## CONTENTS

*Proceedings* of the Indiana Academy of Science

**Volume 123 Number 2 2014**

*Earth Science*

*Ecology*

*Plant Systematics and Biodiversity*

*Zoology*

*2014 Academy Business*

*Proceedings* of the INDIANA ACADEMY OF SCIENCE 2014 VOLUME 123, NUMBER 2

INDIANA
ACADEMY
of SCIENCE
1885

# *Proceedings* of the Indiana Academy of Science

VOLUME 123 2014 NUMBER 2

# *PROCEEDINGS* OF THE INDIANA ACADEMY OF SCIENCE

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

## THE INDIANA ACADEMY OF SCIENCE

*EXCHANGE ITEMS:* Items sent in exchange for the *Proceedings* and correspondence concerning exchange arrangements should be sent to the Indiana Academy of Science, John S. Wright Memorial Library, 140 North Senate Avenue, Indianapolis, Indiana 46204. Questions regarding back issues or undelivered issues should be addressed to Jocelyn R. Lewis at jlewis2@library.in.gov. Telephone (317 232-3686).

*Cover*: The Green Treefrog (*Hyla cinerea*) is a resident of the southeastern United States where it inhabits sloughs, bayous, and adjacent uplands. Green Treefrogs are slender and typically bright green in color, with distinct whitish stripes running along each side of the body from the lip to around the groin. Small, yellow spots frequently occur on the dorsum. The frog's bright green color helps it blend in with the surrounding vegetation in which it often seeks refuge during daylight hours. Green Treefrogs have been found at an increasing number of sites along the northern periphery of their range in the Midwest and were first documented in Indiana in 2003. The individual on the cover was photographed in Point Township, Posey County, Indiana, on 24 June 2009.

Visit the Indiana Academy of Science website at:
www.indianaacademyofscience.org

Publication date: 16 September 2015

**This paper meets the requirement of ANSI/NISO Z39.48-1992 (Permanence of Paper).**

**ISSN 0073-6767**

---

## INSTRUCTIONS TO AUTHORS

*(revised March 2015)*

**General information.**—Manuscripts and all correspondence should be sent to the Editor. To be eligible for publication in the *Proceedings* at least one author must be a member of the Academy. Submission of a manuscript to the Editor implies that it has not been sent to another publication, nor has it been published elsewhere. If it is accepted for publication in the *Proceedings,* it may not be republished without the written consent of the Academy.

All manuscripts are evaluated by referees. Manuscripts may be submitted as a .doc file in 12-point New Times Roman font by e-mail or by mail on a CD. Figures should be saved in 300-dpi TIFF format in the size they should appear in the published article. Galley proofs will be e-mailed to the primary author for approval and correction.

**Voucher specimens and permits.**—Voucher specimens of species used in scientific research should be deposited in a recognized scientific institution. Authors must indicate that the collection of specimens, especially threatened or endangered species, was authorized by the appropriate governmental organization. Those making identification of specimens should be identified.

**Cover Sheet:** To include Corresponding author's name, E-mail address, Title of Manuscript, Principal area of relevance, secondary area of relevance. The author should also include the names and e-mail addresses of three potential reviewers.

**Follow guidelines on the Allen Press web site.**—At allenpress.com under Resources go to Education Library and use information in Guide to Manuscript Preparation.

**Running head.**—The author's surname(s) and an abbreviated title should be typed all in capital letters and must not exceed 60 characters and spaces. The running head should be placed near the top of the title page.

**Title page.**—The title page should include (1) the title in capital letters, (2) each author's name and address, (3) the running head, and (4) the complete name, address, and telephone number, fax number, and e-mail address of the author with whom proofs and correspondence should be exchanged.

**Abstract.**—All manuscripts have an abstract that should summarize the significant facts in the manuscript. The "ABSTRACT" heading in capital letters should be placed at the beginning of the first paragraph set off by a period. Use complete sentences, and limit the abstract to one paragraph and no more than 250 words.

**Keywords.**—Give 3–5 appropriate keywords.

**Text.**—Double-space text, tables, legends, etc. throughout, printing on only one side of the page. Three categories of headings are used. The first category (INTRODUCTION, RESULTS, etc.) is typed in capitals, centered, and on a separate line. The second (lower) category of heading, in bold type, begins a paragraph with an indent and is separated from the text by a period and a dash. (This paragraph begins with an example of this heading.) The third heading category may or may not begin a paragraph, is italicized, and is followed by a colon. (The paragraph below is an example.) The metric system must be used unless quoting text or referencing collection data. Hectare [ha] is acceptable.

*Citation of references in the text:* Cite only papers already published or in press. Include within parentheses the surname of the author followed by the date of publication. A comma separates multiple citations by the same author(s) and a semicolon separates citations by different authors, e.g., (Smith 1990), (Jones 1988; Smith 1993), (Smith 1986, 1987; Smith & Jones 1989; Jones et al. 1990). List citations within a set of parentheses in chronological order, not alphabetical order (see above). Also, in citations with two authors, use "&", not the word "and" (see above).

**Conclusions.**—Do not have a conclusions section. This information should be in either the abstract or the discussion.

**Literature cited.**—Use the following style, and include the full unabbreviated journal title. Repeat the name for multiple references by the same author. Note that book titles have the first letter of each word capitalized. Unless citing a section of a book, pamphlet or report, include the number of pages in the publication. For examples of journal article citations, book citations, chapter/section of a book citations, and website citations, see Instructions to Authors on the Indiana Academy of Science's webpage.

**Footnotes.**—Footnotes are permitted only on the first printed page to indicate current address or other information concerning the author. These are placed together on a separate page at the end of the manuscript. Tables and figures may not have footnotes.

**Tables.**—These should be double-spaced, one table to a page, and numbered consecutively. Most tables contain only three horizontal lines (see recent issues for examples). Do not use vertical lines, boxes, or shading. Include all pertinent information in the table legend at the top of the table (no footnotes).

**Illustrations.**—Figures submitted electronically should be at least 300 dpi in JPEG or TIFF format. You may pre-submit illustrations to Allen Press to be certain that they meet publication standards. Go to http://verifig.allenpress.com. The password is figcheck. Figures should be arranged so that they fit (vertically and horizontally, including the legend) the printed journal page, either one column or two columns, with a minimum of wasted space. When reductions are to be made by the printer, pay particular attention to width of lines and size of lettering in line drawings. Multiple photos assembled into a single plate should be mounted with only a minimum of space separating them. In the case of multiple illustrations mounted together, each illustration must be numbered (1, 2, etc.) rather than given letter (a, b, etc.) designations. In paper manuscripts for review, photocopies are acceptable, and should be reduced to the size that the author prefers in the final publication. Color plates can be printed; but the author must assume the full cost, currently about $600 per color plate.

Legends for illustrations should be placed together on the same page(s) and separate from the illustrations. Each plate must have only one legend, as indicated below:

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.

**Page charges and reprints.**—There are no page charges, but at least one of the authors must be a member of the Academy. Corrections in proof pages must be restricted to printer's errors only; all other alterations will be charged to the author (currently $3 per line).

Reprints are available only through Allen Press and should be ordered (with payment) when the author receives an email from the press.

2014. Proceedings of the Indiana Academy of Science 123(2):95–102

# A CONCEPTUAL MODEL FOR ASSESSMENT OF CLIMATE EXTREMES THAT AFFECT CORN YIELDS

**Ernest M. Agee**[1] and **Samuel Childs**: Department of Earth, Atmospheric & Planetary Sciences, Purdue University, West Lafayette, IN 47906 USA

**ABSTRACT.** The USA Corn Belt was examined to assess the impacts of observed climate change on corn production for the period 1960–2012. Given a modified definition of a Corn Belt State, 13 states were included in the study. Temperature and precipitation trends during the growing season (April–September) showed the following: a) slight warming of 0.73°F, b) increase in growing season of 9 days, and c) mean precipitation increase of 5.51 cm (2.17 in), which along with technological advancements, support the observed increase of 1.7 bushels per acre per year for the period. A conceptual model assessed the impacts of extreme weather and climate on corn yields in bushels per acre. This model is represented by an Upper Bound (based on technological advancements), and a Lower Bound that is defined as the difference between the mean production and the Upper Bound. All values that fall below the Lower Bound were defined as extremely poor yields that can be attributed to extreme weather and climate events. The model was applied to the entire Corn Belt Region for the period 1960–2012. The years 1983, 1988, 1993, and 2012 were identified as extreme events (which are well-recognized in the agroeconomic community). The benchmark model framework can be extended through the 21st century to monitor the number of extreme events and the magnitude of their departure from the Lower Bound, and it is presented as an instrument for assessing climate change impacts on corn yields.

**Keywords:** Corn Belt, extreme weather/climate, yields

## INTRODUCTION

The "Corn Belt" of the United States of America (Fig. 1) is a region of the world known for food production (see Kucharik & Ramankutty 2005). The soil constituents, combined with a favorable climate, have made this area a highly productive food source region for humankind for over five decades. Increasing corn yields from this area are well-recognized, which can be largely attributed to technological advancements. Genetic improvements and enhanced mechanization in the 1930s started the climb in corn yields that achieved record maxima in 1960 and again in 1982 (Thompson 1986). An important question, that continues to gain attention, focuses on the potential role of climate change on corn yields (including current climate trends as well as the prediction of continued global warming through the 21st century). Kaufmann & Snell (1997) estimate that 19% of the variability in corn yield is due to climate variables, and approximately 74% is explained by technology and related factors (such as fertilizers, pesticides, seed varieties, planting methods, labor, and capital). Lobell & Asner (2003) used county level USDA yield information from 1982 to 1998 to study the impacts of climate change on the overall trends in crop yields. They concluded that previous estimates of increased corn yields attributed to technological advances were overestimated by approximately 20% due to climate-driven increases in yield.

It is further noted that the complexity in explaining the various causes of rising corn yields is somewhat difficult. Sacks & Kucharik (2011) have provided a nice overview of this complexity and the contributions of many factors, such as earlier planting dates due to an increase in the number of Growing Degree Days (GDD) necessary for corn maturation. Additional intricacies include the factors that affect leaf and plant development, as well as the grainfill period. Realizing these and other complexities, this analysis presents a somewhat simple approach to separate direct climate effects (i.e., trends in temperature, length of the growing season, and precipitation in the Corn Belt) from all other factors. Specifically, a conceptual model is developed and implemented with observational data to estimate the

---

[1] *Corresponding author:* Ernest M. Agee, 765-494-3282 (phone), eagee@purdue.edu.

