shipman was more likely to include a date when he used this label. (Courtesy of the Field Museum of Natural History.)

herbarium of about 2,000 specimens. We can identify only those specimens that are cited in the literature (Ames 1910; Pennell 1935; Steyermark & Swink 1952; Brooks 1983) or indexed by collector in online herbaria databases. Deam used twenty-two Shipman plants in *Grasses of Indiana* (1929) but does not cite individual specimens. On his maps, he indicates "NW" on the county to indicate that his locality information is based on a specimen from the Northwestern herbarium. By the time Deam wrote *Flora of Indiana* (1940), most of the Northwestern herbarium had been transferred to the Field Museum of Natural History, even though Deam did not update his maps to reflect this. Some of the Shipman grass specimens Deam used can be found in the Field Museum's database.

The Field Museum of Natural History (2012) Botany Collections Database includes a collector index and the database continues to expand. When our research began in 2011, a collector search yielded 75 Shipman plants. The same search in December 2015 yielded 135 Shipman plant specimens. A search by collector in the Harvard University Gray Herbarium database (2014) yields two Shipman specimens. The collector's web page for the University of Nebraska State Museum, Division of Botany, Bessey Herbarium (2013) includes Shipman, but so far only one Shipman plant (NEB-073271) is in their online database, which is not publically available (Labedz, Pers. Comm.).

Marcy noted in his 1886 report (Northwestern University Museum of Natural History 1886, p. 21) that Shipman's herbarium included plants from Indiana, Tennessee, Pennsylvania, New Jersey, North Carolina, and South Carolina. Thus far, the only known Shipman specimens from outside of Illinois or Indiana were collected in June or July 1876, or after June 1880. Did he acquire these plants by exchange or purchase, or did he travel and collect them himself? If he did collect them himself, it does not change our conclusion that the Hoosier frog specimen was collected in 1876. The only Indiana specimen collected in a year other than 1876 is FMNH 1396509, an American white water lily (*Nymphaea odorata* Aiton) collected in Newton County, Indiana, in 1872. This is the earliest of all Shipman's plant records. This specimen has neither a Northwestern label nor a Shipman label; the documentation crediting him as the collector is not in Shipman's handwriting. Shipman started in the Northwestern preparatory school the fall of 1872. Did he collect the plant before attending Northwestern and bring it with him to campus, thus demonstrating an even earlier interest in botany? As herbarium databases grow, we may refine our understanding of Shipman's collecting patterns.

Museums are actively working to database their collections. The value of well-indexed accessible records cannot be overstated. As museums build their databases, the collector field should be included. Collector data can be mined for information about the person's movements and potentially fill in documentation gaps about their specimens, as we have demonstrated with the plants collected by Elias Francis Shipman and the Hoosier frog holotype.

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THE VASCULAR FLORA AND PLANT COMMUNITIES OF HOLTHOUSE WOODS NATURE PRESERVE IN WAYNE COUNTY, INDIANA

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ABSTRACT. Holthouse Woods Nature Preserve (HWNP), owned by the Whitewater Valley Land Trust, Inc., is located along the east fork of the Whitewater River in south-central Wayne County, Indiana, in Abington Township. An inventory of the vascular flora indicates that the 8.9 ha site contains significant regional plant diversity with 331 taxa representing 227 genera and 73 families. Of the 331 taxa, 227 taxa (~69%) are native and 104 taxa (~31%) are non-native, and five represented first records for Wayne County. Although none of the plants documented at the site have state or federal status, one species is on the Indiana Watch List, i.e., *Prenanthes crepidinea*. A detailed physiognomic analysis revealed that the native species consisted of 38 woody species, 155 herbaceous vines or forbs, 33 graminoids, and one fern ally. Of the 104 non-native species, nine were woody, 74 were herbaceous vines or forbs, and 21 were grasses. The major habitats at HWNP are mesic slope woodland, floodplain woodland, a seasonal creek bed, roadside, old-field, drier woodland along River Road, and the Whitewater River corridor which includes the riverbank and sandy/gravel shoreline and two sandy/gravel islands. Floristic Quality Index (FQI) for native species was 43.3, and a mean Coefficient of Conservatism (mean C) was 2.9. For all species FQI = 35.8 and the mean C = 2.0. Given that most of the area is floodplain forest, these numbers indicate that HWNP is a nature preserve quality site but is being compromised by non-natives. The four most invasive non-natives were *Lonicera maackii* in the sloping woodland, *Ranunculus ficaria* var. *bulbifera* in the floodplain woods, and *Artemisia vulgaris* and *Humulus japonicus* along the river corridor. A census of all trees with a dbh ≥ 20 cm revealed that the floodplain woodland is dominated by woody species commonly characteristic of this habitat, e.g., *Acer negundo*, *Populus deltoides*, *Acer saccharinum*, *Platanus occidentalis*, *Juglans nigra*, *Aesculus glabra*, *Celtis occidentalis*, and *Ulmus americana*. A sample of trees with a dbh ≥ 5 cm but < 20 cm suggest that *A. negundo*, *J. nigra*, and *A. glabra* will continue to dominate the site, but that *A. saccharinum*, *P. deltoides*, and *P. occidentalis* will decrease in importance.

Keywords: Floristic quality index (FQI), county records, vascular plants, flora-Indiana, floodplain woods, Wayne County, IN

INTRODUCTION

Using funds received from a Rocky Express Gas Pipeline (REX) Migratory Bird Mitigation grant, the Whitewater Valley Land Trust, Inc. (WVLT) purchased nine properties in the Whitewater River Watershed in 2009. These lands are being conserved, in part, by funding and technical assistance made available as mitigation for impacts caused by the construction and maintenance of Rockies Express Pipeline, LLC in partnership with the U.S. Fish and Wildlife Service. Holthouse Woods Nature Preserve (HWNP), which lies on the east side of the east fork of the Whitewater River just east of Abington, Indiana in southern Wayne County, was one of the properties purchased. Because the property contained a quality floodplain forest along the Whitewater River corridor, and at the request of Mike Hoff, President of WVLT, this study was undertaken.

There have been no formal published studies regarding the flora of HWNP. However, one of the requirements of the REX grant was to create a list of the vascular plants at each site. In 2011, in consultation with WVLT, Don Ruch compiled this list for Holthouse Woods. The list was based on three forays into the site, i.e., late spring, mid-summer, and late summer/early fall. Ruch reported 243 taxa of plants,

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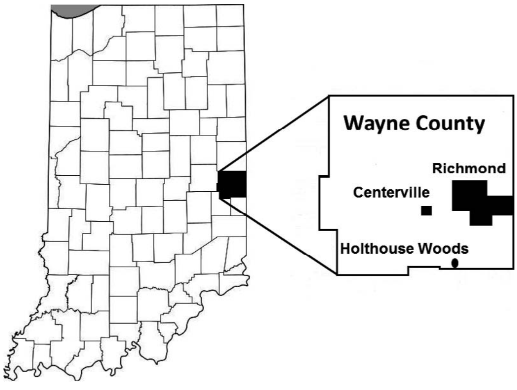

Figure 1.—Map indicating the location of Holthouse Woods Nature Preserve in south-central Wayne County (right), and the location of Wayne County within the state of Indiana (left). (Indiana map modified from https://commons.wikimedia.org/wiki/File:Map_of_Indiana_highlighting_Wayne_County.svg.)

including 182 natives and 61 non-natives (exotics). The only detailed floristic study along the Whitewater River of which we are aware, was of the Wapi-nipi State Nature Preserve, formally known as the Coffman Woods Nature Preserve, adjacent to and just north of HWNP (Ruch et al. 2014a).

An inventory is the necessary first step in developing a long-term resource management plan, is the simplest means to document species diversity, and is a fundamental step in monitoring changes that may occur in species composition. Measures of diversity, such as species richness, are frequently seen as indicators of the well-being of ecological systems (Magurran 1988; García & Martínez 2012). (Species richness is a count of species and does not take into account the abundances of the species or their relative abundance distributions.)

The objectives of this study were (1) to inventory the vascular flora; (2) to determine the floristic quality of the site; (3) to describe the various habitats and summarize species dominance for each; (4) to identify areas of special concern (e.g., areas with rare or threatened plants, if any, and communities sensitive to disturbance); and (5) to analyze the structure and composition of the floodplain forest.

SITE DESCRIPTION

Located in south-central Wayne County, Indiana (Fig. 1), Holthouse Woods Nature Preserve (HWNP) is an 8.9 ha (~ 22 acres) property located directly east and across the Whitewater River from Abington, Indiana (~ 12 km SSE of Richmond, IN). It is located in the NW ¼ Section 2, Twp. 12 N, Rng. 2W, Abington Twp., Wayne Co., or at ~ 39°43’37N and 84°57’40”W [NAD 83] at the southeast corner on River Road at the Union County line. The property is part of the riparian corridor along the Whitewater River. The preserve is bordered on the north by Pottershop Road, the Whitewater River along the west border, the Union County line on the south border, and River Road along the east border. The northern border is adjacent to and directly south of Wapi-nipi Nature Preserve, i.e., formerly Coffman Woods Nature Preserve. It should be noted that within the boundary of this study is a small mesic hillside forest, dropping 21.5 m (~ 70 ft.) over a distance of about 92 m (~ 302 ft.). This one hectare mesic sloping woodland along Pottershop Road is owned by the state and was included in the study.

Although HWNP contains a number of small habitat types, the majority of the site is quality floodplain woodland. Approximately 330 m south of Pottershop Road on River Road is a seasonal creek that flows across HWNP from east to west or from River Road to the Whitewater River. Although this creek holds water that flows in from the elevated river in the spring and drains the elevated land east of River Road after periods of rain, it is dry most of the growing season. Other habitat types present include the small mesic sloping woodland mentioned earlier, the roadside habitat, including a long, very narrow, upland roadside woodland adjacent to River Road, a small, less than 0.1 ha, old field in which WVLT has planted tree seedlings; this field was manicured (mowed periodically) prior to the purchase of the site by WVLT. The final major habitat is the Whitewater River and river corridor, which is quite diverse from both the floristic and topo-edaphographic perspective. Several sections of the shoreline are sandy or sand and gravel and are underwater seasonally or periodically due to rainfall. These shorelines rise slowly upward through sandy and silty soil into the floodplain woods. Most of the shoreline is steep riverbank of gravel, silt and clay that elevates quickly from 1–2.5 m above the river. At the southern end of the property, the riverbank rises over 3 m above the river. Within the river there are three sandy-gravel islands.

Although two are relatively small, the island located at the southern end of the property is ~ 0.5 ha. This "island" is only surrounded by water in the spring and early summer when the river is elevated. As the river recedes, the river channel on the west and south side of the island dries. This large island is the most floristically diverse site on the property.

HWNP lies in the transition zone between the Tipton Till Plain (Central Till Plain) and the Switzerland Hills region (Homoya et al. 1985; Wiseman & Berta 2013). The preserve is within the Whitewater Watershed (USGS Cataloging Unit 05080003, EPA 2015).

The soil of HWNP ranges from loam to silty clay loam (Blank 1987; WSS 2015). The soil along the river corridor and the floodplain woodland is Stonelick loam, which is occasionally flooded, but well drained, with a 0 to 2% slope. The soil of the fairly steep-sloping woodland and the long narrow drier roadside woodlands adjacent to River Road, including the small field, is Eden flaggy silty clay loam having a 25-40% slope and is an eroded, well-drained soil with very high runoff. Lastly, the soil of a small woodland in the southwest corner west of the Whitewater River is Genesee silt loam, which is characterized as having 0 to 2% slope with negligible runoff and being occasionally flooded but is well drained.

METHODS

Inventory and floristic quality index.—During the 2013 and 2014 growing seasons, 27 forays were conducted; forays were made into every major habitat type, and an effort was made to cover all areas within these habitats. Voucher specimens for each species were collected and deposited in the Ball State Herbarium (BSUH). Notes on vegetation consisted of a species list with visual estimates of distribution patterns and relative abundance (see catalog of vascular plants, Appendix 1). Additionally, seasonal changes in the dominant vegetation (based on time of flowering) were noted for the various habitats.

Nomenclature follows the Angiosperm Phylogeny Group (Angiosperm Phylogeny Group 2009; Stevens 2015). List preparation and sources used to identify plant taxa included Deam 1940; Jackson 2004; FNA 2008; Weeks, et al. 2010; Voss & Reznicek 2012; Weakley et al. 2012; USDA 2015; and Kay Yatskievych pers. comm.

A Floristic Quality Index (FQI) for HWNP was determined using the program developed by the Conservation Design Forum in conjunction with Rothrock (2004). This program also calculates the mean Coefficient of Conservatism (mean C), and the mean Wetland Indicator Status (mean W). Additionally, it presents a detailed physiognomic analysis of the flora, both native and non-native species. For a detailed description of how the FQI is determined and an explanation of C-values, see Swink & Wilhelm (1994), Rothrock (2004), and Rothrock & Homoya (2005). Briefly, C-values, which range from zero to ten, are an index of the fidelity of an individual species to undisturbed plant communities characteristic of the region prior to European settlement. The higher the C-value the more conserved the species is to an undisturbed habitat. All exotics are given a C value of 0. The FQI is determined by multiplying the mean C for all species present by the square root of the total number of species. (For native FQI and mean C, only the native species are used.) A FQI greater than 35 suggests that a site has remnant natural quality and contains some noteworthy remnants of natural heritage of the region (Rothrock & Homoya 2005, Swink & Wilhelm 1994). Areas registering in the 50s and higher are considered of paramount importance and should be conserved (Swink & Wilhelm 1994).