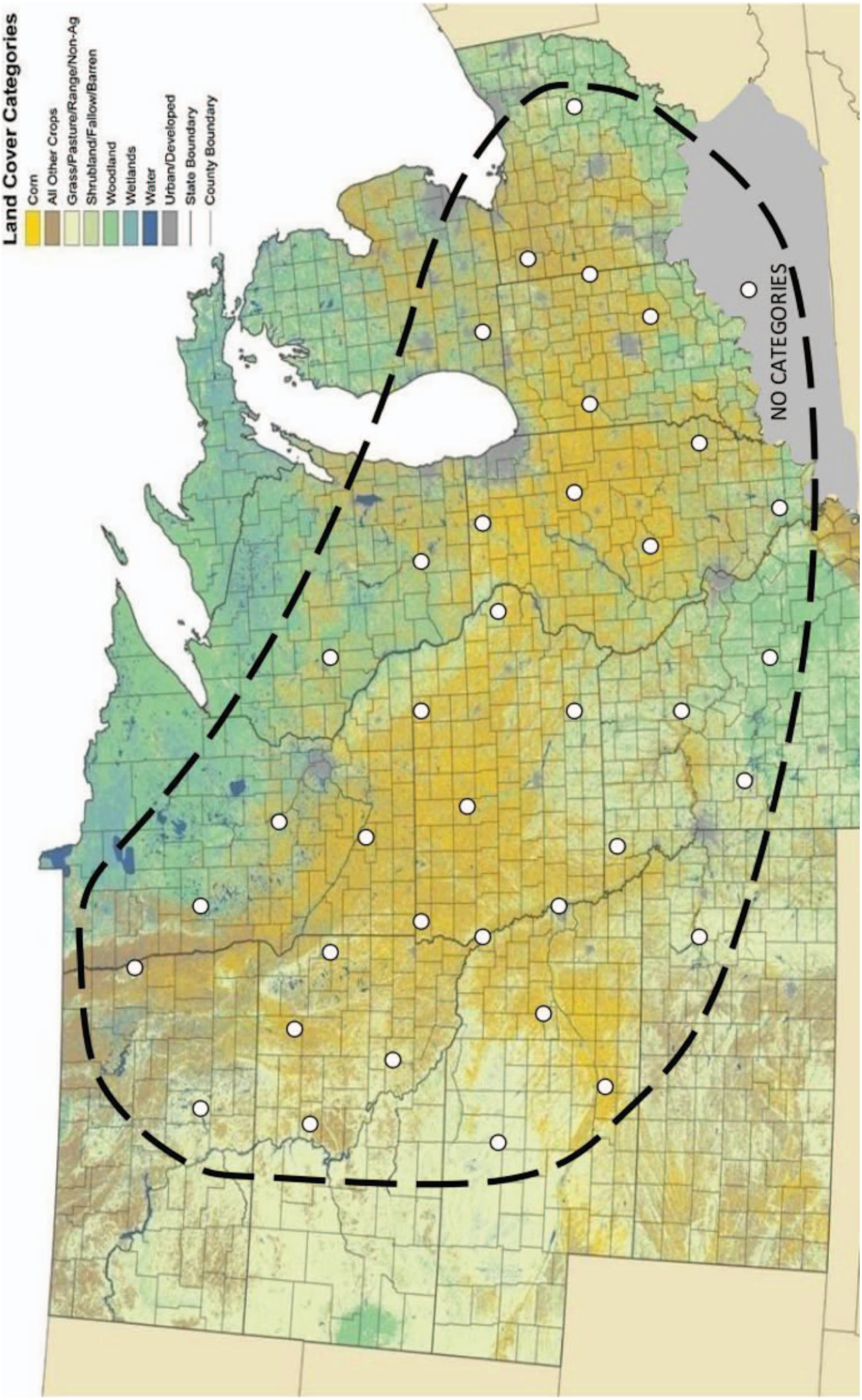


Figure 1.—Land Cover Categories for the Corn Belt region (see http://www.esri.com/mapmuseum/mapbook_gallery/volume24/images/agriculture2_lg.jpg). This study has defined the "Corn Belt Region" to include the states that averaged more than 150,000,000 bushels of corn per year for the 2000–2009 decade. A dashed line has been drawn to show the region, as well as the location of the 38 stations selected for the study.

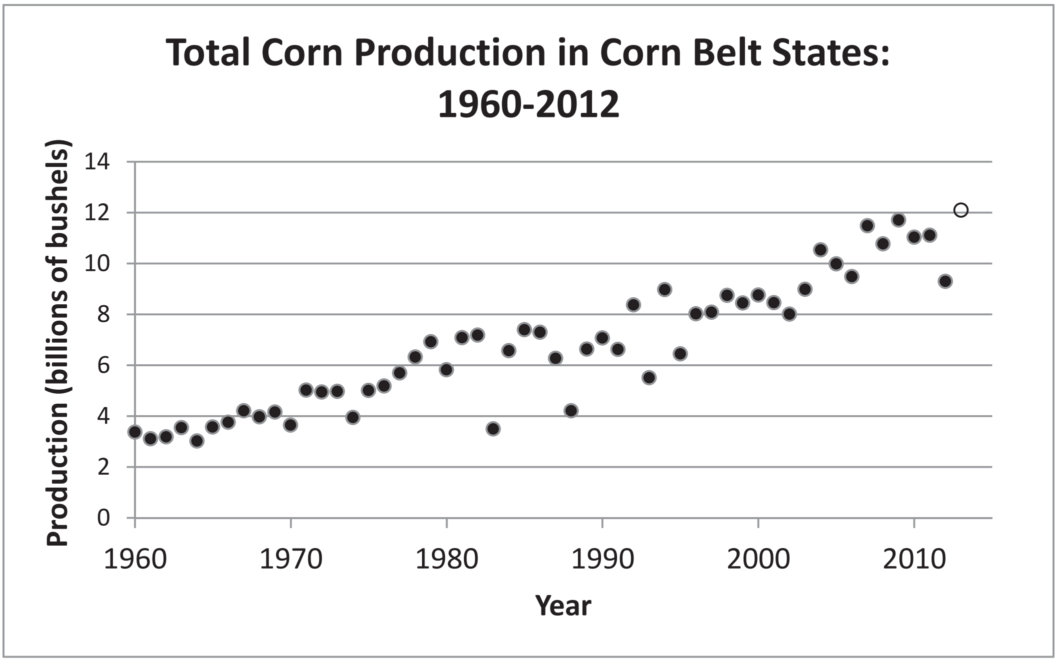


Figure 2.—Total annual corn production (bushels) in the 13-state Corn Belt Region for the period 1960–2012 (NASS 2014). A new record productivity is denoted for 2013 with an open circle.

roles played by technology advancements, mean weather and climate conditions, and extreme weather events, on a climate time scale.

## ASSESSMENT OF WEATHER AND CLIMATE EFFECTS

The Corn Belt Region for this study includes any state that exceeded an average annual yield of 150 million bushels for the decade 2000–2009. This resulted in the inclusion of 13 states, including North Dakota, which has not frequently been included in past studies (e.g., Kucharik 2006). Figure 1 shows the vegetative cover for the Corn Belt (identified by the dashed line), as well as the location of 38 stations selected for compiling the climatic data set. These stations have a mean minimum spacing of 145 km, with an average departure from this mean of 20 km. Efforts were made to avoid the clustering of data points, as well as to maintain equal spacing. Annual corn yield data were taken from the USDA's National Agricultural Statistics Service to assess trends through time (NASS 2014). Figure 2 is presented to show the total annual production in the 13-state Corn Belt Region for the period 1960–2012. Recently released 2013 corn data reveal a new record productivity, which is depicted in Fig. 2 as an open circle. Annual productivity has increased from around $3 \times 10^9$ bushels in the 1960s to a current production of around $11 \times 10^9$ bushels. Realizing the intricacies of farming practices, as well as acres planted for different crops and other considerations, it was decided to examine trend lines and weather/climate effects based on bushels per acre of corn production. Accordingly, Fig. 3 is presented along with a least squares linear fit that shows an r value of 0.934, with an average annual increase of 1.7 bushels/acre. Again, the recent 2013 yield data are included as an open circle. Noteworthy is a record departure below the trend line of 37 bushels per acre for the 2012 growing season, eclipsing previous record departure years of 1988 (26 bushels/acre), 1993 (23 bushels/acre), and 1983 (23 bushels/acre). However, the drought year of 1988 remains the greatest percent departure from the trend.

**Spatial and Temporal Variability.**—To assess trends and variability in temperature and precipitation throughout the Corn Belt, data from the 38 stations for the six months (April–September) most essential to corn production were collected from the National Climatic Data

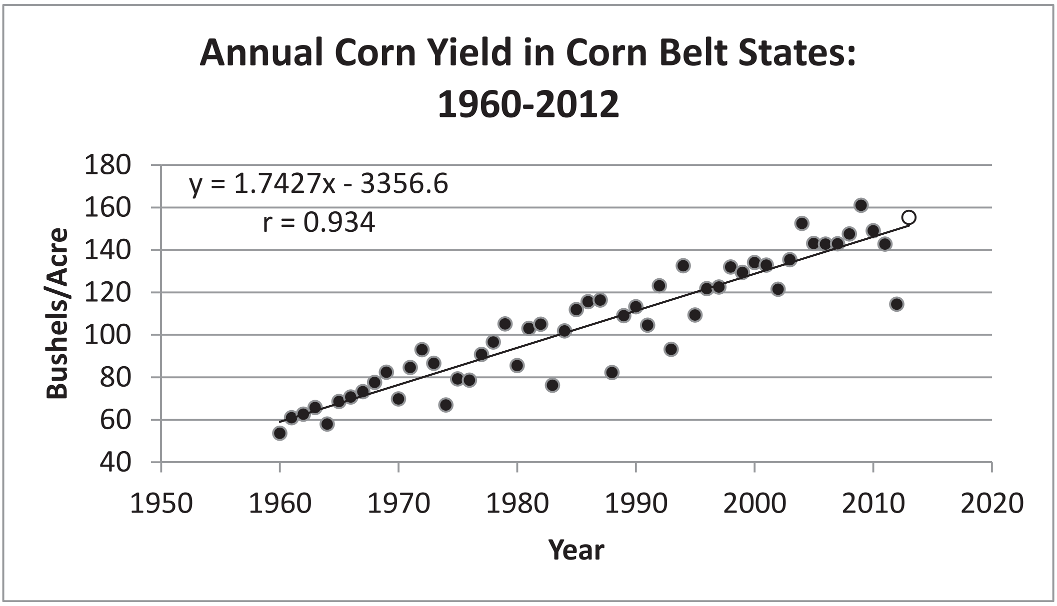


Figure 3.—Variation in corn yields (bushels/acre) for the 13 Corn Belt states from 1960–2012 (NASS 2014). The trend line shows an average annual increase of 1.7 bushels/acre. Recently-released yield data for the 2013 is depicted with an open circle.

Center (NCDC) and analyzed. Further, changes in the length of the growing season, defined as the number of days between the last spring freeze (32°F) and first fall freeze, were computed. These analyses allowed for the opportunity to address the potential role of climate on corn production.

*Temperature and length of growing season:* The trend in mean air temperature, considering all Corn Belt stations for the period April–September since 1960 (Fig. 4) revealed considerable variability, ranging from 62.4°F in 1992 to 67.4°F in 2012 (with a 0.73°F increase in the mean). In addition to this variability, and even more interesting, is the variability in mean temperature among the 38 selected stations in the Corn Belt (which ranges from +3.7°F in northern Minnesota to −1.7°F in eastern Iowa). The complexity of such spatial variability has also been noted in the study by Kucharik & Serbin (2008), and further treatment of this topic is suggested. The change in the length of the Corn Belt growing season, as defined above, is approximately 9 days, with over 8 of these days gained as a result of the last spring freeze occurring earlier. This increase is comparable to the trend toward earlier start dates for planting of 10 to 12 days (Kucharik 2006; Sacks & Kucharik 2011). Thus, it is reasonable to conclude that some fraction of the increased growing season length can be attributed to a longer freeze-free growing season. When growing season lengths for the 38 stations throughout the Corn Belt Region are examined, large spatial variability is present as expected, ranging from 198 days in southern Missouri to 122 days in northern Minnesota.

*Precipitation:* Generally speaking, cooler and wetter summers in the Corn Belt favor increased yields, while hot and dry summers are detrimental to production, as seen in the 2012 disastrous crop season (Thompson 1986; Neild & Newman 1990). Although the Corn Belt shows a rather modest growing season mean temperature increase of 0.73°F from 1960 to 2012 (for the fitted line in Fig. 4), a greater percent increase is noted when precipitation trends are considered. Figure 5 shows an increase in mean precipitation for April–September of 5.51 cm (2.17 in) for the period, but again large variability and weak correlation in the trend line are evident.

## EXTREME WEATHER AND CLIMATE EFFECTS ON CORN YIELDS: A CONCEPTUAL MODEL

In view of the above discussion on temperature and precipitation variability, it might

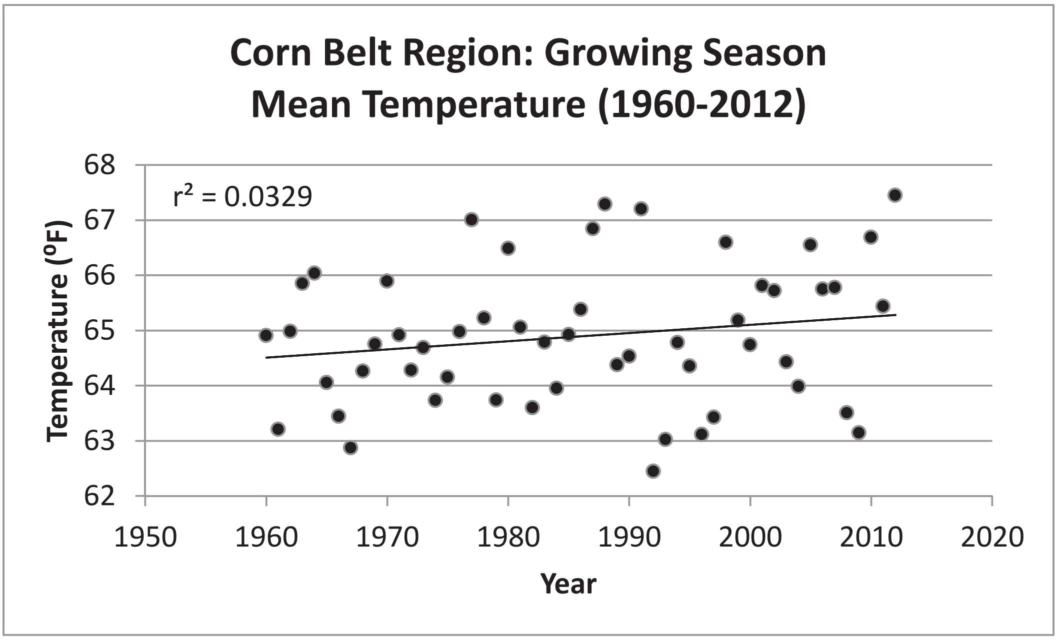


Figure 4.—Variation in the growing season mean temperature (1960–2012) for the Corn Belt Region (NCDC 2014). The slope of the linear fit shows a warming trend of 0.73°F, with evidence of increasing variability through the period.

seem impossible to document the effects of extreme weather and climate on corn yields. However, a unique approach was taken to diagnostically assess the complexities of technology and weather extremes on the climate time scale that affect corn yields. The conceptual model is presented in Fig. 6, which defines an Upper Bound for production that is based on the cumulative effects of technology (which is illustrated in the next section with the 1960–2012 data set). Next, the annual mean for the yield record was plotted, and the difference between the mean line and the Upper Bound defined the equivalent range of corn yield for the Lower Bound. Both the upper and lower bounds are equidistant from and parallel to the mean trend line, and the 53-year data set established these fixed boundaries. Data points in the record that fall below the Lower Bound were defined as low yields attributable to extreme weather and climate events. Increasing severity of extreme weather and climate events results in greater yield departures from the trend line, as noted by the lower dashed line tracing the most extreme low yield values, which fans out through time (Fig. 6). The frequency of seasonal yields that fall below the Lower Bound may also increase with more extreme weather and climate events, a hypothesis worth monitoring in future years. It is again emphasized that the model, and its application, is an instrument for diagnostic assessment of climate change impacts.

**Application of the Model.**—To show the usefulness of the conceptual model, it has been applied to the entire Corn Belt Region (Fig. 7). Four years of poor yield (1983, 1988, 1993, and 2012) fall below the Lower Bound and are thus classified as occurring under extreme weather and climate events that negatively impacted yields. Not surprising, and as well-known, the two worst years for corn productivity (2012 and 1988) were both characterized by extremely hot and dry conditions during the spring and summer months (Namias 1991; NCDC 2015). The other two years of poor corn productivity displayed other noted scenarios, namely extremely cool and wet conditions throughout the 1993 growing season (Kunkel et al. 1994) and cool, wet conditions early in the growing season followed by hot and dry conditions late in the 1983 growing season.

The Upper Bound, as defined in this study, illustrates the limitations of *extraordinary*

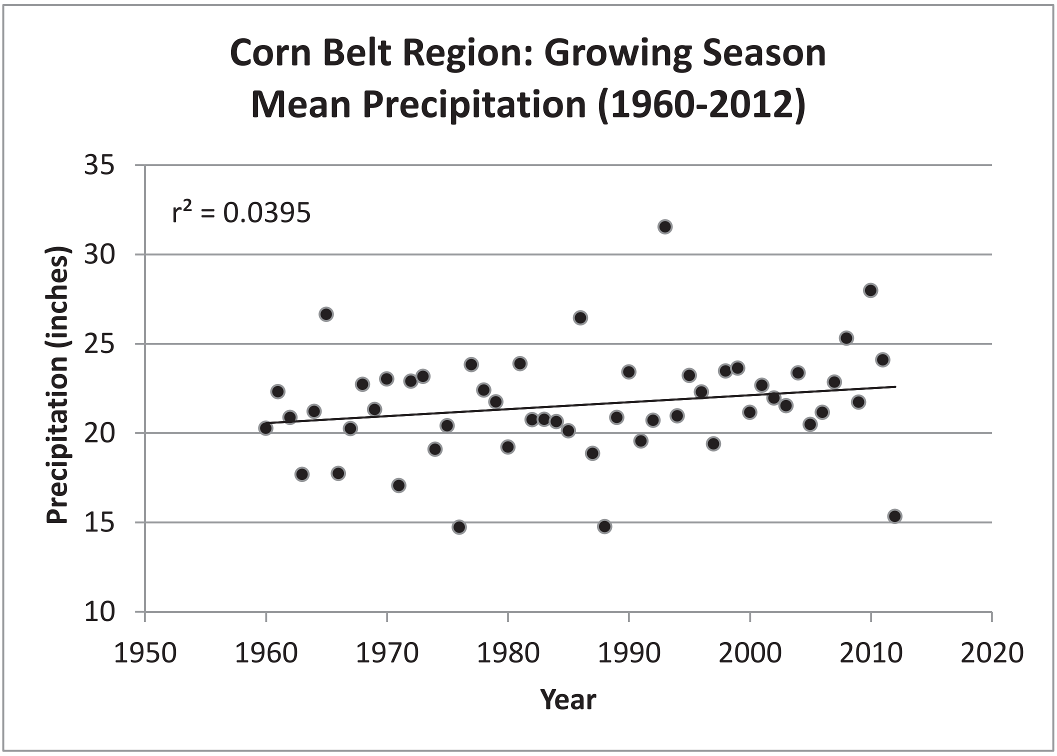


Figure 5.—Variation in the growing season mean precipitation (1960–2012) for the Corn Belt Region (NCDC 2014). The slope of the linear fit shows an increase of 5.51 cm (2.17 in), with evidence of considerable variability through the period.

technological advancements. Five years covering a large span of time (1972, 1979, 1994, 2004, and 2009) had yields near or on the Upper Bound, showing that increases in technology have not been so revolutionary as to reveal a consistent increase in the number of years abutting the Upper Bound, at least since 1960. The four years below the Lower Bound are successfully captured by the methodology of the conceptual model. Finally, the domain of extreme events, highlighted by the crippling 2012 season (Fig. 7), fans out below the Lower Bound, another feature illustrated in the model. As such, the diagnostic methodology in this model is prepared to document the cumulative effects of 21st century extreme weather and climate on corn yields in the USA Corn Belt Region.

## DISCUSSION AND CONCLUSIONS

Data for total corn yields, as well as yields of bushels per acre, for the USA Corn Belt region were assessed for the period 1960–2012, along with relevant weather and climate data records. A definition for a “Corn Belt State” was introduced, which qualifies 13 states for analysis. Weather records from 38 selected stations across the Corn Belt were used, which have a mean station spacing of 145 km, with an average departure from the mean of 20 km. The observational data showed that the essential period during which corn is grown in the Corn Belt (April–September) has become wetter and slightly warmer through time, although considerable spatial and temporal variability was noted and can be expected (as seen in the cause of the disastrous 2012 crop season). More research into spatial and temporal variability is warranted, especially with the anticipated continuation of global warming and the associated extreme weather events. The precipitation increase for April–September found in this study is also consistent with the expected increase in conditions that support summertime convective precipitation (namely humidity and CAPE (convective available potential energy), as seen in the study by Trapp et al. 2007).

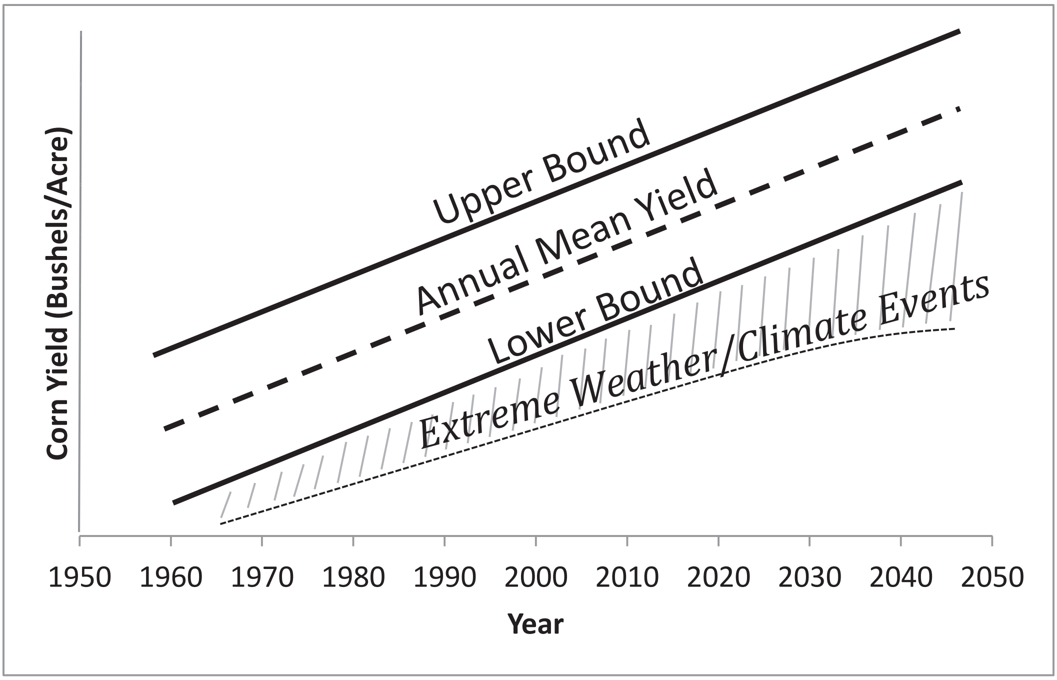


Figure 6.—Conceptual model representing the increase in corn yield with time. Technological improvements define the Upper Bound which, along with climate and weather events, provide a mean annual trend line. The Lower Bound is defined as being equally distant from the mean as the Upper Bound. Annual yields that fall below the Lower Bound are defined as those attributed to extreme weather and climate events.

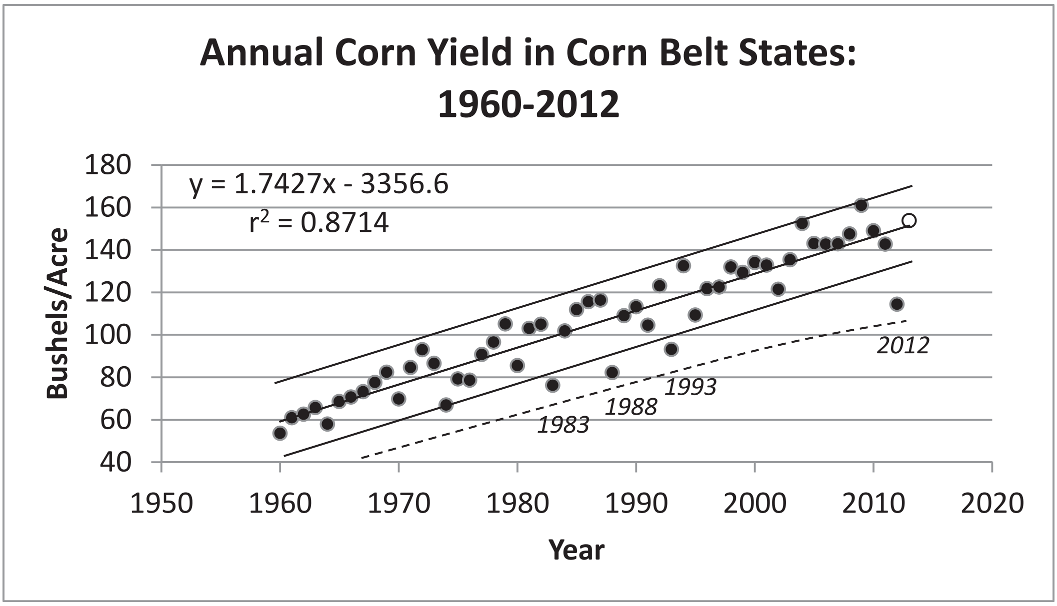


Figure 7.—Annual corn yield for the Corn Belt states during the period 1960–2012. The conceptual model defines four years (1983, 1988, 1993, and 2012) of low yields, attributable to extreme weather and climate events. All features of the conceptual model are illustrated by its application to the 53-year data set.

Based upon the conceptual model, 53 years of data were assessed for the occurrence and effect of extreme weather and climate events on corn yields. This model worked as envisioned, even in the presence of continued increase in annual yields (1.7 bushels per acre per year) contributed in part by technological advancements. Application of the model identified four events that represent extreme weather detrimental to corn yields. These are (from the most extreme to the least extreme in terms of departure from the trend line) 2012, 1988, 1993, and 1983 for the entire Corn Belt Region.