Floodplain woody plant analysis.—The boundary of the floodplain woodland was delineated based on topographic position. The total area of the floodplain (4.45 ha) was determined using ArcGIS software and aerial photography to create a polygon corresponding to the floodplain boundary. The protocol of Jackson & Allen (1966) was used to conduct a complete inventory of all overstory woody stems within the floodplain forest community. A full census of all trees in the study area with a dbh ≥ 20 cm was conducted. For each stem, the species was determined and dbh (diameter at breast height) to the nearest 0.1 cm was measured with Haglöf Aluminum Tree Calipers and standard dbh tapes. For each species, total basal area (BA), BA per ha, relative BA (RBA; = [BA per species / total BA for all species] × 100), density (DEN; number of stems per ha), and relative DEN (RDEN; = [DEN of one species / total DEN for all species] × 100) were computed. Relative importance value (RIV) for each species was determined by dividing the sum of the RDEN and RBA by two.

Stems with a dbh < 20 cm were sampled with a plot technique. Three transects were run parallel to the Whitewater River (roughly north to southwest). Transects were 50 m apart. At 50 m intervals along each transect, a flag was placed in the ground to mark the center point of a 5 m radial plot. Thirty-eight plots were established. For each plot the 5 m radius was determined using a BOSCH laser distance measurer model G1580887. Trees between 5 cm to 19.9 cm dbh were identified and placed into one of two categories, i.e., 5–9.9 cm or 10–19.9 cm, using two precut wooden molds. (Since actual dbh was not measured, the midpoint of each category, i.e., 7.5 cm and 15.0 cm, was used for BA calculations.) For each species, BA per ha and RBA, DEN and RDEN, and frequency (FRE; the number of plots in which the species occurred out of the total number of plots) and relative frequency (RFRE; = [FRE of one species / total FRE for all species] × 100). Relative importance value (RIV) for each species was determined by dividing the sum of the RDEN plus RBA plus RFREQ by three.

RESULTS

Inventory and floristic quality index.—The vascular flora documented at HWNP is listed in Appendix 1. The flora consists of 331 taxa representing 227 genera and 73 families. The twelve families (based upon the APG-III classification) having the highest number of species are Asteraceae (50 species), Poaceae (41), Brassicaceae (16), Cyperaceae (13), Fabaceae (13), Lamiaceae (13), Polygonaceae (12), Apiaceae (10), Caryophyllaceae (8), Plantaginaceae (8), Ranunculaceae (8), and Rosaceae (7). These twelve families account for 199 of the 331 species or ~ 60% of the species documented. Of interest, the families Polypodiaceae and Orchidaceae, with their richness of sensitive species, were lacking in the HWNP flora.

A physiognomic summary of the flora in HWNP is presented in Table 1. Of the 331 documented taxa, 227 taxa (~69%) are native and 104 taxa (~31%) are non-native. Of the 227 native species, 38 (~ 16.7%) are woody, 155 (68.4%) are herbaceous vines or forbs, 33 (~ 14.5%) are graminoids, and only one (~ 0.4%) is a vascular cryptogam. Of the 104 non-native species, 9 (~ 8.7%) are woody, 74 (~ 70.9%) are herbaceous vines or forbs, and 21 (~ 20.4%) are grasses. Native and non-native annuals and biennials, species mostly of ruderal habit, make up 34.4% of the total flora.

Table 1.—Physiognomic analysis of the vascular flora documented at Holthouse Woods Nature Preserve, Wayne County, Indiana. A = annual, B = biennial, H = herbaceous, P = perennial, W = woody.

	Native species summary		Non-native species summary	
	Number	% of Total	Number	% of Total
# of species	227	68.9%	104	31.1%
Tree	26	7.9%	4	1.2%
Shrub	6	1.8%	4	1.2%
W-Vine	6	1.8%	1	0.3%
H-Vine	4	1.2%	1	0.3%
P-Forbs	104	31.8%	27	7.9%
B-Forbs	6	1.8%	15	4.5%
A-Forbs	41	12.4%	31	9.4%
P-Grass	14	4.2%	8	2.4%
A-Grass	6	1.8%	13	3.9%
P-Sedge	11	3.3%	0	0.0%
A-Sedge	2	0.6%	0	0.0%
Fern	1	0.3%	0	0.0%

The Floristic Quality Index and mean Coefficients of Conservatism (mean C) for the native species is 43.8 and 2.9, respectively, and for all species, including the non-natives, is 36.4 and 2.0, respectively. No species were observed with a Coefficient of Conservatism (C) ≥ 9. Two species have a C = 8, i.e., *Carex amphibola* and *Symphyotrichum prenanthoides*. Nine species have a C = 7, i.e., *Hydrophyllum macrophyllum*, *Packera obovata*, *Prenanthes crepidinea*, *Ranunculus hispidus* var. *hispidus*, *Silene nivea*, *Stellaria pubera*, *Symphyotrichum puniceum*, *Thalictrum thalictroides*, and *Valeriana pauciflora*. In comparison, 75 species (~ 22.7%) have C-values of 4-6 (i.e., 11 with C = 6, 28 with C = 5, and 36 with C = 4), and 244 species (~ 73.7%) have C-values ≤ 3 (i.e., 141 species with C = 0 (including 38 native and 104 non-native species), 29 species with C = 1, 27 species with C = 2, and 47 species with C = 3).

Although the non-native species account for ~ 31% of the taxa, they have little visual display or dominance at the site. The majority of the non-natives are confined to the roadside and old-field habitat or to the river corridor,

Table 2.—Stand table for the floodplain forest at Holthouse Woods Nature Preserve, Abington, Indiana; all trees with a dbh ≥ 20 cm; total area = 4.45 ha. Species are listed in descending order based on relative importance values (RIV). Stems equal the total number of stems for a species. DEN (density) is the number of stems per hectare. RDEN (relative density is the percent density of one species compared to all other species. BA (basal area) is in meters squared per hectare for each species. RBA (relative basal area) is the percent basal area for one species compared to the total basal area for all species. RIV is the average of RDEN and RBA expressed in percent. Others include *Acer nigrum*, *Carya cordiformis*, *Gleditsia triacanthos*, *Gymnocladus dioicus*, *Maclura pomifera*, *Malus pumila*, *Morus alba*, *Morus rubra*, *Prunus serotina*, *Robinia pseudoacacia*, and *Tilia americana*.

Species	Stems	DEN	RDEN	BA	RBA	RIV
Acer negundo	360	80.9	41.9	8.7	38.0	40.0
Populus deltoides	97	21.8	11.3	4.2	18.3	14.8
Acer saccharinum	103	23.1	12.0	2.7	11.8	11.9
Platanus occidentalis	69	15.5	8.0	2.8	12.1	10.1
Juglans nigra	85	19.1	9.9	1.7	7.3	8.6
Aesculus glabra	36	8.1	4.2	0.6	2.5	3.4
Celtis occidentalis	26	5.8	3.0	0.8	3.5	3.2
Ulmus americana	20	4.5	2.3	0.3	1.1	1.7
Fraxinus spp.	12	2.7	1.4	0.3	1.4	1.4
Salix nigra	16	3.6	1.9	0.2	0.7	1.3
Others	35	7.9	4.1	0.8	3.3	3.6
Total	859	193.0	100.0	23.1	100.0	100.0

and their occurrence is rare to infrequent with four noteworthy exceptions (Appendix 1). The mesic slope woodland at the northern end of the study area is heavily invaded with *Lonicera maackii*. The floodplain woodland, especially just south of the seasonal creek, is permeated with *Ranunculus ficaria* var. *bulbifera*. Lastly the river corridor, especially at the southern end of the property, is infested with large colonies of *Artemisia vulgaris* and *Humulus japonicus*.

Five species documented at HWNP are reported for the first time and represent Wayne County records. County records were determined using the Indiana Natural Heritage Data Center's records for Wayne County (this is the same plant list in the computer database of Keller et al. (1984)), the USDA Plant Database (2015), The Biota of North America Program (BONAP): Maps by States and Provinces (2014), Overlease & Overlease (2007), Deam (1940), the species listed at Hayes Arboretum (Ruch et al. 2007), Lick Creek Summit Nature Preserve (Ruch et al. 2008a), and Coffman Woods Nature Preserve (now Wapi-nipi State Nature Preserve; Ruch et al. 2014a). The records include the native species *Gratiola neglecta* and *Verbena bracteata*, and the non-native species *Artemisia vulgaris*, *Hordeum vulgare*, and *Sisymbrium officinale*. Additionally, there are two other species at HWNP that have not been previously reported from Wayne County. These are not being reported as county records because we are unsure of their origin although they appear to have occurred naturally. They are *Echinacea purpurea*, woodland edge along River Road, and *Solanum lycopersicum*, several plants on the large sand/gravel island both years of this study. None of the species documented at the site have state rare, threatened, or endangered status (IDNR Nature Preserves 2013), but one species is on the state watch list, i.e., *Prenanthes crepidinea*.

Floodplain woody plant analysis.—Results of the full census of all trees with a dbh ≥ 20 cm in the floodplain woodland are presented in Table 2. Eight hundred and fifty-nine stems were measured from 21 species. The floodplain was dominated by *Acer negundo*, *Populus deltoides, Acer saccharinum*, and *Platanus occidentalis*. Collectively these species comprise over 70% of the total stems and over 80% of the total basal area of the floodplain woodland. *Acer negundo* has by far the highest RIV (40.0) with 41.9% of the total stems and 38% of the total basal area within the floodplain. *Populus deltoides* and *Platanus occidentalis* had the highest average dbh (> 40 cm) and were the only species with multiple stems with dbh > 80 cm. The survey of trees with a dbh ≥ 5 cm but < 20 cm is presented in Table 3. Eighty-six stems from 12 species were measured. The three most important species in the understory with respect to RIV are

Table 3.—Stand table for the floodplain forest at Holthouse Woods Nature Preserve, Abington, Indiana; all trees with a dbh ≥ 5 cm and < 20 cm; thirty-eight 5 m plots, total area = 2.2985 ha. Species are listed in descending order based on relative importance values (RIV). Stems equal the total number of stems for a species. DEN (density) is the number of stems per hectare. RDEN (relative density is the percent density of one species compared to all other species. FRE (frequency) refers to the number of plots out of 38 in which each species occurs. RFRE (relative frequency) is the frequency of occurrence of each species relative to all species. BA (basal area) is in meters squared per hectare for each species. RBA (relative basal area) is the percent basal area for one species compared to the total basal area for all species. RIV is the average of RDEN, RFRE, and RBA expressed in percent. Others include *Carya cordiformis*, *Fraxinus* spp., *Platanus occidentalis*, *Robinia pseudoacacia*, *Salix nigra*, and *Vitis* spp.

Species	Stems	DEN	RDEN	FRE	RFRE	BA	RBA	RIV
Acer negundo	48	160.8	55.8	14	33.3	1.7	53.0	54.4
Juglans nigra	11	36.9	12.8	7	16.7	0.4	13.5	13.1
Aesculus glabra	8	26.8	9.3	6	14.3	0.3	10.7	10.0
Maclura pomifera	5	16.8	5.8	3	7.2	0.3	7.9	6.9
Celtis occidentalis	4	13.4	4.7	1	2.4	0.1	4.7	4.7
Ulmus americana	4	13.4	4.7	3	7.1	0.1	3.3	4.0
Others	6	20.1	6.9	8	19.0	0.3	5.7	6.9
Total	86	288.2	100.0	42	100.0	3.2	100.0	100.0

A. negundo, *Juglans nigra*, and *Aesculus glabra*. These species combine for 77.9% of all stems sampled and 77.2% of the total basal area in the understory. The fourth most important species is *Maclura pomifera*. This size class includes no stems of *A. saccharinum* or *P. deltoides* and only one of *P. occidentalis*, indicating that these were all sapling or pole size individuals.

DESCRIPTION OF THE MAJOR HABITATS

Holthouse Woods Nature Preserve contains several habitats, each with rather distinctive plant communities (Fig. 2). The communities are separated by topographic features, water regime, and soil types. The major habitats at HWNP are listed earlier in the Site Description section. Below is a more detailed description of the plants in each.

Sloping mesic woodland.—Common to abundant trees included *Acer nigrum*, *Celtis occidentalis*, *Juglans nigra*, and *Ulmus americana*. At the base of the slope there were a few *Quercus macrocarpa* and *Q. muehlenbergii*. The slope was heavily infested with *Lonicera maackii*. Other common woody shrubs and vines included *L. japonica*, *Menispermum canadense*, and *Parthenocissus quinquefolia*. Few grasses and sedges occurred here, the most common were *Carex amphibola*, *C. blanda*, *Festuca subverticillata*, and *Poa trivialis* near the base of the slope. This woodland had an excellent display of spring ephemerals, but an absence of summer and fall herbaceous plants. The common spring ephemerals included *Cardamine concatenata*, *Delphinium tricorne*, *Galium aparine*, *Osmorhiza longistylis*, *Packera obovata*, *Polygonatum biflorum* var. *biflorum*, *Trillium sessile*, *Valeriana pauciflora* (lower slope), and *Viola striata*. The most common summer flowering herb was *Circaea lutetiana* ssp. *canadensis*.