Further, it is important to realize that the model framework presented in this study can be 2012, 1988, 1993, and 1983 for the entire Corn Belt Region. extended through the 21st century (assessing any global warming effect) to monitor and quantify the number of extreme events. Specifically, if there are more extreme weather and climate events (e.g., heat, drought, excessive rainfall), the number of events that fall below the Lower Bound for corn yields may increase, and there also exists the opportunity for more record departures from the mean trend line (as seen in 2012). Thus, this model provides a diagnostic assessment of corn yields, categorizing them based on both technological advancements and climate change.

## LITERATURE CITED

Kaufmann, R.K. & S. Snell. 1997. A biophysical model of corn yield: integrating climatic and social determinants. American Journal of Agricultural Economics 79:178–190.

Kucharik, C.J. 2006. A multidecadal trend of earlier corn planting in the Central USA. Agronomy Journal 98:1544–1550.

Kucharik, C.J. & N. Ramankutty. 2005. Trends and variability in U.S. corn yields over the twentieth century. Earth Interactions 9:1–29.

Kucharik, C.J. & S.P. Serbin. 2008. Impacts of recent climate change on Wisconsin corn and soybean yield trends. Environmental Research Letters 3:1–10.

Kunkel, K.E., S.A. Changnon & J.R. Angel. 1994. Climatic aspects of the 1993 Upper Mississippi River Basin flood. Bulletin of the American Meteorological Society 75:811–822.

Lobell, D.B. & G.P. Asner. 2003. Climate and management contributions to recent trends in U.S. agricultural yields. Science 299: 1032.

Namias, J. 1991, Spring and summer 1988 drought over the contiguous United States–causes and prediction. Journal of Climate 4:54–65.

NASS (USDA National Agricultural Statistics Service). 2014. Quick Stats Tools. At: http://nass.usda.gov/Quick_Stats/ (Accessed 1 September 2013)

NCDC (National Climatic Data Center, NOAS). 2014. Land-Based Station Data. At: http://www.ncdc.noaa.gov/data-access/land-based-station-data (Accessed 12 March 2013)

Neild, R.E. & J.E. Newman. 1990. Growing season characteristics and requirements in the Corn Belt. National Corn Handbook (NHC-40). At: https://www.extension.purdue.edu/extmedia/NCH/NCH-40.html (Accessed 15 April 2014)

Sacks, W.J. & C.J. Kucharik. 2011. Crop management and phenology trends in the U.S. Corn Belt: impacts on yields, evapotranspiration and energy balance. Agriculture and Forest Meteorology 151: 882–894.

Thompson, L.M. 1986. Climate change, weather variability, and corn production. Agronomy Journal 78:649–653.

Trapp, R.J., N.S. Diffenbaugh, H.E. Brooks, M.E. Baldwin, E.D. Robinson & J.S. Pal. 2007. Changes in severe thunderstorm environment frequency during the 21st century caused by anthropogenically enhanced global radiative forcing. Proceedings of the National Academy of Science 104:19,719–19,723.

*Manuscript received 14 August 2014, revised 22 May 2015.*

2014. Proceedings of the Indiana Academy of Science 123(2):103–111

# A COMPARISON OF THE EFFICIENCY OF MOBILE AND STATIONARY ACOUSTIC BAT SURVEYS

**Jadelys M. Tonos, Benjamin P. Pauli**[1] and **Patrick A. Zollner**: Department of Forestry and Natural Resources, Purdue University, West Lafayette, IN 47907 USA

**G. Scott Haulton**: Division of Forestry, Indiana Department of Natural Resources, Indianapolis, IN 46204 USA

**ABSTRACT.** Acoustic surveys with echolocation detectors have become a common method for monitoring bats worldwide. In the eastern United States, the spread of white-nose syndrome and the threat it poses for many bat species, particularly endangered species such as the Indiana bat (*Myotis sodalis*), has increased the need to monitor bat populations. Two popular methods, stationary and mobile surveys, are currently used by agencies in the United States to inform management and conservation efforts and by researchers to monitor and study bat populations. Despite the widespread use of these methods, no study has compared the efficiency in echolocation 'capture' success relative to human-hour of effort of these two methods. To compare these techniques we collected acoustic data with Anabat detectors in state forests of southern Indiana using stationary and mobile surveys in the way they are typically implemented. We compared the efficiency of each method at recording identifiable call files and *Myotis* bat call files per survey hour and hour of human effort, the proportion of call files recorded that were identified as *Myotis* bats, and the total number of bat species detected. Stationary surveys detected higher species richness, a higher proportion of *Myotis* bats, and were more efficient at recording *Myotis* bat call files per hour of effort than mobile surveys. Because of limitations in resources faced by many agencies, it is important to understand the efficiency of these methods relative to the effort expended implementing them. Whenever possible, we recommend the preferential use of stationary survey over mobile surveys.

**Keywords:** acoustic surveys, bats, mobile surveys, *Myotis*, stationary surveys

## INTRODUCTION

Bat species worldwide are currently facing many threats, including the loss and fragmentation of habitat (Thomas 1988; Brosset et al. 1996; Fenton et al. 1998; Law & Chidel 2002; Borkin & Parsons 2010), disease (Ingersoll et al. 2013; USFWS 2014), climate change (Humphries et al. 2002), and the development of wind energy facilities (Kunz et al. 2007; Arnett et al. 2008; Jain et al. 2011). In the eastern United States, the threat of white-nose syndrome (WNS) has increased concern for the conservation of many bat species. This infection, caused by the fungus *Pseudogymnoascus destructans* (formerly *Geomyces destructans*; Lorch et al. 2011; Minnis & Linder 2013), originally discovered in New York in 2006, has now been confirmed in 25 states and five Canadian provinces and has killed more than 5.5 million bats (Turner et al. 2011; USFWS 2012; WNS 2015). White-nose syndrome affects seven bat species in the United States, the majority of which belong to the genus *Myotis*. This genus includes the federally endangered Indiana (*M. sodalis*) and gray (*M. grisescens)* bats, the northern long-eared bat (*M. septentrionalis*), which has been proposed for listing as endangered (USFWS 2013), and the little brown bat (*M. lucifugus*) whose population declines have made it a potential candidate for future listing (Frick et al. 2010; Dzal et al. 2011; Thogmartin et al. 2012, 2013; Ingersoll et al. 2013).

The existence of these threats necessitates techniques that will efficiently inventory and monitor bat species for proper management. Methods that effectively estimate population trends are necessary to support listing decisions, to set recovery goals, and to monitor the success of conservation efforts. Methods traditionally employed to survey bat populations include visual counts of roosting bats, evening

---

[1] *Corresponding author:* Benjamin P. Pauli, 208-426-4923 (phone), 208-426-1040 (fax), benjaminpauli@boisestate.edu.

emergence counts, mark-recapture methods, mist netting, harp trapping, and hibernacula surveys (Kunz 2003). More recently, with the development of ultrasonic detectors and automated call identification software, acoustic surveys have become a popular tool for monitoring bats (Walters et al. 2013), particularly in areas of eastern North America where bat populations have been reduced by WNS and managers have sought alternative cost-efficient techniques.

Acoustic surveys provide a non-invasive and relatively simple method for monitoring bat activity and community composition, often providing a more accurate estimate of species richness than the more invasive mist net capture methods (Murray et al. 1999; O'Farrell & Gannon 1999). These surveys are also a cost-effective method to sample many bat species in large areas (Roche et al. 2011; Coleman et al. 2014). Acoustic surveys are implemented using ultrasonic echolocation call detectors that record the calls of foraging and commuting bats. The characteristics of these calls, such as frequency and duration, can later be used to identify the species recorded (O'Farrell et al. 1999) with automated techniques exceeding 90% accuracy in species identification of call libraries (though field recordings are expected to have lower rates of accuracy due to call degradation; Britzke et al. 2002, 2011).

Two common techniques for acoustic survey implementation are stationary and mobile surveys. During stationary surveys, detectors are placed in a sampling location and allowed to passively record calls of bats for a set length of time (Murray et al. 2001; Ford et al. 2011; Stahlschmidt & Brühl 2012). Such an approach is particularly useful for determining species presence/absence, conducting occupancy analysis, assessing species diversity or recording an index of bat activity. During mobile surveys, detectors record bat calls while moving along a route; these surveys can be performed on walking, driving, or boating transects (Roche et al. 2011; Whitby et al. 2014). This technique is well suited for assessing an index of population abundance (since individual bats are rarely resampled), monitoring population trends, and surveying large areas.

Both mobile and stationary surveys are currently being used to monitor and study bat populations by researchers, consulting firms, citizen scientists, and government agencies (e.g., Furlonger et al. 1987; Walsh & Harris 1996; O'Farrell et al. 1999; Baerwald & Barclay 2009; Jain et al. 2011; Beeker et al. 2013; Shier et al. 2013; USFWS 2014; Jack Basiger, Civil and Environmental Consultants, Inc., Pers. Comm.). The USFWS has developed a stationary survey protocol for determining the presence/probable absence of Indiana bats during the summer and other agencies have issued guidelines for conducting mobile driving surveys (Britzke & Herzog 2009; USFWS 2014). Both types of acoustic surveys are currently being used by the Indiana Department of Natural Resources to survey bat communities in Indiana (Shier et al. 2013). In addition, a large-scale monitoring program for North American bats is in development and both mobile and stationary acoustic surveys are included as part of that program (Loeb et al. 2012, L.E. Ellison, Pers. Comm.).

Both stationary and mobile surveys are widely used, though their relative effectiveness in sampling bat populations is unclear. Previous research has identified differences in the effectiveness of acoustic survey techniques relative to the type of surveys used, the type of recording device, the weatherproofing technique, and the height of detectors (Menzel et al. 2005; Collins & Jones 2009; Britzke et al. 2010; Stahlschmidt & Brühl 2012; Whitby et al. 2014; Coleman et al. 2014). Thus, differences in the performance of stationary and acoustic surveys would be expected. Despite their popularity, no study has previously compared the efficiency of driving mobile surveys and stationary surveys at detecting *Myotis* bats relative to time investment.

In this study we examined the relative efficiency of mobile and stationary surveys with particular focus on the human-hours of effort expended implementing each technique. To accurately compare the efficiency of these techniques, we collected data with each in the way in which they are typically implemented when surveying a bat community at a particular property. Thus, we did not pair our mobile and stationary surveys as a means of direct comparison for the same habitat. Rather, as is standard, we deployed multiple stationary acoustic detectors throughout a property of interest and allowed those units to collect ultrasonic data for multiple sequential nights. As is also standard, our mobile acoustic surveys only lasted a single night at a time (though with replicates) and mobile routes were necessarily constrained to roads over which a vehicle could travel. Therefore we did not intend to make a direct comparison between methods based on location, but rather implemented each technique in the way they are typically deployed when surveying large properties. This allowed us to determine the human-hours of effort needed to employ each technique and to compare their efficiency according to time expended. We compared the total number of call files identifiable to species recorded per hour of sampling and per hour of effort for each survey method. Because of the conservation interest of the genus, we also considered the efficiency in capture via the number of *Myotis* call files recorded per hour of sampling and effort and the proportion of call files identified as a *Myotis* species. We also compared the number of bat species detected by each technique. Considering the resource limitations faced by researchers and federal and state agencies, we believe that understanding the effectiveness of sampling techniques at assessing bat communities relative to time investment is crucial (also *see* Whitby et al. 2014).

## STUDY SITES

Our study area consisted of 12 state forest properties in southern Indiana and the surrounding areas within 8 km of the forest property boundary (center of all areas 38°47′32.15″N and 86°29′47.59″W; Fig. 1). These forests are located within the Southwestern Lowlands, Eastern Bottomlands, Shawnee Hills, Highland Rim, and Bluegrass natural regions (Homoya et al. 1985). Southern Indiana is dominated by hardwood forests that have regenerated in the absence of agriculture since the early 1900s (Jenkins 2013). The two most dominant forest types in Indiana's state forests are oak-hickory and mixed hardwoods representing 57% and 26% of the total land cover, respectively (Shao et al. 2014). Our study area encompasses the range of at least six bat species affected by white-nose syndrome and contains habitat types favored by many of them (Whitaker et al. 2007).