Floodplain woodland.—The most abundant tree species throughout this woodland was *Acer negundo*. Other common species included *Acer saccharinum*, *Aesculus glabra*, *Juglans nigra*, *Platanus occidentalis*, and *Populus deltoides*. Woody vines included *Toxicodendron radicans* ssp. *negundo*, which was common and widespread, and *Humulus japonicus*, which was abundant at the southern end of the woodland in open areas. The two most common grasses were *Elymus macgregorii* and *Poa trivialis*. No sedges were common, and very few individual plants were observed. The herbaceous flora was impressive. Flowering herbs common to abundant in the spring and early summer included *Allium vineale*, *Cryptotaenia canadensis*, *Dicentra cucullaria*, *Enemion biternatum*, *Galium aparine*, *Geum vernum*, *Glechoma hederacea*, *Heracleum maximum*, *Hesperis matronalis*, *Hydrophyllum appendiculatum*, *Monarda fistulosa*, *Osmorhiza longistylis*, *Phacelia purshii*, *Ranunculus abortivus*, *R. ficaria* var. *bulbifera*, *and Stellaria media*. Flowering herbs common to abundant in summer through fall included Fallopia scandens, *Galium triflorum*, *Impatiens*

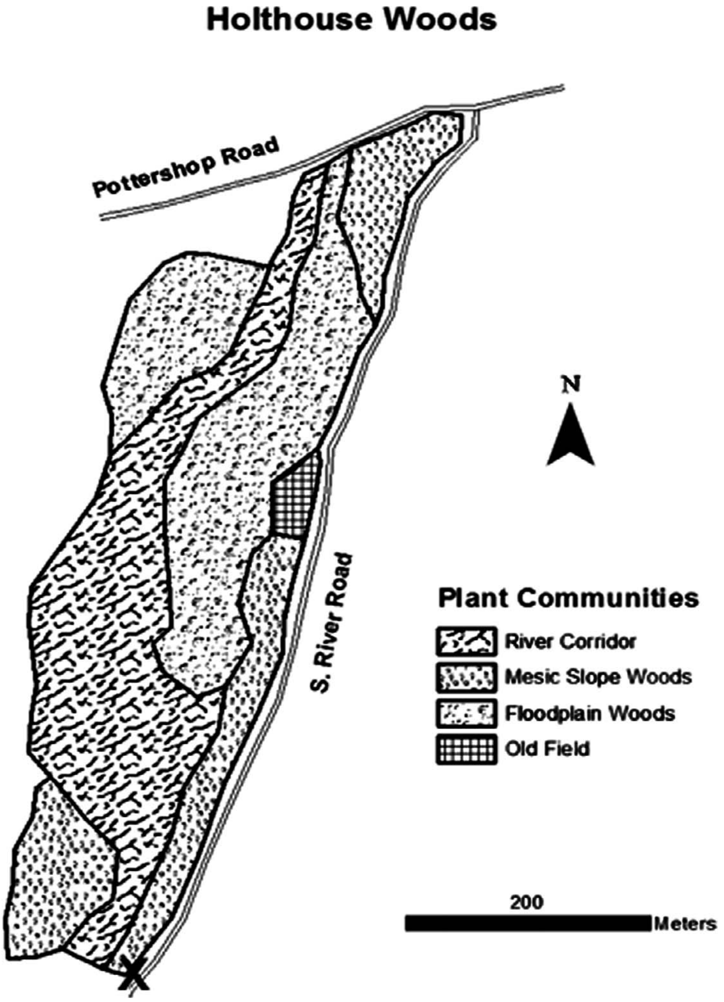

Figure 2.—Diagram illustrating the distribution of the major habitat types in Holthouse Woods Nature Preserve, Wayne County, Indiana. The **X** marks the latitude and longitude coordinates given in the Site Description section.

capensis, *Laportea canadensis*, *Lycopus americanus*, *Pilea pumila*, *Sanicula odorata*, *Solidago altissima*, *S. gigantea*, *Symphyotrichum lateriflorum*, *Tradescantia subaspera*, *Rudbeckia laciniata*, and *Verbesina alternifolia*. The floodplain woodland was severely infested with the exotic *R. ficaria* var. *bulbifera*. On the riverbank between the two bends of the river at the southern end, *Fallopia japonica* occurred, the only site on the property where it is found.

Seasonal creek.—Herbaceous species growing on the creek bank or creek bed included *Ageratina altissima*, *Ambrosia trifida*, *Campanulastrum americanum*, *Glyceria striata*, *Hackelia virginiana*, *Laportea canadensis*, *Leersia virginica*, *Lobelia siphilitica*, *Lysimachia nummularia*, *Mentha spicata*, *Persicaria longiseta, Persicaria maculosa*, *Persicaria punctata* var. *leptostachya, Physalis longifolia* var. *subglabrata*, *Pilea pumila*, *Rumex obtusifolius*, *Samolus parviflorus*, *Scrophularia marilandica*, *Verbena urticifolia, and Xanthium strumarium*. Additionally, the only stem of *Gymnocladus dioicus* occurred at the top of the bank along this creek, as did the only colony of *Poa sylvestris.*

Roadside, old-field, and drier woodland along River Road.—Tree species along the roadside were characteristic of HWNP, as described above, with three notable observations. Several stems of *Juniperus virginiana* occurred along the northern third of the property. *Morus alba* occurred frequently along the woodland edge on the northern half of the property. Lastly, several large *Quercus macrocarpa* stems occurred along the roadside on the southern third of the property. *Parthenocissus quinquefolia* and *Toxicodendron radicans* ssp. *negundo* were common. The roadside and woodland edge herbaceous flora was diverse and included a number of non-native species. The most common herbs were *Arenaria serpyllifolia*, *Capsella bursa-pastoris*, *Cardamine hirsuta*, *Cichorium intybus*, *Claytonia virginica*, *Conium maculatum*, *Conyza canadensis*, *Draba verna*, *Erigeron annuus*, *Galinsoga quadriradiata*, *Geum canadense*, *Impatiens pallida*, *Lepidium virginicum*, *Medicago lupulina*, *Oxalis stricta*, *Plantago lanceolata*, *P. rugelii*, *Polygonatum biflorum* var. *commutatum*, *Polygonum aviculare*, *Polymnia canadensis* (southern third), *Stellaria media*, *Symphyotrichum pilosum*, *Veronica arvensis, V. peregrina*, and *Viola sororia*. The most common and widespread grasses in this habitat were *Dactylis glomerata*, *Digitaria ciliaris*, *Eleusine indica*, *Eragrostis pectinacea*, *Festuca subverticillata*, *Poa annua*, *P. pratensis*, and *Schedonorus arundinaceus.* Lastly, along the extreme southern portion of River Road, where the edge slopes down toward the river, *Carex aggregata*, *C. blanda*, *and C. conjuncta* were common.

Whitewater River corridor.—The habitats within the river corridor contained the greatest diversity of plant species.

Riverbank and sandy/gravel shoreline: The four most common trees along river corridor were *Acer saccharinum*, *Morus alba*, *Platanus occidentalis*, and *Populus deltoides*. The most common or notable herbaceous species were *Acalypha rhomboidea*, *Agrostis stolonifera*, *Alliaria petiolata*, *Allium canadense*, *Amaranthus tuberculatus*, *Amphicarpaea bracteata*, *Angelica atropurpurea*, *Arenaria serpyllifolia*, *Artemisia annua*, *A. vulgaris, Cirsium arvense*, *Echinochloa crus-galli*, *E. muricata*, *Elymus riparius*, *E. virginicus*, *Eragrostis hypnoides*, *Erigeron annuus*, *Helenium autumnale*, *Humulus japonicus* (abundant), *Ludwigia palustris*, *Lycopus americanus*, *Lysimachia nummularia*, *Mimulus alatus*, *Myosotis scopioides*, *Oenothera biennis*, *Persicaria maculosa*, *Phalaris arundinacea* (especially along the shoreline at the northern fifth of the property), *Pilea pumila*, *Plantago rugelii*, *Polanisia dodecandra*, *Rorippa sylvestris*, *Scutellaria lateriflora*, *Solidago gigantea*, *Symphyotrichum prenanthoides*, *Verbena hastata*, *V. urticifolia*, and *Veronica anagallis-aquatica*.

Sandy/gravel islands: Many of the same species occurring along the river corridor were also found on the islands. However, because of its size, the species occurring on the large island at the southern end of the property will be described here. There were several large colonies of *Salix interior* and one large stand of *Acer saccharinum*. The most common grasses were *Echinochloa crus-galli*, *Eleusine indica*, and *Setaria pumila*. The two most common sedges were *Cyperus odoratus* and *C. strigosus*. However, *Cyperus erythrorhizos*, *Eleocharis erythropoda*, and *Schoenoplectus tabernaemontani* were infrequent to rare. The most common herbaceous plants included *Acalypha rhomboidea*, *Amaranthus albus*, *A. tuberculatus, Artemisia annua*, *A. vulgaris*, *Bidens cernua*, *Bidens frondosa*, *Eupatorium serotinum*, *Euphorbia maculata*, *E. nutans*, *Euthamia graminifolia*, *Ludwigia palustris*, *Persicaria maculosa*, *Polanisia dodecandra*, *Rorippa sylvestris*, and *Symphyotrichum pilosum*. Herbaceous plants which only occurred on the islands include *Abutilon theophrasti*, *Amaranthus hybridus*, *Asclepias incarnata*, *Chaenorhinum minus*, *Croton monanthogynus*, *Eclipta prostrata*, *Epilobium coloratum*, *Eutrochium maculatum*, *Lycopus uniflorus*, *Persicaria lapathifolia*, P. *pensylvanica*, *Ranunculus sceleratus*, *Rudbeckia hirta* var. *pulcherrima*, *and Symphyotrichum novae-angliae*.

DISCUSSION

Inventory and floristic quality index.—The vascular flora at HWNP included the same core of plants, and subsequently plant families, reported for other sites in east central Indiana (Rothrock et al. 1993; Rothrock 1997; Ruch et al. 1998, 2002, 2004, 2007, 2008a, 2008b, 2009, 2012, 2014a, 2014b; Stonehouse et al. 2003, Tungesvick 2011; Prast et al. 2014). Twelve plant families, accounting for 60% of the plants reported at HWNP (e.g., 199 of 331 documented species) and the sites referred to above, are the Apiaceae, Asteraceae, Brassicaceae, Caryophyllaceae, Cyperaceae, Fabaceae, Lamiaceae, Plantaginaceae, Poaceae, Polygonaceae, Ranunculaceae, and Rosaceae (see Appendix 1). Based on variations between the Cronquist system (USDA 2015) and the

Angiosperm Phylogeny Group (Stevens 2015), the noted variation between earlier studies and the current one is the absence of the Liliaceae and Scrophulariaceae and the addition of the Plantaginaceae.

The FQI for the native vascular flora at HWNP was 43.3 and the mean C was 2.9. Swink & Wilhelm (1994) suggested that areas with FQI higher than 35 possess sufficient conservatism and richness to be of profound importance from a regional perspective. We have been using FQI = 45 for designating a site as nature preserve quality. Rothrock & Homoya (2005) reported that the average C-values for Indiana are 1.2 units lower than those of the Chicago region. Based on this information, HWNP is a site of profound importance from a regional perspective, and based on the lower C-values for Indiana, it should be considered a nature preserve quality site. In further support of this statement, floodplain forests are areas of high biodiversity and biomass (Mitsch & Gosselink, 2000; Naiman & Decamps, 1997) but typically do not contain many plant species with high C-values. At HWNP only 11 species (3.3%) had a C ≥ 7, while 244 species (73.7%) have C ≤ 3. Because FQI is determined by multiplying the square root of the number of species by the mean C, it would be harder for a site with a low mean C, such as floodplain woods, to obtain a FQI of nature preserve quality. A similar situation was seen at Mississinewa Woods in Randolph County (Ruch et al. 2012).

Floodplain woody plant analysis.—The top eight overstory species based on RIV, in order, are *A.* n*egundo*, *P. deltoides*, *A. saccharinum*, *P. occidentalis*, *J. nigra*, *A. glabra*, *C. occidentalis*, and *U. americana* (Table 2). These are the typical species found in floodplain woodlands of east-central Indiana, e.g., Wilbur Wright Fish and Wildlife Area in Henry County (Ruch et al. 2002), Botany Glen in Grant County (Stonehouse et al. 2003), Lick Creek Summit Nature Preserve in Wayne County (Ruch et al. 2008a), Mississinewa Woods in Randolph County (Ruch et al. 2013), and Coffman Woods Nature Preserve in Wayne County (Ruch et al. 2014a). These woody species are common components of floodplain woods throughout Indiana (Lee 1945; Lindsey & Schmelz 1970; Schmelz & Lindsey 1970). Although a typical floodplain species, the absolute dominance of *A. negundo* was unexpected, i.e., having the highest RDEN and RBA, and a RIV over two and one-half times that of *P. deltoides*, the second most important species.

The understory (Table 3) can be used to predict the future composition of the woods. *Acer negundo* was also the most prominent species in the understory with the highest RDEN and RBA, as well as the highest RFRE, and a RIV over four times that of *J. nigra*, the second most important species in this group. Based on the information in Table 3, it would appear the *A. negundo* will continue to dominate the site, and longer-lived *J. nigra* as well as *A. glabra* will increase in importance. *Populus deltoides*, *A. saccharinum*, and *P. occidentalis* having the second to fourth RIV at the site, respectively (Table 2), will decrease in importance since each species recorded only one or no stems in the smaller category. However predictions based on a single sampling event have limited certainty. Floodplain forest woody regeneration is impacted by periodic flooding and severe competition from a dense herbaceous community. Extremely high mortality rates for understory species may occur during severe flooding events. Some species, such as *P. deltoides* and *Salix* spp., may benefit by colonizing open areas created by flooding (Yin 1999).).

Summary.—Following the completion of the study, we recommended that WVLT develop a management plan to remove and monitor future growth of *Lonicera maackii* growing in the slope woodland at the northern end of the property. Several years ago, we made a similar recommendation for the Wapi-nipi State Nature Preserve and much of the honeysuckle on the southern end of the property had been removed. Similarly, we recommended that they implement some program to monitor and attempt to reduce or eliminate the large colonies of *Artemisia vulgaris* and *Humulus japonicus* along the river corridor at the southern end of the property. Since there was only one clump of *Fallopia japonica*, Japanese knotweed, we removed it at the completion of the study. However, WVLT will need to continually monitor for any new growth in the area. Lastly, because HWNP is of nature preserve quality, we recommended it be added as additional acreage to the Wapi-nipi State Nature Preserve along its northern border.