## METHODS

A total of 48 stationary and mobile acoustic surveys was conducted from 30 May to 7 August, 2012. A passive stationary survey consisted of four detectors deployed at randomly selected sites within one forest property for five consecutive nights. Each of 12 distinct forest properties was sampled once or twice for a total of 22 stationary surveys (440 detector-nights at 88 sites). A stratified random sampling design (as part of a separate experiment; Pauli 2014) based upon distance to the nearest road was used to select four stationary sampling sites per sampling session per property. Locations were established within forested areas in the immediate vicinity. The average distance between a site and its closest neighbor was 1443 m (range 62–9748 m). Sites that were inaccessible or were in areas where detectors would be conspicuous and at risk of being tampered with were rejected and a new location within the same stratum was chosen. At sampling sites the recording equipment was placed in a flat area within 3 m of the selected

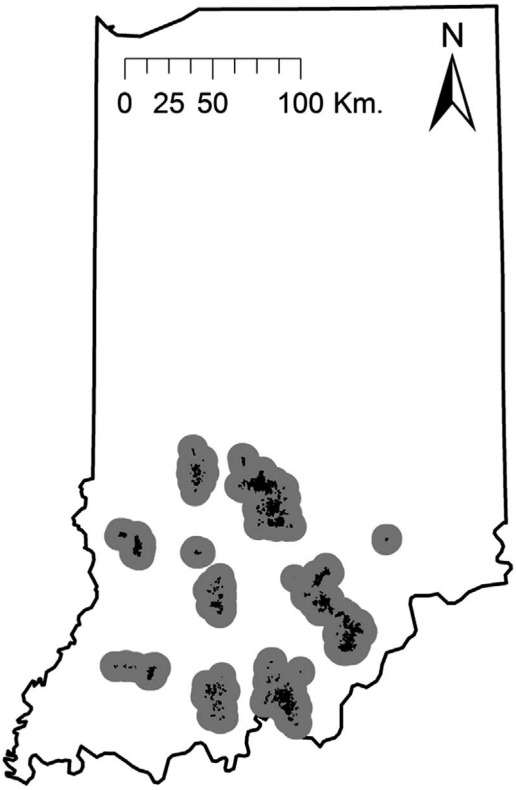


Figure 1.—Study areas sampled using mobile and stationary acoustic surveys May–August, 2012. Black areas represent the 12 Indiana State Forest properties sampled while gray areas denote the 8 km buffer area surrounding those properties. Note: two pairs of forest properties border one another but were sampled independently.

point, positioned in the direction of lowest understory clutter, and set to record for five consecutive nights. Each survey night, detectors recorded for 12 h and began recording at least 30 min before sunset and stopped at least 30 min after sunrise. Bat calls were recorded using Anabat II detectors, powered by 9 V and AA batteries, with a division ratio of 16 and stored digitally using compact flash cards in zero-crossing interface modules (ZCAIMs; Titley Electronics, Ballina, NSW, Australia). The recording equipment was placed 1 m off the ground and was enclosed in a plastic container for weatherproofing fitted with a PVC tube angled at 45° and facing the microphone (O'Farrell 1998; *see* Duchamp et al. 2006 for exact weatherproofing specifications).

Twelve routes were designed for mobile surveys, one for each forest property. Each route was sampled two to three times over our field season for a total of 26 mobile surveys. Mobile and stationary surveys did not sample the same property concurrently. Each mobile survey route was 40–48 km (25–30 mi) long and included roads in the state forests or within 8 km (5 mi) of property boundaries. We designed routes to avoid overlap in sampling area during each survey and preferentially used low-traffic roads. Routes were driven at a rate of 24–32 km/h (15–20 mph), starting 20 min after sunset on nights with low wind ($<$ 24 km/h), no fog or rain, and temperatures suitable for bat activity ($>$ 12.8°C; Britzke & Herzog 2009). We used an Anabat SD2 ultrasound detector (Titley Electronics, Ballina, NSW, Australia) set at a division ratio of 8 with a vehicle roof-mounted microphone (without weatherproofing) pointing 5–15 degrees off vertical and an Ipaq PDA recording device with Anapocket software to store calls (Britzke & Herzog 2009).

All Anabat detectors (Anabat II and SD2 units) were calibrated before the surveys using an ultrasonic sound emitter to ensure consistent detector sensitivity (Larson & Hayes 2000) and were set with a sensitivity setting near 7 for all units. We used the automated echolocation classification software EchoClass v2.0 (U.S. Army Engineer Research and Development Center, Vicksburg, MS, USA; available at www.fws.gov) to identify the species of bat calls from the recorded call files. Identifiable species were limited to those somewhat common to our study areas (species in "species set 2" in EchoClass; G.S. Haulton, unpublished data) to reduce the potential candidate species and thus, reduce the likelihood of misclassification. Only a portion of the total call files collected could be identified to species due to poor call quality or interference from other sources, such as insect noise.

To determine the efficiency of each method, we calculated the number of hours of effort expended in each survey. For mobile surveys, hours of effort were defined as the time spent driving routes plus an estimated 5 min for setting up and putting away the equipment. The estimated time of effort expended in a single stationary survey (four detectors at a single property) included the time spent traveling to each sampling location within the forest property, set-up time, and pick-up time for each detector once sampling was completed. We did not include the time required to get to the study area for either survey method as this varied for each forest property but was consistent between methods.

We determined the number of call files identifiable to species recorded and the number of *Myotis* bat call files recorded per sampling hour by dividing the number of each by the amount of time the detector was actively sampling. We calculated the number of call files identifiable to species that could be recorded per hour of effort and the number of *Myotis* species bat call files per hour of effort for each method by dividing the total number of call files recorded during each sampling round (four stationary locations for five nights at a particular property) or route (single route for one night at a property) by the total time invested for that survey. We defined species richness for each survey as the number of species identified in at least one call file by EchoClass v2.0 during a sampling occasion. We determined the proportion of identifiable call files classified as *Myotis* bats by dividing the number of *Myotis* bat call files by the total number of call files identified during each survey. For all of these data we conducted two-sample $t$-tests assuming unequal variances to determine if these values differed significantly between the two methods using Bonferroni correction ($\alpha = 0.0083$) to account for multiple comparisons.

## RESULTS

During our sampling, a total of 23,215 files were recorded: 2,691 files using mobile surveys and 20,524 files using stationary surveys.

Table 1.—Comparison of the efficiency and effectiveness of stationary and mobile Anabat surveys. Data measured are the number of identifiable files recorded per sampling hour, number of *Myotis* bat call files recorded per sampling hour, number of identifiable files recorded per hour of effort expended, number of *Myotis* bat call files recorded per hour of effort expended, percentage of identifiable calls classified as *Myotis* bats, and species richness recorded. Included for each response variable is the mean (and standard deviation) for stationary and mobile surveys and the test statistic (t), degrees of freedom (df) and p-value ($p$) from a two-sample $t$-test assuming unequal variances. Stars denote significantly different results (Bonferroni corrected $\alpha = 0.0083$).

| Measurement | Stationary | Mobile | t | df | $p$ |
|---|---|---|---|---|---|
| Ident. files/hour sampled | 0.52 (0.86) | 11.22 (4.96) | 10.81 | 27 | <0.0001* |
| *Myotis* files/hour sampled | 0.04 (0.06) | 0.10 (0.23) | 1.15 | 29 | 0.260 |
| Ident. files/hour effort | 17.99 (29.41) | 10.66 (4.69) | 1.16 | 22 | 0.259 |
| *Myotis* files/hour effort | 1.47 (2.19) | 0.09 (0.22) | 2.95 | 21 | 0.008* |
| Percentage of *Myotis* files | 8.72 (6.40) | 0.70 (1.71) | 5.71 | 24 | <0.0001* |
| Species richness | 4.59 (2.32) | 2.69 (0.93) | 3.60 | 27 | 0.001* |

Of these, stationary surveys recorded 2,771 files that could be identified to species, including 227 *Myotis* call files, whereas mobile surveys recorded 466 identifiable files, only four of which we identified as *Myotis* call files. Sampling time of effort expended on mobile surveys averaged 1.7 hours per route (SD = 0.10) for a total of 44.1 hours. The estimated time of effort expended for stationary surveys totaled 154 hours, or seven hours per survey.

On average, our mobile surveys recorded 21.6 times as many identifiable calls per survey hour compared to stationary surveys and this difference was highly significant (Table 1). Using stationary surveys we recorded 1.7 times as many identifiable files per hour of effort relative to mobile surveys though this difference in efficiency was not significant (Table 1). Stationary and mobile surveys sampled equivalent number of *Myotis* calls per survey hour (Table 1) but stationary surveys recorded significantly more *Myotis* bat call files per unit effort with 16.3 times the efficiency of mobile surveys (Table 1). Stationary surveys also identified a significantly higher proportion of *Myotis* calls and a greater mean species richness as compared to mobile surveys (Table 1). Stationary surveys detected nine species: big brown bat (*Eptesicus fuscus*), silver-haired bat (*Lasionycteris noctivagans*), eastern red bat (*Lasiurus borealis*), hoary bat (*L. cinereus*), eastern small-footed bat (*Myotis leibii*), little brown bat, northern long-eared bat, Indiana bat, and the tri-colored bat (also known as the eastern pipistrelle, Whitaker et al. 2011; *Perimyotis subflavus*). Mobile surveys only detected six of these nine species, not recording any Indiana bat, little brown bat, or eastern small-footed bat call files.

## DISCUSSION

By determining the relative efficiency of these two techniques at surveying bat communities in terms of time of effort expended and richness recorded, we demonstrated that stationary surveys are more effective than mobile surveys when considering investment of human effort. Mobile surveys not only detected lower species richness, lower number of *Myotis* call files per hour of effort, and lower proportion of *Myotis* call files, but they failed to detect three species detected by stationary surveys. The length of the sampling periods and the ratio of sampling time to time of effort expended were important factors determining the efficiency of each method. The time of effort (human-hours) spent on stationary surveys is considerably shorter than the length of the sampling period, whereas in mobile surveys the hours of effort expended are equivalent to the sampling period. Thus, stationary surveys sample for longer periods per time of effort. Therefore, even though stationary surveys recorded significantly fewer identifiable files per sampling hour, they were more efficient relative to effort expended. This difference may explain why mobile surveys were less efficient at capturing *Myotis* calls per hour of effort. Stationary survey detectors sample an area for five consecutive nights, whereas, mobile surveys record for very short periods at any given location along the route. Skalak et al. (2012) demonstrated that in order to record higher levels of species richness during acoustic surveys, multiple nights and sampling stations as well as continuous sampling through the night was required. They further found that few nights were necessary to detect common species but longer sampling periods were required to capture rare species. Other studies have also demonstrated nightly bat activity can vary due to a variety of factors, so that in order to capture true nightly activity or species presence it is necessary to survey for multiple nights (Hayes 1997; Fisher et al. 2009; Rodhouse et al. 2012; Romeling et al. 2012). Stationary surveys that are conducted for fewer nights than this research, however, would be expected to have reduced efficiency relative to that measured in this study.

Stationary detectors, capable of sampling over multiple nights and with less time effort, have a greater chance of capturing call files of all the species present, especially those of target *Myotis* species. Mobile surveys, in comparison, spend relatively little time recording in a given area and thus have a greater probability of missing species. This is of particular importance when the species being missed are those that are of most interest for conservation efforts, as was the case in this study. If mobile surveys are unable to efficiently detect rare species or provide accurate estimates of richness, this method, despite having some advantages, may be insufficient.

The partial avoidance of roads by bats could be another factor influencing the efficiency of mobile driving surveys. Bats have been shown to avoid crossing roads, particularly when a vehicle is present (Schaub et al. 2008; Zurcher et al. 2012; Bennett & Zurcher 2013; Bennett et al. 2013). These behaviors may be the result of road noise interfering with foraging activities, the perception bats have of cars as predators, or the predation threat bats face in the open areas created by roads (Schaub et al. 2008; Zurcher et al. 2012; Bennett & Zurcher 2013). It is interesting to note that partial road avoidance appeared to be taxonomically skewed in this study. Independent of sampling time, stationary surveys recorded a proportionally higher sample of *Myotis* call files than mobile surveys. Such a phenomenon could be the result of the rapid attenuation of the high frequency calls emitted by *Myotis* species (Lawrence & Simmons 1982). Alternatively, because *Myotis* bats are considered clutter-adapted species (Patriquin & Barclay 2003) they may be less likely to forage over roads. Thus, this genus may be more sensitive to roads as barriers or vehicular disturbance than other species, though more research is needed to further elucidate this relationship.

In this study Anabat II and Anabat SD2 detectors and EchoClass v2.0 software were used for collection and analysis of data. It should be noted that although detectors were calibrated against one another, mobile surveys were conducted with Anabat SD2 detectors, a division ratio of 8, and microphones specially fitted for vehicle mounting while stationary surveys were conducted with Anabat II detector within waterproofing containers and a division ratio of 16. While such an approach is typical for many bat surveys, there is potential that some of our findings were the result of differences in survey equipment rather than the technique itself. Furthermore, we used the classification of a single file to the species level by EchoClass as our primary data. Such an approach is less restrictive than other studies that use maximum likelihood estimates for determining positive species identification (e.g., Coleman et al. 2014). Therefore, our results may contain more species misclassifications than other studies. It will be necessary to test similar results with other types of recording equipment and analysis software, but we suspect where some patterns in the data may be different, the general trends observed in our results will hold.

Monitoring populations is an important aspect of bat management and conservation, but all agencies involved in such activities are constrained by limited resources. Thus sampling efficiency is a priority. Given that stationary surveys seem to be more efficient than mobile surveys in sampling bat community richness and at detecting species of the genus *Myotis* for the effort expended, we recommend that, when possible, stationary surveys should be used preferentially over mobile driving surveys.

There are situations, however, where mobile surveys may be more practical than stationary sampling techniques. Mobile surveys are useful when surveying large areas for common species. In addition, because mobile surveys limit the potential for sampling a single bat multiple times, they may be more adept at providing an index of population size which cannot be done with typical stationary surveys. Mobile surveys can be conducted on public roads so areas with difficult terrain can be sampled easily. There is also no need to request landowner permission to conduct such surveys if they are done on public roads. Stationary surveys also require detectors to be left unattended thus exposing them to potential tampering or damage. In addition, since detectors are obligated for longer periods of time in stationary surveys, mobile surveys are also better suited to sampling large areas if time and detectors are limiting factors. These types of surveys are also useful in citizen science programs or for training purposes since they are easier to implement and do not require the participants to leave their vehicles.

Mobile surveys risk obtaining inaccurate measures of richness and missing rare species, however, and so should not be used for such purposes. It is also important to note that our data were collected within two-years of when white-nose syndrome had been first detected in Indiana, and we suspect in this short period of time that bat populations had not yet declined significantly in our study area. We speculate that the efficiency of surveys at detecting *Myotis* species will only worsen with population reductions which could exacerbate this discrepancy. If a more accurate index of the bat community of an area is needed, stationary surveys are a better option as they provide a more efficient method for monitoring.

## ACKNOWLEDGMENTS

This research was supported by the Indiana Department of Natural Resources, Division of Forestry. Thanks to K. DeCosta for conducting much of the field work for the stationary surveys and to C.R. Bienz, C. Bleke, A.J. Cohen, L.E. D'Acunto, C.C. Day, J.T. Rodkey, G.L. White, S.H Smith, R.J. Spaul, and J.A. Heath for providing feedback on this manuscript.

## LITERATURE CITED

Arnett, E.B., W.K. Brown, W.P. Erickson, J.K. Fiedler, B.L. Hamilton, T.H. Henry, A. Jain, G.D. Johnson, J. Kerns, R.R. Koford, C.P. Nicholson, T.J. O'Connell, M.D. Piorkowski & R.D. Tankersley. 2008. Patterns of bat fatalities at wind energy facilities in North America. Journal of Wildlife Diseases 72:61–78.

Baerwald, E.F. & R.M. R Barclay. 2009. Geographic variation in activity and fatality of migratory bats at wind energy facilities. Journal of Mammalogy 90:1341–1349.

Beeker, T.A., K.F. Millenbah, M.L. Gore & B.L. Lundrigan. 2013. Guidelines for creating a bat-specific citizen science acoustic monitoring program. Human Dimensions of Wildlife 18:58–67.

Bennett, V.J. & A.A. Zurcher. 2013. When corridors collide: road-related disturbance in commuting bats. Journal Wildlife Management 77:93–101.

Bennett, V.J., D.W. Sparks & P.A. Zollner. 2013. Modeling the indirect effects of road networks on the foraging activities of bats. Landscape Ecology 28:979–991.

Borkin, K.M. & S. Parsons. 2010. The importance of exotic plantation forest for the New Zealand long-tailed bat (*Chalinolobus tuberculatus*). New Zealand Journal of Zoology 37:35–51.

Britzke, E.R. & C. Herzog. 2009. Using acoustic surveys to monitor population trends in bats. United States Army Engineer Research and Development Center, Vicksburg, Mississippi. 4 pp.

Britzke, E.R., J.E. Duchamp, K.L. Murray, R.K. Swihart & L.W. Robbins. 2011. Acoustic identification of bats in the eastern United States: a comparison of parametric and nonparametric methods. Journal of Wildlife Management 75:660–667.

Britzke, E.R., K.L. Murray, J.S. Heywood & L.W. Robbins. 2002. Acoustic identification. Pp. 220–224. *In* The Indiana Bat: Biology and Management of an Endangered Species. (A. Kurta & J. Kennedy, Eds.) Bat Conservation International, Austin, Texas.

Britzke, E.R., B.A. Slack, M.P. Armstrong & S.C. Loeb. 2010. Effects of orientation and weatherproofing on the detection of bat echolocation calls. Journal Fish Wildlife Management 1:136–141.

Brosset, A., P. Charles-Dominique, A. Cockle, J.F. Cosson & D. Masson. 1996. Bat communities and deforestation in French Guiana. Canadian Journal of Zoology 74:1974–982.

Coleman, L.S., W.M. Ford, C.A. Dobony & E.R. Britzke. 2014. A comparison of passive and active acoustic sampling for bats impacted by white-nose syndrome. Journal of Fish and Wildlife Management 5:217–226.

Collins, J. & G. Jones. 2009. Differences in bat activity in relation to bat detector height: implications for bat surveys at proposed windfarm sites. Acta Chiropterologica 11:343–350.

Duchamp, J.E., M. Yates, R.M. Muzika & R.K. Swihart. 2006. Estimating probabilities of detection for bat echolocation calls: an application of the double-observer method. Wildlife Society Bulletin 34:408–412.

Dzal, Y., L.P. McGuire, N. Veselka & M.B. Fenton. 2011. Going, going, gone: the impact of white-nose syndrome on the summer activity of the little brown bat (*Myotis lucifugus*). Biology Letters 7:392–394.

Fenton, M.B., D.H.M. Cumming, I.L. Rautenbach, G.S. Cumming, M.S. Cumming, G. Ford, R.D. Taylor, J. Dunlop, M.D. Hovorka, D.S. Johnston, C.V. Portfors, M.C. Kalcounis & Z. Mahlanga. 1998. Bats and the loss of free canopy in African woodlands. Conservation Biology 12:399–407.

Fisher, J., J. Stott, B.S. Law, M.D. Adams & R.I. Forrester. 2009. Designing effective habitat studies: quantifying multiple sources of variability in bat activity. Acta Chiropterologica 11:127–137.

Ford, W.M., E.R. Britzke, C.A. Dobony, J.L. Rodrigue & J.B. Johnson. 2011. Patterns of acoustical activity of bats prior to and following white-nose syndrome occurrence. Journal of Fish Wildlife Management 2:125–134.

Frick, W.F., J.F. Pollock, A.C. Hicks, K.E. Langwig, D.S. Reynolds, G.G. Turner, C.M. Butchkoski & T.H. Kunz. 2010. An emerging disease causes regional population collapse of a common North American bat species. Science 329:679–682.

Furlonger, C.L., H.J. Dewar & M.B. Fenton. 1987. Habitat use by foraging insectivorous bats. Canadian Journal Zoology 65:284–288.

Hayes, J.P. 1997. Temporal variation in activity of bats and the design of echolocation-monitoring studies. Journal of Mammalogy 78:514–524.

Homoya, M.A., D.B. Abrell, J.R. Aldrich & T.W. Post. 1985. The natural regions of Indiana. Proceedings of the Indiana Academy of Science 94:245–268.

Humphries, M.M., D.W. Thomas & J.R. Speakman. 2002. Climate-mediated energetic constraints on the distribution of hibernating mammals. Nature 418:313–316.

Ingersoll, T.E., B.J. Sewall & S.K. Amelon. 2013. Improved analysis of long-term monitoring data demonstrates marked regional declines of bat populations in the eastern United States. Plos One 8:e65907.

Jain, A.A., R.R. Koford, A.W. Hancock & G.G. Zenner. 2011. Bat mortality and activity at a northern Iowa wind resource area. American Midland Naturalist 165:185–200.

Jenkins, M.A. 2013. The history of human disturbance in forest ecosystems of southern Indiana. Pp. 2-11. *In* The Hardwood Ecosystem Experiment: a Framework for Studying Responses to Forest Management. (R.K. Swihart, M.R. Saunders, R.A. Kalb, G.S. Haulton & C.H. Michler, Eds.) United States Department of Agriculture, Forest Service, Northern Research Station. General Technical Report NRS-P-108 2-11, Newtown Square, Pennsylvania.

Kunz, T.H. 2003. Censusing bats: challenges, solutions, and sampling biases. Pp. 9-19. *In* Monitoring Trends in Bat Populations of the United States and Territories: Problems and Prospects. (T.J. O'Shea & M.A. Bogan, Eds.) USGS Information and technology report 0003, Fort Collins, Colorado.

Kunz, T.H., E.B. Arnett, W.P. Erickson, A.R. Hoar, G.D. Johnson, R.P. Larkin, M.D. Strickland, R.W. Thresher & M.D. Tuttle. 2007. Ecological impacts of wind energy development on bats: questions, research needs, and hypotheses. Frontiers in Ecology and the Environment 5:315–324.

Larson, D.J. & J.P. Hayes. 2000. Variability in sensitivity of Anabat II bat detectors and a method of calibration. Acta Chiropterologica 2:209–213.

Law, B. & M. Chidel. 2002. Tracks and riparian zones facilitate the use of Australian regrowth forest by insectivorous bats. Journal of Applied Ecology 39:605–617.

Lawrence, B.D. & J.A. Simmons. 1982. Measurements of atmospheric attenuation at ultrasonic frequencies and the significance for echolocation by bats. The Journal of the Acoustical Society of America 71:585–590.

Loeb, S., J. Coleman, L. Ellison, P. Cryan, T. Rodhouse, T. Ingersoll & R. Ewing. 2012. Development of a North American bat population monitoring and modeling program [abstract]. North American Society for Bat Research (NASBR), 42nd Annual Symposium on Bat Research, San Juan, Puerto Rico, 24-27 October, 2012.

Lorch, J.M., C.U. Meteyer, M.J. Behr, J.G. Boyles, P.M. Cryan, A.C. Hicks, A.E. Ballmann, J.T.H. Coleman, D.N. Redell, D.M. Reeder & D.S. Blehert. 2011. Experimental infection of bats with *Geomyces destructans* causes white-nose syndrome. Nature 480:376–378.

Menzel, J.M., M.A. Menzel, J.C. Kilgo, W.M. Ford, J.W. Edwards & G.F. McCracken. 2005. Effect of habitat and foraging height on bat activity in the coastal plain of South Carolina. Journal of Wildlife Management 69:235–245.

Minnis, A.M. & D.L. Lindner. 2013. Phylogenetic evaluation of *Geomyces* and allies reveals no close relatives of *Pseudogymnoascus destructans*, comb. nov., in bat hibernacula of eastern North America. Fungal Biology 117:638–649.

Murray, K.L., E.R. Britzke, B.M. Hadley & L.W. Robbins. 1999. Surveying bat communities: a comparison between mist nets and the Anabat II bat detector system. Acta Chiropterologica 1:105–112.

Murray, K.L., E.R. Britzke & L.W. Robbins. 2001. Variations in search-phase calls of bats. Journal Mammalogy 82:728–737.

O'Farrell, M.J. 1998. A passive monitoring system for Anabat II using a laptop computer. Bat Research News 39:147–150.

O'Farrell, M.J. & W.L. Gannon. 1999. A comparison of acoustic versus capture techniques for the inventory of bats. Journal of Mammalogy 80:24–30.

O'Farrell, M.J., B.W. Miller & W.L. Gannon. 1999. Qualitative identification of free-flying bats using the Anabat detector. Journal of Mammalogy 80:11–23.

Patriquin, K.J. & R.M.R. Barclay. 2003. Foraging by bats in cleared, thinned and unharvested boreal forest. Journal of Applied Ecology 40:646–657.