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APPENDIX 1

CATALOG OF VASCULAR FLORA AT HOLTHOUSE WOODS NATURE PRESERVE, WAYNE COUNTY, INDIANA

Species are listed alphabetically by family, then genera, under major plant groups. Non-native (exotic) species are capitalized. Nomenclature follows the Angiosperm Phylogeny Group (Stevens 2015). Each species report contains the following information: (1) current scientific name; (2) vegetation association (FPW = floodplain woods; MSW = sloping mesic woodland; SC = seasonal creek; RC = river corridor (i.e., riverbank, shoreline, sand/gravel islands); RS = roadside, field & woodland edge along River Road); (3) a visual estimate of its relative abundance (see below); (4) the Indiana Coefficient of Conservation, C = # (Rothrock 2004); and (5) the Ball State University Herbarium (BSUH) number(s). The relative abundance for species is defined as follows; rare = ≤ 5 sites although a species may be abundant at one site; infrequent = occasional, not widespread throughout its potential habitats, but may be locally abundant at a site; common = frequent throughout its potential habitats and may be locally abundant at one or more sites; and abundant = common and numerous throughout its potential habitats. Potential Wayne County records are indicated by a pound-symbol (#) in parentheses immediately preceding a species. (See results section for determination of Wayne County records and comments concerning endangered, threatened or rare plants of Indiana.

MONILOPHYTA

EQUISETACEAE (Horsetail Family)

Equisetum arvense L. – RC; Rare; C = 1; BSUH 19288, 19328.

CONIFEROPHYTA

CUPRESSACEAE (Redwood or Cypress Family)

Juniperus virginiana L. – RS; Rare; C = 2; BSUH 19391, 19441

MAGNOLIOPHYTA

MAGNOLIOPSIDA (Dicotyledons)

ACANTHACEAE (Acanthus Family)

Justicia americana (L.) Vahl – RC; Rare; C = 6; BSUH 19551.

Ruellia strepens L. – RS; Rare; C = 4; BSUH 19641.

ADOXACEAE (Moschatel Family)

Sambucus canadensis L. (= *S. nigra* L. var. *canadensis* (L.) R. Bolli) – RC; Rare; C = 2; BSUH 19273.

AMARANTHACEAE (Goosefoot or Pigweed Family)

Amaranthus albus L. (= *Amaranthus graecizans* L. in Deam 1940) – RC; Common; C = 0; BSUH 19611.

AMARANTHUS HYBRIDUS L. – RC; Infrequent; C = 0; BSUH 19607.

Amaranthus tuberculatus (Moq.) J.D. Sauer –RC; Abundant; C = 1; BSUH 19477, 19567, 19572.

CHENOPODIUM ALBUM L. – RS; Infrequent; C = 0; BSUH 19540.

ANACARDIACEAE (Cashew Family)

Toxicodendron radicans (L.) Kuntze ssp. *negundo* (Greene) Reveal – FPW, MSW; Abundant; C = 1; BSUH 19556.

APIACEAE (Carrot Family)

Angelica atropurpurea L. – FPW, RC; Infrequent; C = 6; BSUH 19343.

Cicuta maculata L. var. *maculata* – FPW; Infrequent; C = 6; BSUH 19276.

CONIUM MACULATUM L. – RS; Rare but locally abundant; C = 0; BSUH 19378.

Cryptotaenia canadensis (L.) DC. – FPW; Abundant; C = 3; BSUH 19346.

DAUCUS CAROTA L. – RC, RS; Infrequent; C = 0; BSUH 19371.

Heracleum maximum W. Bartram – FPW; Rare but locally abundant; C = 6; BSUH 19397.

Osmorhiza longistylis (Torr.) DC. – FPW, MSW; Abundant; C = 3; BSUH 19429.

PASTINACA SATIVA L. – RC, RS; Rare; C = 0; BSUH 19363.

Sanicula odorata (Raf.) Pryer & Philippe – FPW; Abundant; C = 2; BSUH 19398.

Thaspium trifoliatum (L.) A. Gray var. *aureum* (L.) Britt. – FPW, MSW; Infrequent; C = 5; BSUH 19384, 19399, 19518.

APOCYNACEAE (Dogbane or Milkweed Family)

Apocynum cannabinum L. – RS; Infrequent; C = 2; BSUH 19296.

Asclepias incarnata L. ssp. *incarnata* – RC; Rare; C = 4; BSUH 19500.

Asclepias syriaca L. – RS; Infrequent; C = 1; BSUH 19297.

ARISTOLOCHIACEAE (Birthwort Family)

Asarum canadense L. – MSW; Infrequent; C = 5; BSUH 19404.

ASTERACEAE (Aster or Daisy Family)

Ageratina altissima (L.) R.M. King & H. Rob. var. *altissima* – FPW, MSW, RC; Abundant; C = 2; BSUH 19638.

Ambrosia artemisiifolia L. var. *elatior* Descourt. – RC, RS; Abundant; C = 0; BSUH 19511.

Ambrosia trifida L. var. *trifida* – FPW especially along SC; Infrequent but locally abundant; C = 0; BSUH 19537.

ARCTIUM MINUS (Hill) Bernh. – RC; Rare; C = 0; BSUH 19508.

ARTEMISIA ANNUA L. – RC; Common; C = 0; BSUH 19609.

(#) *ARTEMISIA VULGARIS* L. – RC; Common; C = 0; BSUH 19608.

Bidens cernua L. – RC; Abundant; C = 2; BSUH 19624, 19626.

Bidens frondosa L. – RC; Common; C = 1; BSUH 19625.

Bidens vulgata Greene – RC; Infrequent; C = 0; BSUH 19635.

CICHORIUM INTYBUS L. – RS; Common; C = 0; BSUH 19370.

CIRSIUM ARVENSE (L.) Scop. – RC; Infrequent; C = 0; BSUH 19272, 19313.

CIRSIUM VULGARE (Savi) Ten. – RS; Rare; C = 0; BSUH 19539.

Conyza canadensis (L.) Cronquist var. *canadensis* – RS; Abundant; C = 0; BSUH 19558.

Echinacea purpurea (L.) Moench – RS; Rare; C = 6; BSUH 19299.

Eclipta prostrata (L.) L. – RC; Infrequent; C = 3; BSUH 19527, 19545.

Erigeron annuus (L.) Pers. – RS; Common; C = 0; BSUH 19368.

Erigeron philadelphicus L. var. *philadelphicus* – RS; Infrequent; C = 3; BSUH 19415.

Eupatorium perfoliatum L. var. *perfoliatum* – FPW; RC; Common; C = 4; BSUH 19507.

Eupatorium serotinum Michx. – RC (big island); Common; C = 0; BSUH 19531, 19634.

Euthamia graminifolia (L.) Nutt. – RC; Rare; C = 3; BSUH 19532.

Eutrochium maculatum (L.) E.E. Lamont var. *maculatum* – RC; Rare; C = 5; BSUH 19566.

GALINSOGA QUADRIRADIATA Ruiz & Pavón – RS; Infrequent; C = 0; BSUH 19315.

Helenium autumnale L. var. *autumnale* – RC; Rare; C = 3; BSUH 19550.

HELIANTHUS ANNUUS L. – RC (big island); Rare; C = 0; BSUH 19462.

Helianthus tuberosus L. – RS; Rare; C = 2; BSUH 19576.

Heliopsis helianthoides (L.) Sweet var. *helianthoides* – FPW; Rare; C = 4; BSUH 19327, 19534.

Lactuca floridana (L.) Gaertn. var. *floridana* – RS; Rare; C = 5; BSUH 19563.

LACTUCA SERRIOLA L. – RC; Infrequent; C = 0; BSUH 19503.

MATRICARIA DISCOIDEA DC. – RS; Infrequent; C = 0; BSUH 19438.

Nabalus crepidineus (Michx.) DC. (= *Prenanthes crepidinea* Michx.) – FPW; Rare; C = 7; BSUH 19263.

Packera glabella (Poir.) C. Jeffrey – FPW, RC; Infrequent; C = 0; BSUH 19417.

Packera obovata (Muhl. ex Willd.) W.A. Weber & Á. Lõve – MSW; Common; C = 7; BSUH 19430.

Polymnia canadensis L. – MSC; Rare but locally abundant; C = 3; BSUH 19304.

Rudbeckia hirta L. var. *pulcherrima* Farw. – RC; Rare; C = 2; BSUH 19265.

Rudbeckia laciniata L. var. *laciniata* – RS; Common; C = 3; BSUH 19522.

Silphium perfoliatum L. var. *perfoliatum* – RC; Infrequent; C = 4; BSUH 19400, 19498.

Solidago altissima L. – RC, RS; Abundant; C = 0; BSUH 19628.

Solidago gigantea Aiton – FPW, RC; Abundant; C = 4; BSUH 19535, 19577.

SONCHUS OLERACEUS L. – RC; Rare; C = 0; BSUH 19485.

Symphyotrichum cordifolium (L.) Nesom – MSW; Infrequent; C = 5; BSUH 19654.

Symphyotrichum lanceolatum (Willd.) Nesom var. *lanceolatum* – MSW, RC; Infrequent; C = 3; BSUH 19601, 19617.

Symphyotrichum lateriflorum (L.) Á. Löve & D. Löve var. *lateriflorum* – FPW; Abundant; C = 3; BSUH 19616.

Symphyotrichum novae-angliae (L.) Nesom – RC; Rare; C = 3; BSUH 19600.

Symphyotrichum pilosum (Willd.) Nesom var. *pilosum* – RC, RS; Common; C = 0; BSUH 19618.

Symphyotrichum prenanthoides (Muhl. ex Willd.) Nesom – RC; Infrequent; C = 8; BSUH 19643.

Symphyotrichum puniceum (L.) Á. Löve & D. Löve var. *puniceum* – RC; Rare; C = 7; BSUH 19653.

TARAXACUM OFFICINALE F.H. Wigg. – RC, RS; Infrequent; C = 0; BSUH 19403.

Verbesina alternifolia (L.) Britton ex Kearney – FPW; Abundant; C = 3; BSUH 19555.

Vernonia gigantea (Walter) Trel. ssp. *gigantea* – RS; Infrequent; C = 2; BSUH 19523.

Xanthium strumarium L. var. *canadense* (Mill.) Torr. & A. Gray – RC, SC; Rare but locally abundant; C = 0; BSUH 19639.

BALSAMINACEAE (Touch-Me-Not Family)

Impatiens capensis Meerb. – RC; Common; C = 2; BSUH 19461.

Impatiens pallida Nutt. – RS; Rare but locally common; C = 4; BSUH 19459.

BERBERIDACEAE (Barberry Family)

Podophyllum peltatum L. – FPW, MSW; Common; C = 3; BSUH 19418.

BIGNONIACEAE (Trumpet-Creeper Family)

Catalpa speciosa (Warder) Warder ex Engelm. – RC; Rare; C = 0; BSUH 19325.

BORAGINACEAE (Borage Family)

Hackelia virginiana (L.) I.M. Johnst. – FPW, SC; Infrequent; C = 0; BSUH 19553.

Hydrophyllum appendiculatum Michx. – FPW; Abundant; C = 6; BSUH 19419.

Hydrophyllum macrophyllum Nutt. – MSW; Infrequent; C = 7; BSUH 19410.

MYOSOTIS SCOPIOIDES L. – RC; Rare; C = 0; BSUH 19481.

Phacelia purshii Buckley – FPW; Abundant; C = 3; BSUH 19421.

BRASSICACEAE (Mustard Family)

ALLIARIA PETIOLATA (M. Bieb.) Cavara & Grande – FPW, RC; Infrequent; C = 0; BSUH 19423.

Arabis laevigata (Muhl. ex Willd.) Poir. var. *laevigata* – MSW; Infrequent; C = 5; BSUH 19603.

BARBAREA VULGARIS R. Br. – RS; Infrequent; C = 0; BSUH 19446.

BRASSICA NIGRA (L.) W.D.J. Koch – RC; Rare but locally abundant; C = 0; BSUH 19282, 19283.

CAPSELLA BURSA-PASTORIS (L.) Medik. – RS; Infrequent; C = 0; BSUH 19414.

Cardamine concatenata (Michx.) O. Schwarz – MSW; Abundant; C = 4; BSUH 19597.

CARDAMINE HIRSUTA L. – RS; Abundant; C = 0; BSUH 19586.

DRABA VERNA L. – RS; Abundant; C = 0; BSUH 19587.

HESPERIS MATRONALIS L. – FPW, RC; Common; C = 0; BSUH 19422.

Iodanthus pinnatifidus (Michx.) Steud. – FPW; Rare; C = 6; BSUH 19348.

LEPIDIUM CAMPESTRE (L.) R. Br. – RS; Infrequent; C = 0; BSUH 19443.

Lepidium virginicum L. var. *virginicum* – RS; Common; C = 0; BSUH 19360.

Rorippa palustris (L.) Besser ssp. *fernaldiana* (Butters & Abbe) Jonsell – RC; Rare; C = 2; BSUH 19284.

RORIPPA SYLVESTRIS (L.) Besser – RC; Common; C = 0; BSUH 19536.

(#) *SISYMBRIUM OFFICINALE* (L.) Scop. – RS; Rare; C = 0; BSUH 19393.

THLASPI ARVENSE L. – RS; Rare; C = 0; BSUH 19437.

CAMPANULACEAE (Bellflower Family)

Campanula americana L. (= *Campanulastrum americanum* (L.) Sm.) – SC; Rare; C = 4; BSUH 19471.

Lobelia siphilitica L. var. *siphilitica* – FPW, SC; Common; C = 3; BSUH 19579.

CANNABACEAE (Indian Hemp Family)

Celtis occidentalis L. – MSW; Common; C = 3; BSUH 19435.

HUMULUS JAPONICUS Siebold & Zucc. – RC; Abundant; C = 0; BSUH 19278, 19476, 19629.

CAPRIFOLIACEAE (Honeysuckle Family)

DIPSACUS FULLONUM L. – RS; Rare but locally abundant; C = 0; BSUH 19295.

LONICERA JAPONICA Thunb. – MSW; Rare but locally common; C = 0; BSUH 19433.

LONICERA MAACKII (Rupr.) Maxim. – MSW; Abundant; C = 0; BSUH 19444.

Symphoricarpos orbiculatus Moench – FPW; Infrequent along riverbank; C = 1; BSUH 19515.

Valeriana pauciflora Michx. – FPW, MSW; Infrequent; C = 7; BSUH 19406.

Valerianella umbilicata (Sull.) Wood – FPW, RC; Infrequent; C = 5; BSUH 19420.

CARYOPHYLLACEAE (Pink Family)

ARENARIA SERPYLLIFOLIA L. – RC, RS; Common; C = 0; BSUH 19387.

CERASTIUM FONTANUM Baumg. ssp. *VULGARE* (Hartm.) Greuter & Burdet – RS; Infrequent; C = 0; BSUH 19262, 19595.

SAPONARIA OFFICINALIS L. – RC; Rare but locally abundant; C = 0; BSUH 19322.

Silene antirrhina L. – RC; Infrequent but locally abundant; C = 0; BSUH 19279.

SILENE LATIFOLIA Poir. ssp. *ALBA* (Mill.) Greuter & Burdet – RC; Infrequent; C = 0; BSUH 19319.

Silene nivea (Nutt.) Muhl. ex Otth – RS; Rare; C = 7; BSUH 19316.

STELLARIA MEDIA (L.) Vill. ssp. *MEDIA* – FPW, RC; Abundant; C = 0; BSUH 19293, 19453.

Stellaria pubera Michx. – FPW; Infrequent; C = 7; BSUH 19396.

CLEOMACEAE (Cleome Family)

Polanisia dodecandra (L.) DC. var. *dodecandra* – RC; Abundant; C = 1; BSUH 19321, 19585.

CONVOLVULACEAE (Morning-Glory Family)

Calystegia sepium (L.) R. Br. – RC; Infrequent; C = 1; BSUH 19463.

Cuscuta gronovii Willd. ex Schult. – RC; Rare; C = 2; BSUH 19630.

IPOMOEA HEDERACEA Jacq. – RC; Rare; C = 0; BSUH 19497.

IPOMOEA PURPUREA (L.) Roth – RC; Rare; C = 0; BSUH 19570.

CUCURBITACEAE (Gourd Family)

Echinocystis lobata (Michx.) Torr. & A. Gray – RS; Infrequent; C = 3; BSUH 19578.

Sicyos angulatus L. – RS; Infrequent; C = 3; BSUH 19524, 19631.

EUPHORBIACEAE (Spurge Family)

Acalypha rhomboidea Raf. – RC; Abundant; C = 0; BSUH 19478, 19512, 19615.

CROTON MONANTHOGYNUS Michx. – RC (big island); Infrequent; C = 0; BSUH 19584, 19660.

Euphorbia dentata Michx. var. *dentata* – RS; Infrequent; C = 0; BSUH 19521, 19613.

Euphorbia maculata L. – RC (big island); Common; C = 0; BSUH 19479.

Euphorbia nutans Lag. – RC (big island); Common; C = 0; BSUH 19506.

FABACEAE (Pea or Bean Family)

Amphicarpaea bracteata (L.) Fernald var. *comosa* (L.) Fernald – RC; Rare; C = 5; BSUH 19574.

Cercis canadensis L. var. *canadensis* – RS; Rare; C = 3; BSUH 19347.

Gleditsia triacanthos L. – FPW; Rare; C = 1; BSUH 19280.

Gymnocladus dioicus (L.) K. Koch – SC; Rare; C = 4; BSUH 19364.

MEDICAGO LUPULINA L. – RS; Common; C = 0; BSUH 19361.

MELILOTUS ALBUS Medik. – RC; Rare; C = 0; BSUH 19324.

MELILOTUS OFFICINALIS (L.) Pall. – RC; Rare; C = 0; BSUH 19344.

Robinia pseudoacacia L. – FPW; Rare but locally common; C = 1; BSUH 19379, 19542.

SECURIGERA VARIA (L.) Lassen – RS; Infrequent; C = 0; BSUH 19332.

TRIFOLIUM HYBRIDUM L. – RC; Rare; C = 0; BSUH 19302.

TRIFOLIUM PRATENSE L. – RS; Infrequent; C = 0; BSUH 19373.

TRIFOLIUM REPENS L. – RS; Infrequent; C = 0; BSUH 19390.

VICIA CRACCA L. – RS; Rare but locally common; C = 0; BSUH 19375.

FAGACEAE (Beech Family)

Quercus macrocarpa Michx. var. *macrocarpa* – MSW, RS; Rare; C = 5; BSUH 19271, 19388.

Quercus muehlenbergii Engelm. – MSW; Rare; C = 4; BSUH 19405.

FUMARIACEAE (Fumitory Family)

Corydalis flavula (Raf.) DC. – FPW; Rare; C = 3; BSUH 19599.

Dicentra cucullaria (L.) Bernh. – FPW; Abundant; C = 6; BSUH 19592.

GROSSULARIACEAE (Gooseberry Family)

Ribes cynosbati L. – FPW; Rare; C = 4; BSUH 19267.

HYPERICACEAE (St. John's-Wort Family)

HYPERICUM PERFORATUM L. – RC; Rare; C = 0; BSUH 19475.

JUGLANDACEAE (Walnut Family)

Carya cordiformis (Wang.) K. Koch – RS; Rare; C = 5; BSUH 19274.

Juglans nigra L. – FPW; Common; C = 2; BSUH 19412.

LAMIACEAE (Mint Family)

GLECHOMA HEDERACEA L. – FPW, MSW; Infrequent; C = 0; BSUH 19424.

LAMIUM AMPLEXICAULE L. – RS; Rare; C = 0; BSUH 19594.

LAMIUM PURPUREUM L. var. *PURPUREUM* – RS; Infrequent; C = 0; BSUH 19440.

Lycopus americanus Muhl. ex W. Barton – FPW, RC; Abundant; C = 3; BSUH 19486, 19632.

Lycopus uniflorus Michx. var. *uniflorus* – RC; Rare but locally common; C = 5; BSUH 19645.

Mentha arvensis L. – RC; Infrequent; C = 4; BSUH 19482.

MENTHA SPICATA L. – SC; Rare but locally common; C = 0; BSUH 19519, 19538.

Monarda fistulosa L. ssp. *fistulosa* – FPW; Common; C = 3; BSUH 19468.

NEPETA CATARIA L. – RC; Rare; C = 0; BSUH 19460.

PRUNELLA VULGARIS L. ssp. *VULGARIS* – FPW; Infrequent; C = 0; BSUH 19552.

Scutellaria lateriflora L. var. *lateriflora* – RC; Rare; C = 4; BSUH 19573.

Stachys hispida Pursh – FPW; Infrequent; C = 4; BSUH 19292.

Teucrium canadense L. var. *canadense* – RC; Rare but locally abundant; C = 3; BSUH 19281.

LIMNANTHACEAE (False Mermaid Family)

Floerkea proserpinacoides Willd. – FPW; Rare; C = 5; BSUH 19605.

MALVACEAE (Mallow Family)

ABUTILON THEOPHRASTI Medik. – RC; Infrequent; C = 0; BSUH 19637.

MALVA NEGLECTA Wallr. – RS; Rare; C = 0; BSUH 19334.

Tilia americana L. var. *americana* – FPW; Rare; C = 5; BSUH 19266.

MENISPERMACEAE (Moonseed Family)

Menispermum canadense L. – MSW; Abundant; C = 3; BSUH 19409.

MONTIACEAE (Blinks Family)

Claytonia virginica L. var. *virginica* – RS; Abundant; C = 2; BSUH 19589.

MORACEAE (Mulberry Family)

MACLURA POMIFERA (Raf.) C.K. Schneid. – FPW; Infrequent; C = 0; BSUH 19395, 19517.

MORUS ALBA L. – FPW; Abundant; C = 0; BSUH 19392, 19402.

Morus rubra L. var. *rubra* – FPW; Rare; C = 4; BSUH 19268.

OLEACEAE (Olive Family)

Fraxinus americana L. – MSW; Infrequent; C = 4; BSUH 19289, 19561, 19580.

Fraxinus pennsylvanica Marshall – FPW; Infrequent; C = 1; BSUH 19289, 19350.

LIGUSTRUM OBTUSIFOLIUM Siebold & Zucc. – RS; Rare; C = 0; BSUH 19349.

ONAGRACEAE (Evening Primrose Family)

Circaea lutetiana L. ssp. *canadensis* (L.) Asch. & Magnus – MSW; Common; C = 2; BSUH 19294.

Epilobium coloratum Biehl. – RC; Rare; C = 3; BSUH 19571.

Ludwigia palustris (L.) Ell. – RC; Infrequent but locally abundant; C = 3; BSUH 19487, 19525, 19623.

Oenothera biennis L. – RC; Infrequent; C = 0; BSUH 19483.

OXALIDACEAE (Wood Sorrel Family)

Oxalis dillenii Jacq. – RS; Common; C = 0; BSUH 19339.

Oxalis stricta L. – RS; Common; C = 0; BSUH 19309.

PAPAVERACEAE (Poppy Family)

Sanguinaria canadensis L. – MSW; Infrequent; C = 5; BSUH 19432.

PENTHORACEAE (Ditch Stonecrop Family)

Penthorum sedoides L. – RC; Infrequent; C = 2; BSUH 19513.

PHRYMACEAE (Lopseed Family)

Mimulus alatus Aiton – RC; Common; C = 4; BSUH 19488.

Mimulus ringens L. var. *ringens* – RC; Rare but locally common; C = 4; BSUH 19465

Phryma leptostachya L. – RS; Infrequent; C = 4; BSUH 19458.

PHYTOLACCACEAE (Pokeweed Family)

Phytolacca americana L. var. *americana* – RS; Rare; C = 0; BSUH 19333.

PLANTAGINACEAE (Plantain Family)

CHAENORHINUM MINUS (L.) Lange – RC; Rare; C = 0; BSUH 19501, 19528.

(#) *Gratiola neglecta* Torr. – RC; Rare but locally common; C = 4; BSUH 19464.

Leucospora multifida (Michx.) Nutt. – Rare but locally abundant; C = 3; BSUH 19640.

PLANTAGO LANCEOLATA L. – RS; Common; C = 0; BSUH 19338.

Plantago rugelii Decne. var. *rugelii* – RC, RS; Common; C = 0; BSUH 19369, 19533.

Veronica anagallis-aquatica L. – RC, RS; Common; C = 5; BSUH 19298, 19376.

VERONICA ARVENSIS L. – RS; Abundant; C = 0; BSUH 19372, 19394.

VERONICA PEREGRINA L. – RS; Abundant; C = 0; BSUH 19454.

PLATANACEAE (Plane-Tree Family)

Platanus occidentalis L. – FPW; Common; C = 3; BSUH 19442.

POLEMONIACEAE (Phlox Family)

Phlox divaricata L. ssp. *divaricata* – MSW; Infrequent; C = 5; BSUH 19425.

Phlox paniculata L. – FPW; Rare; C = 3; BSUH 19275.

Polemonium reptans L. var. *reptans* – MSW; Infrequent; C = 5; BSUH 19428.

POLYGONACEAE (Smartweed Family)

FALLOPIA JAPONICA (Houtt.) Ronse Decr. – RC; Rare; C = 0; BSUH 19474, 19541.

Fallopia scandens (L.) Holub – FPW, RC; Infrequent; C = 0; BSUH 19627.

Persicaria lapathifolia (L.) Delarbre – RC; Infrequent; C = 0; BSUH 19529, 19530.

PERSICARIA LONGISETA (Bruijn) Kitag. – SC; Abundant here; C = 0; BSUH 19492, 19614.

PERSICARIA MACULOSA Gray – RC; Common; C = 0; BSUH 19509, 19612.

Persicaria pensylvanica (L.) M. Gómez – RC; Rare; C = 0; BSUH 19636.

Persicaria punctata (Ell.) Sm. – RC, SC; Common; C = 3; BSUH 19560, 19621.

Persicaria virginiana (L.) Gaertn. (= *Tovara virginiana* (L.) Raf.) – SC; Common; C = 3; BSUH 19520.

POLYGONUM AVICULARE L. – RS; Abundant; C = 0; BSUH 19336.

Rumex altissimus A. Wood – RC; Infrequent; C = 2; BSUH 19314, 129401.

RUMEX CRISPUS L. var. *CRISPUS* – RS; Common; C = 0; BSUH 19374.

RUMEX OBTUSIFOLIUS L. – SC; Common; C = 0; BSUH 19331.

PRIMULACEAE (Primrose Family)

Lysimachia ciliata L. – RS; Rare; C = 4; BSUH 19301.

LYSIMACHIA NUMMULARIA L. – RC, SC; Common and locally abundant; C = 0; BSUH 19330, 19345.

Samolus parviflorus Raf. – SC; Infrequent; C = 5; BSUH 19514.

RANUNCULACEAE (Buttercup Family)

Delphinium tricorne Michx. – MSW; Common; C = 5; BSUH 19427, 19451.

Enemion biternatum Raf. – FPW; Common; C = 5; BSUH 19593.

Ranunculus abortivus L. – FPW; Common; C = 0; BSUH 19604.

RANUNCULUS FICARIA L. var. *BULBIFERA* Marsden-Jones – FPW; Common and locally abundant; C = 0; BSUH 19591.

Ranunculus hispidus Michx. var. *hispidus* – FPW; Infrequent; C = 7; BSUH 19606.

Ranunculus sceleratus L. var. *sceleratus* – RC; Rare; C = 3; BSUH 19569.

Thalictrum dasycarpum Fisch. & Avé-Lall. – FPW; Rare; C = 4; BSUH 19286, 19329.

Thalictrum thalictroides (L.) Eames & B. Boivin – FPW; Infrequent; C = 7; BSUH 19416.

ROSACEAE (Rose Family)

Geum canadense Jacq. var. *canadense* – FPW, RS; Common; C = 1; BSUH 19367.

Geum vernum (Raf.) Torr. & A. Gray – FPW; Abundant; C = 1; BSUH 19259.