Pauli, B.P. 2014. Nocturnal and diurnal habitat of Indiana and northern long-eared bats, and the simulated effect of timber harvest on habitat suitability. Ph.D. Dissertation. Purdue University, West Lafayette, Indiana, USA. 182 pp. At: http://gradworks.umi.com/36/69/3669524.html

Roche, N., S. Langton, T. Aughney, J.M. Russ, F. Marnell, D. Lynn & C. Catto. 2011. A car-based monitoring method reveals new information on bat populations and distributions in Ireland. Animal Conservation 14:642–651.

Rodhouse, T.J., P.C. Ormsbee, K.M. Irvine, L.A. Vierling, J.M. Szewczak & K.T. Vierling. 2012. Assessing the status and trend of bat populations across broad geographic regions with dynamic distribution models. Ecological Applications 22:1098–1113.

Romeling, S., C.R. Allen & L. Robbins. 2012. Acoustically detecting Indiana bats: how long does it take? Bat Research News 53:51–57.

Schaub, A., J. Ostwald & B.M. Siemers. 2008. Foraging bats avoid noise. Journal of Experimental Biology 211:3174–3180.

Shao, G., B.P. Pauli, G.S. Haulton, P.A. Zollner & G. Shao. 2014. Mapping hardwood forests through a two-stage unsupervised classification by integrating Landsat Thematic Mapper and forest inventory data. Journal of Applied Remote Sensing 8:083546.

Shier, T.A., C.M. Hudson & S.A. Johnson. 2013. 2012 Indiana mobile acoustic bat survey program. Indiana Department of Natural Resources, Bloomington, Indiana. 8 pp.

Skalak, S.L., R.E. Sherwin & R.M. Brigham. 2012. Sampling period, size and duration influence measures of bat species richness from acoustic surveys. Methods in Ecology and Evolution 3:490–502.

Stahlschmidt, P. & C.A. Brühl. 2012. Bats as bioindicators – the need of a standardized method for acoustic bat activity surveys. Methods in Ecology and Evolution 3:503–508.

Thogmartin, W.E., R.A. King, P.C. MacKann, J.A. Szymanski & L. Pruitt. 2012. Population-level impact of white-nose syndrome on the endangered Indiana bat. Journal of Mammalogy 93:1086–1098.

Thogmartin, W.E., C.A. Sanders-Reed, J.A. Szymanski, P.C. McKann, L. Pruitt, R.A. King, M.C. Runge & R.E. Russell. 2013. White-nose syndrome is likely to extirpate the endangered Indiana bat over large parts of its range. Biological Conservation 160:152–172.

Thomas, D.W. 1988. The distribution of bats in different ages of Douglas-fir forests. Journal of Wildlife Management 52:619–629.

Turner, G.G., D.M. Reeder & J.T.H. Coleman. 2011. A five-year assessment of mortality and geographic spread of white-nose syndrome in North American bats and a look to the future. Bat Research News 52:13–27.

USFWS (United States Fish and Wildlife Service). 2012. White-nose syndrome: the devastating disease of hibernating bats in North America. United States Fish and Wildlife Service. 2 pp.

USFWS. 2013. Endangered and threatened wildlife and plants; 12-month finding on a petition to list the eastern small-footed bat and the northern long-eared bat as endangered or threatened species; listing the northern long-eared bat as an endangered species. Federal Register 78:61046–61080.

USFWS. 2014. Range-wide Indiana bat summer survey guidelines. United States Fish and Wildlife Service. 41 pp.

Walsh, A.L. & S. Harris. 1996. Foraging habitat preferences of vespertilionid bats in Britain. Journal of Applied Ecology 33:508–518.

Walters, C.L., A. Collen, T. Lucas, K. Mroz, C.A. Sayer & K.E. Jones. 2013. Challenges of using bioacoustics to globally monitor bats. Pp. 479-500. *In* Bat Evolution, Ecology, and Conservation. (R.A. Adams & S.C. Pedersen, Eds.) Springer, New York, New York.

Whitaker, J.O., V. Brack, Jr., D.W. Sparks, J.B. Cope & S. Johnson. 2007. Bats of Indiana. Indiana State University Center for North American Bat Research and Conservation, Terre Haute, Indiana. 59 pp.

Whitaker, J.O., A. Kurta & T.C. Carter. 2011. Retention of the common name eastern pipistrelle for *Perimyotis subflavus*. Bat Research News 52:53–54.

Whitby, M.D., T.C. Carter, E.R. Britzke & S.M. Bergeson. 2014. Evaluation of mobile acoustic techniques for bat population monitoring. Acta Chiropterologica 16:223–230.

WNS (White-Nose Syndrome.org; A Coordinated Response to the Devastating Bat Disease). 2015. At: https://www.whitenosesyndrome.org/ (Accessed 12 February 2015).

Zurcher, A.A., D.W. Sparks & V.J. Bennett. 2012. Why the bat did not cross the road? Acta Chiropterologica 12:337–340.

*Manuscript received 24 October 2014, revised 13 February 2015.*

2014. Proceedings of the Indiana Academy of Science 123(2):112–121

# MACROINVERTEBRATE COMMUNITY RESPONSE TO A SPATE DISTURBANCE IN A THIRD ORDER OHIO STREAM

**Dawn T. DeColibus**[1], **Julia K. Backus**[1], **Nicole M. Howard**[2] and **Leslie A. Riley**[3]: Department of Biological and Allied Health Sciences, Ohio Northern University, 525 S. Main Street, Ada, OH 45810 USA

**ABSTRACT.** A spate, or sudden flood, is a common disturbance in streams and can be an important factor in structuring macroinvertebrate communities. However, the effects of spates are likely mediated by other factors, such as habitat. This study tested whether a spate (22.5 times higher than base flow) influenced macroinvertebrate community composition and abundance in riffles and pools within the Kokosing River in Knox County, Ohio. Five pools and five riffles were sampled before and after a spate for macroinvertebrates and physical parameters during fall 2011. Macroinvertebrate communities and physical parameters differed between riffles and pools. Riffles had higher flow rates, a higher % EPT (Ephemeroptera, Plecoptera and Trichoptera) index and increased Shannon diversity compared to pools. We found that habitat was more influential on macroinvertebrate communities than the occurrence of a single spate. However, this single spate disturbance altered water depth and current velocity, increased diversity in riffles and pools, and homogenized community composition across habitat types. Changes in community structure resulted from decreased abundance for some of the dominant riffle taxa (e.g., Hydropsychidae, Baetidae) and an increased abundance of some taxa in pools after the spate (e.g., Chironomidae). We also found more similarity between riffle and pool communities following the spate. These results suggest that the macroinvertebrate community is relatively resistant and resilient to a spate of this magnitude, but flooding can alter community composition in both riffles and pools in this river.

**Keywords:** flood, flow refugia, Kokosing River, pools, riffles

## INTRODUCTION

Natural flow disturbance is central in shaping lotic community structure (Power et al. 1988; Resh et al. 1988). During droughts, drastic declines in flow usually result in a reduction of available habitat for stream biota (Hynes 1958; Smock et al. 1994; Erman & Erman 1995). Alternatively, during sudden floods, or spates, greater discharge can increase the availability of habitat by inundating previously dry areas or scouring streambeds, resulting in a mosaic of patches that can be recolonized (Mackay 1992; Brooks 1998; Lake 2000). Spates, though, also increase current velocity and turbulence (Hose et al. 2007). Higher volumes of fast-moving water can suspend sediments; redistribute organic and inorganic benthic materials (e.g., detritus and debris); uproot plants; and displace, injure, or kill aquatic animals (Lake 2000).

The impacts of spates on macroinvertebrate communities are usually negative. Macroinvertebrate abundance (Bond & Downes 2003; Melo et al. 2003; Mundahl & Hunt 2011) and species richness (Bond & Downes 2003; Death & Winterbourn 1995; Death 2002) may be significantly lower immediately after spates or experimental flow disturbance events. Angradi (1997) found that most macroinvertebrate taxa decreased in abundance by 70–95% following one spate. Alternatively, some spates had no significant effects on macroinvertebrate abundance (Palmer et al. 1992; Dole-Olivier et al. 1997) or Shannon diversity (Reice 1984) and, in some cases, evenness (Death & Winterbourn 1995; Mesa 2010) or Simpson's diversity increased (Death & Winterbourn 1995).

Stream habitats can potentially mitigate the response of macroinvertebrate communities to spates. For example, current velocity can increase substantially in riffles while maintaining relatively slower speeds in other areas

---

[1] *Current address:* Department of Biology, Ball State University, Muncie, Indiana 47306.

[2] *Current address:* Ohio Division of Wildlife, Inland Fisheries Research Unit, 10517 Canal Road, Hebron, Ohio 43025.

[3] *Corresponding author:* Leslie A. Riley, 419-772-3143 (phone), 419-772-2330 (fax), l-riley.1@onu.edu.

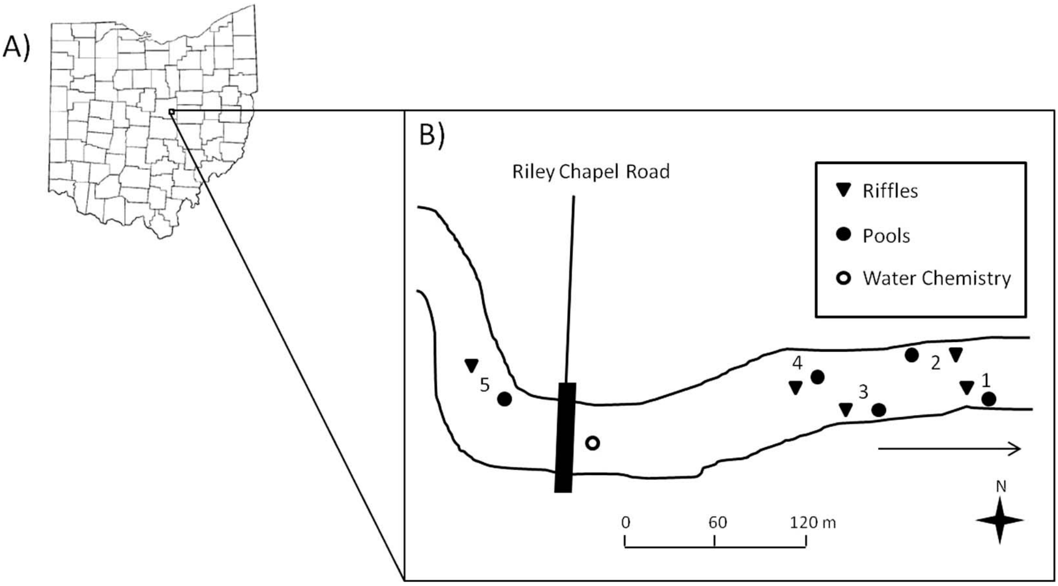


Figure 1.—Location of study site in Knox County, Ohio (A). Sampling sites (1–5) in the Kokosing River (B). Arrow indicates the direction of water flow.

(Negishi et al. 2002). As a result, some stream habitats might act as flow refugia where density-independent losses of macroinvertebrates are likely to be minimal (Lancaster & Hildrew 1993). Flow refugia have been documented in pools, backwaters, interstitial spaces, and hyporheic zones (Brooks 1998; Palmer et al. 1992; Dole-Olivier et al. 1997; Negishi et al. 2002). Because streams differ in the amount of flow refugia that are present, the resilience of macroinvertebrate communities to spates is also likely to differ. Systems with larger rocks, intact riffle and pool sequences, and potentially more refugia (Matthaei et al. 1996, 1997; Brooks 1998) should display faster recolonization of disturbed habitat patches, while streams with sandy substrates and few refugia are likely to demonstrate slower recolonization rates after spates (Fisher et al. 1982; Grimm & Fisher 1989).

While it is well-known that flow disturbances influence macroinvertebrate communities, the direction and magnitude of these effects are unresolved (Death & Winterbourn 1995). In this study, we examined how macroinvertebrate communities in two habitat types were affected by a spate in the Kokosing River (Knox Co., Ohio). The Kokosing River experiences a wide range of flow regimes and has a variety of habitat types that are well-represented. Our specific objectives were to (1) characterize macroinvertebrate communities in pools and riffles within the Kokosing River, (2) document community changes within each habitat type after a spate, and (3) compare changes in community structure across habitat types after a spate.