MALUS PUMILA Mill. – MSW; Rare; C = 0; BSUH 19269.

Potentilla norvegica L. ssp. *monspeliensis* (L.) Asch. & Graebn. – RC; Rare; C = 0; BSUH 19499.

Prunus serotina Ehrh. var. *serotina* – FPW; Rare; C = 1; BSUH 19270.

ROSA MULTIFLORA Thunb. ex Mur. – RS; Rare; C = 0; BSUH 19377.

Rubus occidentalis L. – RS; Rare; C = 1; BSUH 19340.

RUBIACEAE (Madder Family)

Galium aparine L. – MSW; Abundant; C = 1; BSUH 19436.

Galium triflorum Michx. – FPW; Common; C = 5; BSUH 19469.

SALICACEAE (Willow Family)

Populus deltoides Bartr. ex Marshall var. *deltoides* – FPW; Common; C = 1; BSUH 19445.

Salix exigua Nutt. var. *interior* (Rowlee) Cronq. (= *Salix interior* Rowlee) – FPW; Rare but locally common; C = 1; BSUH 19494.

Salix nigra Marshall – RC (big island); Abundant; C = 3; BSUH 19351.

SAPINDACEAE (Soapberry Family)

Acer negundo L. – FPW; Abundant; C = 1; BSUH 19449.

Acer nigrum Michx. f. – FPW, MSW; Infrequent; C = 6; BSUH 19434.

Acer saccharinum L. – FPW, RC; Abundant; C = 1; BSUH 19450.

Acer saccharum Marshall var. *saccharum* – MSW; Infrequent; C = 4; BSUH 19307.

Aesculus glabra Willd. var. *glabra* – FPW; Common; C = 5; BSUH 19389.

SCROPHULARIACEAE (Figwort Family)

Scrophularia marilandica L. – SC; Common; C = 5; BSUH 19490.

VERBASCUM BLATTARIA L. – RC, RS; Infrequent; C = 0; BSUH 19323, 19337.

VERBASCUM THAPSUS L. – RC; Rare; C = 0; BSUH 19320.

SIMAROUBACEAE (Quassia Family)

AILANTHUS ALTISSIMA (Mill.) Swingle – FPW; Rare; C = 0; BSUH 19277.

SOLANACEAE (Nightshade Family)

Physalis longifolia Nutt. var. *subglabrata* (Mack. & Bush) Cronq. – RC, SC; Infrequent; C = 0; BSUH 19285, 19622.

SOLANUM LYCOPERSICUM L. – RC; Rare; C = 0; BSUH 19505.

Solanum ptycanthum Dunal – RC, RS; Infrequent but locally abundant; C = 0; BSUH 19480, 19642.

STAPHYLEACEAE (Bladdernut Family)

Staphylea trifolia L. – FPW; Rare; C = 5; BSUH 19413.

ULMACEAE (Elm Family)

Ulmus americana L. – FPW; Infrequent; C = 3; BSUH 19407, 19448.

URTICACEAE (Nettle Family)

Boehmeria cylindrica (L.) Sw. – RC; Infrequent; C = 3; BSUH 19516.

Laportea canadensis (L.) Wedd. – FPW, SC; Abundant; C = 2; BSUH 19489, 19575.

Parietaria pensylvanica Muhl. ex Willd. – RS; Rare; C = 1; BSUH 19655.

Pilea pumila (L.) A. Gray var. *pumila* – FPW, RC; Abundant; C = 2; BSUH 19557.

Urtica gracilis Aiton (= *Urtica dioica* L. ssp. *gracilis* (Aiton) Seland.) – FPW, RC; Infrequent; C = 1; BSUH 19287, 19467.

VERBENACEAE (Vervain Family)

(#) *Verbena bracteata* Lag. & Rodr. – RC; Rare; C = 0; BSUH 19318.

Verbena hastata L. var. *hastata* – RC; Infrequent; C = 3; BSUH 19466.

Verbena urticifolia L. var. *leiocarpa* L.M. Perry & Fernald – RC, SC; Common; C = 3; BSUH 19470.

VIOLACEAE (Violet Family)

Viola sororia Willd. var. *sororia* – RS; Common; C = 1; BSUH 19588.

Viola striata Aiton – MSW; Common; C = 4; BSUH 19426.

VITACEAE (Grape Family)

Parthenocissus quinquefolia (L.) Planch. – FPW, MSW; Common; C = 2; BSUH 19341.

Vitis riparia Michx. – FPW, MSW; Common; C = 1; BSUH 19308.

Vitis vulpina L. – RS; Rare; C = 3; BSUH 19652.

MAGNOLIOPHYTA
LILIOPSIDA (Monocotyledons)

ALISMATACEAE (Water-Plantain Family)

Alisma subcordatum Raf. – RC; Infrequent; C = 2; BSUH 19504.

AMARYLLIDACEAE (Amaryllis Family)

Allium burdickii (Hanes) A.G. Jones (= *Allium tricoccum* Aiton var. *burdickii* Hanes) – MSW; Infrequent; C = 6; BSUH 19411.

Allium canadense L. var. *canadense* – FPW, RC; Common; C = 1; BSUH 19342.

ALLIUM VINEALE L. ssp. *VINEALE* – FPW; Abundant; C = 0; BSUH 19590.

ARACEAE (Arum Family)

Lemna minor L. – RC; Rare but locally abundant; C = 3; BSUH 19633.

ASPARAGACEAE (Asparagus Family)

Camassia scilloides (Raf.) Cory – RS (southern end); Rare; C = 5; BSUH 19261.

ORNITHOGALUM UMBELLATUM L. – RS; Rare; C = 0; BSUH 19362.

Polygonatum biflorum (Walter) Ell. var. *biflorum* – MSW; Common; C = 4; BSUH 19602.

Polygonatum biflorum (Walter) Ell. var. *commutatum* (Schult. & Schult. f.) Morong – RS; Rare; C = 4; BSUH 19300.

COMMELINACEAE (Spiderwort Family)

COMMELINA COMMUNIS L. – RC; Infrequent; C = 0; BSUH 19317.

Tradescantia subaspera Ker Gawl. – FPW; Common; C = 4; BSUH 19326.

CYPERACEAE (Sedge Family)

Carex aggregata Mack. – RS; Infrequent; C = 2; BSUH 19264, 19357.

Carex amphibola Steud. – MSW; Infrequent; C = 8; BSUH 19380.

Carex blanda Dewey – MSW; Common; C = 1; BSUH 19355.

Carex conjuncta Boott – RS; Infrequent but locally common; C = 6; BSUH 19356.

Carex grisea Wahlenb. – FPW, RC; Infrequent; C = 3; BSUH 19354.

Carex vulpinoidea Michx. – RS; Infrequent; C = 2; BSUH 19306.

Cyperus erythrorhizos Muhl. – RC; Rare; C = 1; BSUH 19381.

Cyperus odoratus L. – RC; Infrequent; C = 1; BSUH 19581, 19659.

Cyperus strigosus L. – RC; Infrequent; C = 0; BSUH 19564, 19619.

Eleocharis erythropoda Steud. – RC (big island); Rare; C = 2; BSUH 19526.

Schoenoplectus tabernaemontani (C.C. Gmel.) Palla – RC (big island); Rare; C = 4; BSUH 19544.

Scirpus atrovirens Willd. – RS; Infrequent; C = 4; BSUH 19305.

JUNCACEAE (Rush Family)

Juncus dudleyi Wieg. – RS; Rare; C = 2; BSUH 19447.

Juncus tenuis Willd. – MSW; Infrequent; C = 0; BSUH 19303.

LILIACEAE (Lily Family)

Erythronium americanum Ker Gawl. ssp. *americanum* – MSW; Rare; C = 5; BSUH 19598.

POACEAE (Grass Family)

AGROSTIS STOLONIFERA L. var. *STOLONIFERA* – RC, RS; Infrequent but locally abundant; C = 0; BSUH 19312, 19472.

BROMUS INERMIS Leyss. ssp. *INERMIS* – RC, RS; Infrequent; C = 0; BSUH 19290.

BROMUS JAPONICUS Thunb. ex Mur. – RC; Rare; C = 0; BSUH 19358.

BROMUS RACEMOSUS L. – RS; Rare; C = 0; BSUH 19386.

BROMUS TECTORUM L. – RS; Infrequent; C = 0; BSUH 19452.

Cinna arundinacea L. – FPW; Common; C = 4; BSUH 19559.

DACTYLIS GLOMERATA L. – RS; Common; C = 0; BSUH 19455.

Dichanthelium clandestinum (L.) Gould – FPW; Rare; C = 3; BSUH 19291.

DIGITARIA CILIARIS (Retz.) Kőler – RC, RS; Infrequent but locally common; C = 0; BSUH 19510, 19547.

DIGITARIA ISCHAEMUM (Schreb.) Muhl. – RS; Infrequent; C = 0; BSUH 19648.

DIGITARIA SANGUINALIS (L.) Scop. – RS; Infrequent; C = 0; BSUH 19657.

ECHINOCHLOA CRUSGALLI (L.) P. Beauv. – RC, RS; Infrequent; C = 0; BSUH 19473, 19548, 19565.

Echinochloa muricata (P. Beauv.) Fernald var. *muricata* – RC; Abundant; C = 1; BSUH 19495.

ELEUSINE INDICA (L.) Gaertn. – RC (big island), RS; Abundant; C = 0; BSUH 19491.

Elymus macgregorii R.E. Brooks & J.J.N. Campb. – FPW; Abundant; C = 3; BSUH 19359.

ELYMUS REPENS (L.) Gould – RS; Rare; C = 0; BSUH 19366.

Elymus riparius Wieg. – FPW, RC; Infrequent but locally common; C = 5; BSUH 19658.

Elymus virginicus L. var. *virginicus* – FPW, RC, RS; Common; C = 3; BSUH 19311, 19656.

Eragrostis frankii Steud. – RC; Infrequent; C = 2; BSUH 19650.

Eragrostis hypnoides (Lam.) Britton, Sterns & Poggenb. – RC; Common; C = 3; BSUH 19610.

Eragrostis pectinacea (Michx.) Nees var. *pectinacea* – RC, RS; Common; C = 0; BSUH 19493, 19546, 19651.

Festuca subverticillata (Pers.) Alexeev – MSW, RS; Common; C = 4; BSUH 19353.

Glyceria striata (Lam.) Hitchc. – SC; Common; C = 4; BSUH 19543.

(#) *HORDEUM VULGARE* L. – RS; Rare; C = 0; BSUH 19385.

Leersia oryzoides (L.) Sw. – FPW, RC; Infrequent; C = 2; BSUH 19646.

Leersia virginica Willd. – FPW, SC; Common; C = 4; BSUH 19554.

Muhlenbergia frondosa (Poir.) Fernald – MSW; Infrequent but locally abundant; C = 3; BSUH 19649.

Muhlenbergia schreberi J.F. Gmel. – RS; Common; C = 0; BSUH 19644.

Panicum dichotomiflorum Michx. var. *dichotomiflorum* – RC; Infrequent; C = 0; BSUH 19647.

Panicum philadelphicum Bernh. ex Trin. ssp. *gattingeri* (Nash) Freckman & Lelong – RC; Infrequent; C = 4; BSUH 19582, 19583.

Paspalum setaceum Michx. – RS; Infrequent but locally common; C = 3; BSUH 19310.

Phalaris arundinacea L. – RC; Rare but locally abundant; C = 0; BSUH 19352.

PHLEUM PRATENSE L. – RS; Rare; C = 0; BSUH 19365.

POA ANNUA L. – RS; Common; C = 0; BSUH 19439.

POA PRATENSIS L. – RS; Abundant; C = 0; BSUH 19456.

Poa sylvestris A. Gray – SC; Rare; C = 5; BSUH 19260.

POA TRIVIALIS L. – FPW; Common; C = 0; BSUH 19382, 19457.

SCHEDONORUS ARUNDINACEUS (Schreb.) Dumort. – RS; Abundant; C = 0; BSUH 19383.

SETARIA FABERI Herrm. – RC; Common; C = 0; BSUH 19495, 19620.

SETARIA PUMILA (Poir.) Roem. & Schult ssp. *pumila* – RC, RS; Common; C = 0; BSUH 19562.

SETARIA VIRIDIS (L.) P. Beauv. var. *viridis* – RC; Rare; C = 0; BSUH 19502.

SMILACACEAE (Carrion-flower Family)

Smilax hispida Raf. – MSW; Infrequent; C = 3; BSUH 19408.

TRILLIACEAE (Trillium Family)

Trillium sessile L. – MSW; Common; C = 4; BSUH 19431.

Trillium sessile L. f. *luteum* – MSW; Infrequent; C = 4; BSUH 19596.

XANTHORRHOEACEAE (Day-lily Family)

HEMEROCALLIS FULVA (L.) L. – RS; Rare; C = 0; BSUH 19335.

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TEMPORAL SURVEY OF A CARRION BEETLE (COLEOPTERA: SILPHIDAE) COMMUNITY IN INDIANA

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ABSTRACT. Carrion beetles (Coleoptera: Silphidae) play an important role in vertebrate decomposition as they utilize carcasses to carry out their life cycles. These beetles represent novel models for behavioral ecology, and can act as important forensic indicators in death investigations. However, population and community dynamics of silphids in Indiana are currently outdated. The aim of this study is to update surveys of a single silphid community with high temporal resolution in order to explore diversity and abundance patterns over time. Beetles were collected from Purdue University multiple times ($N = 13$) over a period of seven months in order to assess population dynamics at a single site. A total of 1607 specimens constituting seven different species were collected. Species abundance over time and space changed dramatically, and only one species (*Nicrophorus tomentosus* Weber) was present in nearly all collections (eleven out of thirteen, June–October 2014). It was demonstrated that the community dynamics of silphids at a single site in Indiana aligns with previous studies in the state. Additionally, the community structure of this family appears to change drastically over time in the summer months.

Keywords: Silphidae, carrion, forensic entomology, *Nicrophorus tomentosus*

INTRODUCTION

After death, a vertebrate carcass assumes the role of a quality, yet highly ephemeral, nutrient resource that is utilized by insects and other organisms (Benbow et al. 2015). Though blow flies (Diptera: Calliphoridae) represent the most heavily scrutinized carrion-breeders by ecologists and forensic scientists (Amendt et al. 2004), beetles can also play a critical role in the decomposition process (Dekeirsschieter et al. 2013b). In particular, carrion beetles (Coleoptera: Silphidae) utilize carcasses to carry out their life cycles and represent novel models for behavioral ecology (Ratcliffe 1996).

Silphids are widespread in North America, with recorded observations in Arkansas (Holloway & Schnell 1997), Colorado (Smith et al. 2000), Indiana (Shubeck et al. 1977; Perez et al. 2014), Iowa (Coyle & Larsen 1998), Louisiana (Watson & Carlton 2005), Michigan (Werner & Raffa 2003), Missouri (Shubeck & Schleppnik 1984), Nebraska (Ratcliffe 1996), New Jersey (Shubeck 1983), Texas (Mullins et al. 2013), and Virginia (Beirne 2013). Two subfamilies (Nicrophorinae and Silphinae) comprise this family (Anderson & Peck 1985), and can be differentiated by both morphology (i.e., body shape) and resource utilization. Nicrophorine beetles ("Burying Beetles") not only directly consume the carcass (necrophagy), but also bury it for their offspring, thereby preventing intruders from "stealing" the carcass (Trumbo 1990). In particular, nicrophorines (e.g., *Nicrophorus investigator* Zetterstedt) preferentially bury small (16–48 g) vertebrate carcasses (Smith & Heese 1995; Smith & Merrick 2001), thereby providing a protected, consistent resource on which to rear offspring. Larvae of this species are altricial, requiring one or both parents (biparental brood care) to feed them for the extent of their immature life stages. Meanwhile, silphine beetles (e.g., *Necrophila americana* Linnaeus) consume larger carcasses for feeding and will prey on other scavengers (necrophily), but do not bury carcasses or exhibit any parental care.

Members of the subfamily Nicrophorinae have been the focus of intense ecological research in the last century, as they exhibit a suite of remarkable reproductive behaviors, including communal breeding in response to competition with flies (Scott 1994), carcass modification (Pukowski 1933), and biparental care (Scott 1998). Nicrophorines also possess specialized chemosensory adaptations to efficiently locate a carcass (Dekeirsschieter et al. 2013a) and emit volatiles to kill microorganisms on the carcass (Haberer et al. 2014). In addition,

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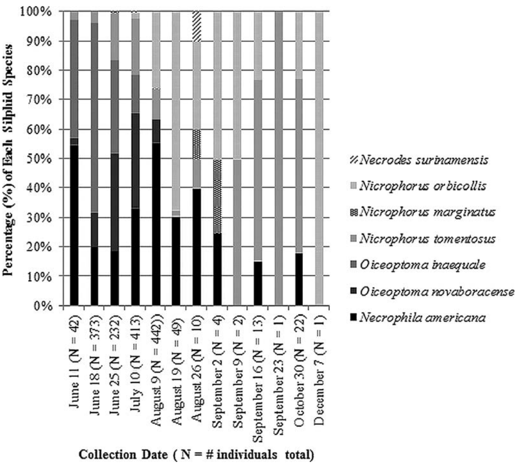

Figure 1.—Stacked bar plot showing the percentage of each silphid species (N = 7) of the total silphid abundance at Purdue University over 13 collection periods.

nicrophorines exhibit complex ecological and evolutionary associations with phoretic mites in which the beetle acts as a vehicle to transport up to hundreds of mites to ephemeral resources, including carcasses. The mites, in turn, may consume eggs or larvae of competitors (Springett 1968; Wilson 1983; Schwarz & Müller 1992).

The population dynamics of common silphids have been previously investigated in other regions, including *Nicrophorus americanus* Olivier in Arkansas (Holloway & Schnell 1997), Indiana (Shubeck et al. 1977), and particularly populations of *N. investigator* in Colorado (Smith & Heese 1995; Smith et al. 2000; Smith & Merrick 2001). Silphid population sizes tend to be significantly correlated with small mammal biomass (Holloway & Schnell 1997; Smith & Merrick 2001). The purpose of this study was to re-assess a community of silphids that had been surveyed many years prior at Purdue University (West Lafayette, IN) (Shubeck et al. 1977). Results of this study are compared to what was previously found at the Purdue site, as well as results from a nearby site seeded with 53 pig (*Sus scrofa* Linnaeus) carcasses in Rensselaer, IN (Perez et al. 2014).

MATERIALS AND METHODS

Silphids were sampled from the FERC (Forensic Entomology Research Center) at Purdue University from June to December 2014. Beetles were collected passively via pitfall traps consisting of a plastic 6-quart (5.7 L) storage box filled with approximately 5 cm of pet-friendly RV & marine antifreeze (Super Tech®) and baited with approximately 500 g aged chicken liver and blood in a 710 mL plastic food storage container. This apparatus was buried flush with the surface of the ground and covered with chicken wire to exclude scavengers, and covered with an aluminum roof approximately two inches above ground to protect the trap from rain. Three pitfall traps were placed at approximately 15 m intervals and were checked every week in June and July 2014, and every two to three weeks thereafter for a total of 13 collections.

At each collection, antifreeze containing trapped insects was filtered through a 20 cm diameter 88 mesh strainer and stored in 95% ethanol. Traps were reset with aged chicken liver bait, and filled with clean antifreeze. Silphids were identified to species via morphological taxonomy (Anderson & Peck 1985; Mullins et al. 2013), counted, and stored at –20° C. Temperature data (average, maximum, and minimum (° C)), for each site was posteriorly collected from archived historical weather data (www.wunderground.com). Specimens are vouchered at the Purdue Entomology Research Collection.

Statistics were performed in R using standard packages (R Core Team 2015), as well as the vegan package for biodiversity statistics (abundance, species richness, Simpson's index of diversity, and Jaccard's similarity coefficient) (Oksanen et al. 2015).

RESULTS

A total of 1607 silphids were collected from June to December 2014 (Fig. 1). Seven silphid species were collected (*Necrodes surinamensis* (Fabricius), *Necrophila americana* (Linnaeus), *Oiceoptoma novaboracense* (Forster), *Oiceoptoma inaequale* (Fabricius), *Nicrophorus marginatus* (Fabricius), *Nicrophorus orbicollis* (Say), and *Nicrophorus tomentosus* (Weber).

The summer months of June – August exhibited the greatest abundance of silphids (N = 543), as well as the highest average species richness (*R* = 5.28). Simpson's Index of Diversity (*1-D*) was greatest for late June/early July (*1-D* = 0.751), and late August (*1-D* = 0.720) when temperatures averaged 22.2° C (9.4 – 30.6° C) and 24.4° C (15.6 – 31.7° C), respectively. These dates also clustered together using Jaccard's

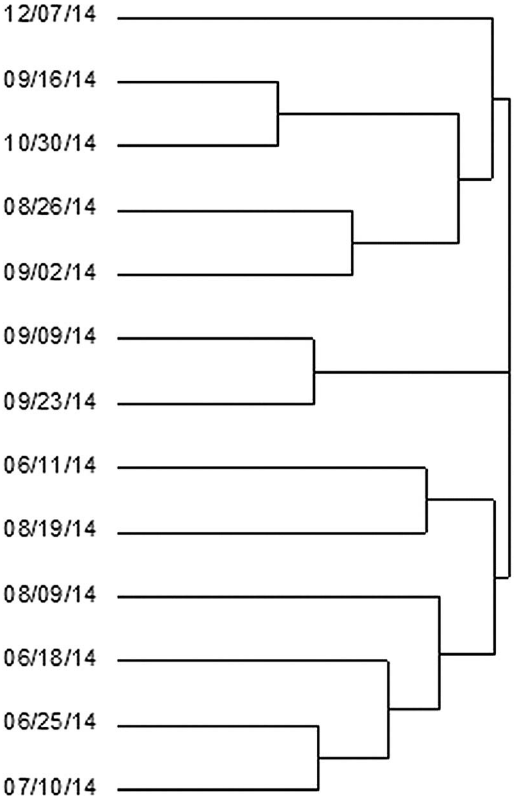

Figure 2.—Dendrogram representing Purdue University site collection dates clustered by number of shared species.

Index (clustering between sites based on shared species), whereas dates of low abundance and low diversity also clustered together (Fig. 2). Silphid abundances were as follows: *Np. americana* (N = 551, June – October), followed by *O. inaequale* (N = 386, June – August), *O. novaboracense* (N = 293, June – August), *N. tomentosus* (N = 199, June – October), *N. orbicollis* (N = 171, August – December), *N. marginatus.* (N = 5, June, August – September), and *Ne. surinamensis* (N = 2, July, August).

DISCUSSION

Silphid species sampled in this study corresponded to those reported previously by Shubeck et al. (1977), except for the absence of *Nicrophorus pustulatus* (Herschel) in our survey. Shubeck et al. (1977) observed *O. novaboracense* as the most prominent species (N = 2033, April – July), followed by *O. inaequale* (N = 756, April – July), *Np. americana* (N = 572, April – July), *N. orbicollis* (N = 318, August – September), *N. tomentosus* (N = 201, June – July), *Ne. surinamensis* (N = 25, June – July), and *N. pustulatus* (N = 13, June – September). Though rank order differs slightly, both Shubeck et al. (1977) and the current study show that the subfamily Silphinae predominates this region in early to mid-summer, and is replaced temporally by the Nicrophorinae from mid-summer to fall. Silphid diversity in the current study also aligns with observations made from 53 pig carcasses at Rensselaer, IN (Perez et al. 2014), the only discrepancy was that *O. inaequale*, was observed in our study but not in theirs.

The American Carrion Beetle, *Np. americana,* was the most predominant species collected (N = 551), and was present from mid-June to early October. This ground-dwelling silphid, with its preferences for an open-field habitat (Shubeck 1983), arrives at carcasses in late spring to early summer (Anderson 1982), and may arrive early in decomposition (Tabor et al. 2004). Collections of *Np. americana* have been made with carrion-baited pitfall traps (Coyle & Larsen 1998; Shubeck 1983; Werner & Raffa 2003), carcasses (Tabor et al. 2004), and isopropanol-baited pitfall traps (Reut et al. 2010). Two *Oiceoptoma* species (*O. inaequale* and *O. novaboracense*) comprised the second and third most abundant silphid sampled, but were only present from June to August. This genus appears 2–3 days after carcass deposition and can remain on or near remains until advanced decay (Tabor et al. 2004). Patterns of *Oiceoptoma* spp. sampled here align with those seen for *O. inaequale* and *O. novaboracense* in New Jersey, as they are most active in the early part of the summer and decline in abundance thereafter (Shubeck 1983). Though *N. tomentosus* was not the most abundant silphid overall, it was the most prevalent species in its subfamily, appearing at 11 of the 13 collections. This species has been speculated to be the "most active" species in this genus, as it may exhibit a broad flight range when searching for a carcass (Shubeck 1983). According to these collection data, *N. tomentosus* emerges in mid-late June and reaches peak abundance in August and September, a pattern that aligns with Anderson (1982).

Overall, this study demonstrated that silphid beetle communities exhibit consistent interannual diversity and abundance patterns for this site. Additional molecular analyses of silphid communities and individual species in the Midwest would greatly improve upon this work and would shed light on the population genetic structure of carrion beetles. A community-based molecular approach to track changes in allele frequencies over time could give insight into why population dynamic patterns do not vary over time.

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130TH ANNUAL ACADEMY MEETING[1]

Presidential Plenary Address by Arden L. Bement Jr.[2]

"CONNECTIVE PATHWAYS IN SCIENCE"

INTRODUCTION

I have chosen "Connective Pathways in Science"' as my topic this morning for a particular reason. Just as dark matter drives the acceleration of the expansion of the universe, connections are the driving force for accelerating the pace of scientific and technological advancement. Such connections make available exchanges of a broad diversity of opinions, concepts, and perspectives; stimulate new discoveries; create still more knowledge; and drive still more scientific and technological advancement. It's an autocatalytic process that makes us all more knowledgeable.

An appropriate starting point for this presentation is the mission of the Indiana Academy of Science, which is now 130 years young:

- Promoting scientific research and diffusing information connects the various science communities in Indiana and also connects these communities with the public at large;
- Encouraging communication and cooperation among scientists promotes collaborations and the discovery of new concepts; and
- The improvement of education in the sciences provides generational connections between Academy members and aspiring young scientists.

CONNECTIONS IN A CONTRACTING WORLD

The world is shrinking figuratively due to advances in communications and information technologies and the ease of international travel. An increasing number of the world's universities aspire to become international universities. In the United States the growth in international students, foreign-born faculty members, study abroad programs, international collaborations, and joint publications has already accomplished this.

Furthermore, the growth of large-scale, virtually-connected, research facilities; the open exchange of information and courseware; and the harmonization of curricula and degree programs support growth in the international connectivity of STEM fields.

Most countries in the world now view science and technology as an engine for economic growth and have increased investments in higher education and research. The BRIC nations and emergent economies in Central and South America, Africa, The Middle East and the Far East are beginning to 'get it'; that it is far more important to build their own higher education and research base in order to solve their own problems than to rely on foreign assistance.

Universities in these countries are increasing their numbers of PhD faculty to increase research capacity. Their governments are increasing research grants to support academic research at home and collaborations with top researchers and members of their diaspora at leading world universities. The overall strategy is to both broaden their economic base beyond a current primary dependence on natural resources and export more high-value added products.

As a result the fraction of the world's research being done in the U.S., which is now estimated to be about 30%, is expected to decline to about 20% by 2020. Likewise, the number of U.S. universities ranked in the top 100 of the world's universities, now about 50, will likewise steadily decrease, especially those that are STEM intensive. Therefore, connectivity with the top researchers and universities in the world will be an imperative to avoid becoming 'blindsided' to important new scientific discoveries and technological innovations occurring abroad. As mentioned in my introduction it will also be a key driver for scientific advancement in the U.S.

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[1] J.W. Marriott, Indianapolis, IN, 21 March 2015.

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CONNECTIONS IN ADDRESSING GRAND CHALLENGE GLOBAL ISSUES

Global issues abound in the world today. A few examples include sustainable energy, global warming, disruptive natural events, world hunger, pandemics, loss of biodiversity, invasive species, and failed states (Yemen being the latest example).

Each of these global issues is highly complex. The interrelationships among them compound this complexity. For example, sustainable energy is connected with sustainable ecology and a sustainable economy. The growing intensity of weather events is connected with global warming, which in turn is connected with carbide dioxide emitted from fossil fuel burning to generate electric power. Food production and processing to meet the needs of a burgeoning world's population is energy intensive, challenged by invasive species, and consumes 70% of the world's available fresh water. Likewise, growing high-water-content crops, such as tomatoes and cucumbers, and raising livestock in arid countries using water obtained by energy-intensive desalination is not as economically viable as importing these foods from other countries where water is plentiful.

Solutions to these problems by technical approaches alone are insufficient. One must also consider a wide range of social, behavioral, historical, and economic contexts. For example, the chlorination of water is resisted in some societies where water is regarded sacred. Also, pumping potable water is not helpful if it is stored and consumed in contaminated containers where sanitation training is lacking. Scientists and engineers who advocate normative approaches to these problems without taking contextual factors and safeguards into account do a disservice to society.

These are so-called 'nasty' or 'wicked' problems because long-range predictions are unlikely … only projections over limited time steps. Also, there may not be a 'best' solution but several competing solutions that may require political choices.

CONNECTIONS IN RESEARCH AND LEARNING

For three or four decades the major emerging technologies worldwide have been information technology, biotechnology, and nanotechnology. Lately, neurotechnology has been added. One now finds a number of new fields of science and engineering emerging from the interdisciplinary connections among these technologies; such as biometrics, bioinformatics, nanobioscience, nanobiotoxicology, and many more.

However, I should note as director of the National Science Foundation during the first decade of this century when I asked visiting ministers of science and education what their priorities were they invariably responded info-, bio-, and nanotechnologies. However, as the world recession set in their priorities shifted to innovation and entrepreneurship.

As educators began wrestling with the problem of teaching these subjects, they found that mentoring students by seasoned innovators and entrepreneurs through activity-based, self-based, and peer-based learning was far more effective than instructor-based learning solely in the classroom.

Some universities, Purdue University included, are now inverting their approach to STEM education by better integrating all modalities of learning. Students now study pre-distributed instructor's lectures augmented by self-learning on the Internet in their pajamas. They do their homework in class in a team setting mentored by their instructor and teaching assistant to stimulate peer learning. Students no longer have to pretend to be awake in the classroom or lecture hall.

CONNECTIONS IN COGNITION

The reverse engineering of the brain is one of the fourteen grand challenges for the 21st Century identified by the National Academy of Engineering. This challenge may be closer to realization than most people might suppose. With the near advent of exoflop, quantum, and synaptic computing, it will soon be possible to 'cyber-model' the human brain down to the synaptic level.

Synaptic computing based on a neural network chip introduced last year by IBM and the synthesis of 'Big Data' using tailored algorithms and parallel servers have already demonstrated some attributes previously reserved to the human brain; such as, self-awareness, pattern recognition, and prediction.

It might soon be possible to discover natural pathways between the human brain and high-capacity computers, smart devices, and anticipatory controllers to accelerate coupled analysis, decision-making, and conceptualization. Also, through applying 'Big Data' tools designed for open innovation, the self-organization of more effective teams and organizations for tackling education, research, and innovation challenges can result.

With the resulting time compression made possible by these new methodologies, the pace of creativity and innovation might outpace even the imagination of science fiction writers.

CONNECTIONS AMONG THE FORCES OF NATURE

In March of 2014 scientists who had been observing the cosmic microwave background with a microwave telescope at the South Pole announced the discovery of gravity waves that formed in less than a quintillionth of a second after the 'Big Bang'. This observation not only pointed to connections between quantum theory and the general theory of relativity but also the unification of the gravitational force with electromagnetic, strong nuclear, and electroweak forces before the highly dense seed of our universe became unstable and erupted into the 'Big Bang. It further provided indirect evidence of multiple universes.

This discovery would be an automatic candidate for a Nobel Prize. However, since the announced level of confidence of this discovery, although encouraging, has been challenged several research teams around the world are actively conducting experiments to either confirm or refute the claim. We should soon know their findings.

A year earlier, in March of 2013, the discovery of the Higgs boson, the key to unlocking some conundrums in sub-atomic physics, was tentatively confirmed by CERN. Unfortunately, supersymmetry or 'Susy' particles, which should have been observed at the then existing collision energy were not observed.

Supersymmetry theory is a key link for connecting quantum physics with classical physics. It provides needed credibility for string theory and an elegant pathway for explaining electroweak symmetry breaking and the high energy interactions among weak, strong, and electromagnetic forces, all important to the 'Theory of Everything' advanced by Stephen Hawking. If 'Susy' particles exist, especially the neutralino', the big sister of the neutrino, they would be prime candidates for the 'dark matter' driving the accelerated expansion of the universe.

Unfortunately, 'Susy' has been in the hospital waiting for a doubling of the LHC collision energy to renew the search for her particles. This search will recommence this spring. Discoveries of 'Susy' particles will not only provide needed confirmation for the connections just mentioned, they will lead to the greatest connection between theoretical and experimental physics in the history of science.

But … what if Susy particles are not discovered under experimental conditions where they certainly should be? In this case 'Susy' will make a short trip from the hospital to the morgue and theoretical physicists around the world will have to push a 'reset button' and start over.

FINAL REMARKS

With this short list of connections I am not trying to demonstrate that scientists are living in interesting times. You already know this from your own fields of interest. Rather, I am trying to drive home a different point.

Scientists and engineers in Indiana such as you are making important connections in science, such as I outlined in this talk. For example our membership over the past decade has included two Nobel Laureates and a Medal of Technology and Innovation Laureate:

- The late Elinor Ostrom from Indiana University received her Nobel Prize in Economic Sciences for advancing our understanding of resource management, the governance of local public institutions, and the 'tragedy of the commons'.
- Ei-ichi Negishi from Purdue University received his Nobel Prize in Chemistry for developing chemical reaction pathways for synthesizing complex organic compounds used in a broad range of applications.
- Rakesh Agrawal also from Purdue University received his National Medal of Technology and Innovation for improving the energy efficiency of gas liquefaction and the separation of industrial gases from air, which resulted in over 500 international patents.

Physicists at Purdue University have also made important contributions to the design and operation of the CMS detector at CERN, which was key to the discovery of the Higgs boson.

Likewise, your many scientific achievements have not only contributed to a better understanding of nature by Indiana citizens, but also addressed Indiana's grand-challenge issues and inspired young aspiring scientists throughout the state.

I am inviting you to increase the strength and representation of our sections by inviting into our ranks such remarkable scientists, colleagues, prospective young aspiring scientists and classmates who understand the importance of connective pathways in science and what they can mean for our future.

I joined the Indiana Academy of Science because I wanted to be connected with scientific developments in Indiana and to meet young aspiring scientists as they present their research and make connections that might prove valuable in their career.

I hope you will invite prospective members to visit our web page. The value proposition of what the Academy can do for them and what they can do for the Academy is clearly explained on the application form. By helping to build our membership you will be strengthening its connective driving force for the 21st Century.

Thank you

Arden Lee Bement, Jr., PhD, 2014–2015 Indiana Academy of Science President. Arden L. Bement, Jr. is an American engineer and scientist and has served in executive positions in government, industry and academia. He is a former Deputy Undersecretary of Defense for Research and Advanced Technology, Chief Technical Officer of Technical Resources and of Science and Technology (TRW), Director of the National Science Foundation (NSF), and Director of the National Institute of Standards and Technology (NIST). Following the end of his six-year term at NSF, he became the founding director of the Global Policy Research Institute and Chief Global Affairs officer at Purdue University. He is currently serving on the Science Advisory Council of the Skolkovo Foundation, the Board of Trustees of the Skolkovo Institute of Science and Technology, the Board of Visitors of the National Intelligence University, and the Board of Trustees of Radian Research Inc. He is also a retired lieutenant colonel of the United States Army Corps of Engineers.

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MINUTES OF THE BUSINESS MEETING
SATURDAY, MARCH 21, 2015
JW MARRIOTT, INDIANPOLIS, IN

The meeting was called to order at 5:20 pm

President **Arden Bement** called the meeting to order and welcomed everyone. He thanked the attendees for participating in the meeting.

President Arden then brought the bylaw change recommended by the Council pertaining to section leadership to the membership for a vote to amend the bylaw (printed below).

Proposed Bylaw for Article IX, Section 3: Each section shall have a chair to preside at meetings and to contact section members when necessary and a vice chair who will act in place of the chair and accede to chair if necessary. The vice chair shall be elected in the section business meeting at each annual meeting to serve one year as vice chair (chair-elect) and then one year as chair. If necessary the President may appoint a chair to a section without a chair or vice chair.

Arden called for a vote. The proposed bylaw passed by voice vote.

Following the vote to amend the bylaws, the section chairs reported on the activities of the section meetings during the day and named section chairs and vice chairs for 2015–2016.

Anthropology
Chair – **Robert Mahaney**
Vice Chair – **Helen Brandt**

Botany
Chair – **D. Blake Janutolo**
Vice Chair – **Darrin Rubino**

Cell Biology
Chair – **Jennifer Kowalski**
Vice Chair – **Eric Rubenstein**

Chemistry
Chair – **Jennifer Holt**
Vice Chair – **Mahamud Subir**

Earth Science
Chair – **James Farlow**
Vice Chair – **Solomon Isiorho**

Ecology
Chair – **Jason Hoverman**
Vice Chair – **Elizabeth Flaherty**

Engineering
Chair – **Terry West**
Vice Chair – **Nils I. Johansen**

Environmental Quality
Chair – **Charles G. Crawford**
Vice Chair – **Aubrey Bunch**

Microbiology and Molecular Biology
Chair – **David Treves**
Vice Chair – **Pamela Pretorius**

Physics and Astronomy
Chair – **Eric Hedin**
Vice Chair – **Antonio Cancio**

Plant Systematics and Biodiversity
Chair – **Scott Namestnik**
Vice Chair – **Alice Heikens**

Science Education
Chair – TBN
Vice Chair – TBN

Zoology and Entomology
Chair – **Brad Poteat**
Vice Chair – **Kristi Bugajski**

Following section reports, the results of the elections for officers and committee members were announced:

President Elect – **Darrin Rubino** (2015-2016)
Secretary – **Vanessa Quinn** (2015-2018)
Foundation Committee – **Stan Burden** (2015-2018)
Council Member – **Horia Petrache** (2015-2017)
Research Grants – **Darrell Schulze** (2015-2018)
Research Grants – **James Mendez** (2015-2018)

The date of the next annual meeting of the Indiana Academy of Science was announced to be

March 26, 2016, at the JW Marriott in Indianapolis.

President Arden Bement introduced the incoming President **Mike Homoya** and passed the gavel.

President- Elect Mike Homoya then made a few comments and thanked Arden for leadership during the past year and **Delores Brown** for organizing and planning the meeting. He said he looks forward to being president.

The meeting was adjourned at 5:49 pm. A wine and cheese reception followed.

Respectfully submitted,
Mike Foos
IAS Secretary

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INDIANA ACADEMY OF SCIENCE
2015 Year End Financial Report

	Balance 1-Jan-15	Revenues	Expenses	Balance 31-Dec-15
OPERATING FUND				
Dues		19,350.00		
Interest		17.07		
Misc. Income		390.62		
Contributions		6,257.44		
Annual Meeting		35,288.84		
Foundation Support		153,851.31		
Officer's Expenses			142,201.61	
Operating Expenses			15,964.97	
Financial Expenses			4,268.43	
Newsletter Expenses			0.00	
Annual Meeting			82,528.70	
Academy Store		0.00	0.00	
Web Site Expenses			11,375.48	
Operating Funds Total	108,513.42	215,155.28	256,339.19	67,329.51
RESTRICTED FUNDS				
Proceedings	14,492.06	36,757.97	29,568.97	21,681.06
Publications	(49,292.24)	3,323.36	27,626.36	(73,595.24)
Research Grants*	10,511.31	79,002.44	78,214.79	11,298.96
Lilly Library	6,756.47	0.00	0.00	6,756.47
Welch Fund	6,108.56	0.00	3,121.00	2,987.56
Life Member's Fund	14,343.61	0.00	0.00	14,343.61
Past President's Fund	8,599.17	75.00	0.00	8,674.17
Special Projects	1,040.55	5,375.00	11,375.00	(4,959.45)
Total Restricted Funds	12,559.49	124,533.77	149,906.12	(12,812.86)
TOTAL FUNDS	**121,072.91**	**339,689.05**	**406,245.31**	**54,516.65**
FUNDS ON DEPOSIT				
Checking Account	31,070.00	459,863.19	472,509.27	18,423.92
Money Market Savings Account	50,153.38	80017.07	89,000.00	41,170.45
Cert. of Deposit	13,323.52	200.24		13,523.76
TOTAL FUNDS DEPOSITED	**94,546.90**			**73,118.13**

* Provided support for 28 senior member grants and 3 high school grants

ACADEMY FOUNDATION FUNDS				
TOTAL FOUNDATION FUNDS	**8,552,292**			**8,543,914**

Foundation Funding Used For	
Operating Fund	153,851.31
Proceedings	29,493.97
Grants	94,355.54
Special Projects	5,375.00
Total	**283,075.82**

Michael S. Finkler
Treasurer

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