## METHODS

**Study site and design.**—The Kokosing River (40° 22.352' N and 82° 12.029' W) is a third order stream in Knox County, Ohio located within the Muskingum (Ohio) River drainage basin (Fig. 1). The Kokosing River bears a Scenic River designation from the Ohio Department of Natural Resources, indicating a waterway that retains much of its natural character with limited human disturbance (Ohio EPA 2010). The substrate of the Kokosing River is primarily composed of bedrock, boulders, and large cobble derived from the Blackhand Sandstone formation (Slucher et al. 2006).

Our study site in the Kokosing River was designated as Exceptional Warmwater Habitat (EWH) and was in full attainment prior to this study (Ohio EPA 2010). A relatively high QHEI score (88) also indicated the presence of a diversity of stream habitats and a moderately intact riparian zone (Ohio EPA 2006).

The riparian zone was dominated by sycamore (*Platanus occidentalis* L.), eastern cottonwood (*Populus deltoides* Bartram ex Marshall), silver maple (*Acer saccharinum* L.), and box elder (*Acer negundo* L.).

On 18 October 2011, the river was at base flow, approximately1.22 $m^3$/s (USGS 03136500 gauging station, http://waterdata.usgs.gov/nwis/uv?site_no=03136500). We sampled ten areas before the spate – five riffles and five pools (Fig. 1). At each pool and riffle, we measured water depth with a meter stick and current velocity with a flow meter (General Oceanics Flow Meter Model 2030, Miami, FL). For riffles, water depth and current velocity were measured at 20%, 40%, 60%, and 80% of the width of the riffle. The average of each variable was used in later analyses. For pools, water depth and current velocity were measured in the center of each pool. At each location, macroinvertebrates were collected with a Surber sampler (area: 900 $cm^2$; 250 µm mesh) and preserved in 70% ethanol. In pools, we added a base extension to the Surber sampler to minimize collection of fine sediments outside of the target area. We used a YSI® 556 Multi-Parameter Water Quality Meter (Yellow Springs, Ohio) to measure basic water chemistry (e.g., water temperature, specific conductance, dissolved oxygen, pH) between sites 4 and 5 (Fig. 1). Water samples were also collected between sites 4 and 5 and placed on ice for transport back to the laboratory for further laboratory analyses of $SiO_2$, $PO_4$, $NO_3$-N, $SO_4$, Cl, total hardness, turbidity and total alkalinity (see Lab Methods).

Over 5 cm of precipitation occurred on 19 and 20 October 2011, resulting in a peak discharge of 22 $m^3$/s on 20 October 2011. On 26 October 2011, the Kokosing River was revisited during its flood state, when discharge was 6.03 $m^3$/s. We sampled ten areas after the spate – five riffles and five pools (Fig. 1). Collection of macroinvertebrates and physicochemical properties during the flood stage followed the protocol utilized during the first visit.

**Lab methods.**—Macroinvertebrates were examined using stereoscopes. Insects were identified to family level; other invertebrates were identified to class or order using Voshell (2002), Merritt et al. (2008), and Thorp & Covich (2010). Taxonomic resolution to family is sufficient for most bioassessment studies of anthropogenic and natural disturbance using macroinvertebrates (Waite et al. 2004).

Water samples were analyzed for $SiO_2$ (Method 8185), $PO_4$ (Method 8048), $NO_3$-N (Method 8171), and $SO_4$ (Method 8051) using a Hach DR/890TM colorimeter (Loveland, CO). Total hardness (Ca mg/L) and chlorine (mg/L) were measured with testing strips (Hach Company, Loveland, CO). Stream water turbidity was determined with a HACH 2100P$^{TM}$ turbidity meter (Loveland, CO) and total alkalinity was determined using titration (Hanna Instruments Method 4811).

**Statistical analyses.**—To analyze the effects of habitat type and spate condition, we used analyses of variance (ANOVAs) (Minitab 16 (Minitab Inc., 2010)). Response variables were water depth, current velocity, and macroinvertebrate community metrics (i.e., abundance (individuals/$m^2$), taxa richness, Shannon diversity (*H'*), and % EPT [the percentage of total organisms in the orders Ephemeroptera, Plecoptera and Trichoptera] (Resh & Jackson 1993; Magurran 2004). Normality of response variables was assessed with probability plots and Anderson-Darling tests. Square root transformations were used for abundance and current velocity and an arcsine transformation was used for % EPT.

To evaluate macroinvertebrate community composition, we used non-metric multidimensional scaling (NMDS) to create an ordination plot of samples based on a Bray-Curtis dissimilarity matrix (Kruskal 1964; Mather 1976). Rare taxa were defined as those occurring in only one sample and were removed from the data set prior to ordination analysis. A Monte Carlo test was used to compare 50 runs of our data to 50 runs of randomized data to determine whether an ordination solution with comparable stress could be obtained by chance alone. To test for significant differences between habitat types and spate condition, nonparametric multi-response permutation procedures (MRPP) were used. Finally, indicator species analyses were employed to determine which taxa were most influential for distinguishing among habitats before and after the spate. Indicator analysis combines information on the relative abundance and relative frequency of each taxon within each sample group (Dufrêne & Legendre 1997). A perfect indicator would be both exclusive to that group and always present in samples from that group

Table 1.—Water chemistry in the Kokosing River on 18 October 2011 (Pre-spate) and 26 October 2011 (Post-spate).

| | Pre-spate | Post-spate |
|---|---|---|
| Conductivity (mS/cm) | 0.52 | 0.45 |
| Total Dissolved Solids (g/L) | 0.34 | 0.29 |
| Salinity (mg/L) | 0.25 | 0.22 |
| Dissolved Oxygen (mg/L) | 11.30 | 12.07 |
| pH | 8.90 | 8.43 |
| Alkalinity ($CaCO_3$ mg/L) | 300 | 260 |
| $NO_3$ (mg/L) | 1.20 | 3.60 |
| $PO_4$ (mg/L) | 0.12 | 0.22 |
| $SiO_2$ (mg/L) | 5.60 | 8.00 |
| $SO_4$ (mg/L) | 30 | 32 |
| Turbidity (NTUs) | 2 | 4 |
| Water Temperature (°C) | 12.5 | 11.0 |

(McCune & Grace 2002). Two Monte Carlo tests with 5000 randomizations were used to test the significance of indicator values for habitat type before and after the spate. MRPP and indicator analyses were all conducted in PC-ORD version 6.08 (McCune & Mefford 2011).

## RESULTS

Water chemistry in the Kokosing River was similar on both sampling days and was not included in further analyses (Table 1). Physical parameters changed during the study: water depth (Table 2, Fig. 2A) and current velocity (Table 2, Fig. 2B) both significantly increased after the spate. Current velocity was also faster in riffles compared to pools throughout the course of the study (Table 2, Fig. 2A).

Some macroinvertebrate community metrics were different between habitats and changed after the spate. Riffles had a significantly higher % EPT index than pools (Table 2, Fig. 3A). Percent EPT decreased in riffles after the spate, but increased in pools, as indicated by a significant habitat × spate interaction term (Table 2, Fig. 3A). Shannon diversity ($H'$) was significantly higher in riffles (Table 2, Fig. 3B) and there was a trend towards increased Shannon diversity after the spate in both habitat types, although this result was not significant ($p$ = 0.057, Table 2, Fig. 3B). Variance in % EPT index and Shannon diversity (H') was also greater in pools after the spate (Fig. 3A & 3B). Taxa richness and total macroinvertebrate abundance were not significantly affected by habitat or spate condition (Table 2, Figs. 3C & 3D).

The NMDS ordination showed that macroinvertebrate community composition was distinctly different between riffles and pools before the spate, but overlapped after the spate (Fig. 4) (3-dimensional solution stress = 7.06, $p = 0.04$). MRPP analysis confirmed the visual patterns evident with NMDS. Riffle communities differed significantly from pool communities

Table 2.—ANOVA summary of the effects of habitat type and spate condition on physical parameters and macroinvertebrate community metrics in the Kokosing River.

| Response | N | Source | F | $p$ |
|---|---|---|---|---|
| **Water Depth** | 20 | Habitat Type | 0.75 | 0.400 |
| | | Spate Condition | 6.73 | 0.020 |
| | | Habitat × Spate | 0.07 | 0.790 |
| **Current Velocity** | 20 | Habitat Type | 91.73 | <0.001 |
| | | Spate Condition | 5.72 | 0.029 |
| | | Habitat × Spate | 1.15 | 0.298 |
| **% EPT** | 20 | Habitat Type | 25.19 | <0.001 |
| | | Spate Condition | 0.01 | 0.933 |
| | | Habitat × Spate | 6.00 | 0.026 |
| **Shannon Diversity** | 20 | Habitat Type | 10.31 | 0.005 |
| | | Spate Condition | 4.22 | 0.057 |
| | | Habitat × Spate | 1.82 | 0.196 |
| **Taxa Richness** | 20 | Habitat Type | 0.37 | 0.553 |
| | | Spate Condition | 0.11 | 0.741 |
| | | Habitat × Spate | 0.00 | 0.947 |
| **Abundance** | 20 | Habitat Type | 0.00 | 0.955 |
| | | Spate Condition | 1.04 | 0.323 |
| | | Habitat × Spate | 0.23 | 0.634 |

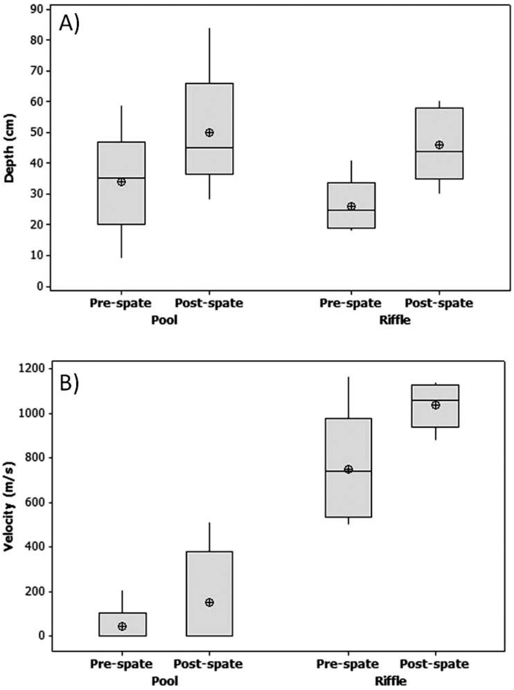


Figure 2.—Depth (A) and current velocity (B) in five pools and five riffles in the Kokosing River before (18 October 2011) and after (26 October 2011) a spate event (N=20). For each response, circles represent the mean, horizontal lines show the median, gray boxes represent the interquartile range (IQR) and whiskers indicate values occurring within the upper (3rd quartile + 1.5*IQR) and lower (1st quartile + 1.5*IQR) limit.

before the spate (T = -2.20, A = 0.16, $p$ = 0.038) while post-spate communities in the two habitats were not significantly different from one another (T = -1.09, A = 0.05, $p$ = 0.127). Pre-spate macroinvertebrate communities demonstrated stronger separation between habitats (more negative T values) as well as greater within-habitat homogeneity (higher A values) compared to post-spate communities. However, MRPP analyses within each habitat type indicated macroinvertebrate assemblages were not significantly different before and after the spate (Riffles: T = 1.09, A = -0.05, $p$ = 0.883; Pools: T = -0.11, A = 0.01, $p$ = 0.364).

Indicator species analysis prior to the spate showed that Baetidae (IndVal = 43.9, $p$ = 0.007) and Hydropsychidae (IndVal = 47.5, $p$ = 0.007) were indicative of riffle habitat due to high abundance and high frequency in riffle samples (Table 3). Heptageniidae (IndVal = 42.6, $p$ = 0.086) were somewhat indicative of riffle habitat, but had lower abundance than the two aforementioned families (Table 3). After the spate, only Heptageniidae (IndVal= 37.7, $p$ = 0.046) were indicative of riffle habitat.

In general, the average abundance of dominant macroinvertebrate taxa declined after the spate. In riffles, the three most abundant macroinvertebrate groups decreased 51.6% - 83.8% after the spate (Baetidae: 83.8%, Hydropsychidae: 80.3%, Heptageniidae: 51.6%) (Table 3). In pools, the most abundant group decreased by 94.6% after the spate (Pleuroceridae), but the second most abundant group actually increased by 43.0% (Chironomidae) (Table 3).

## DISCUSSION

Water depth and current velocity both increased significantly after the spate, but macroinvertebrate riffle and pool communities were relatively resistant and resilient to a spate of this magnitude. For example, total macroinvertebrate abundance was not reduced by the spate. This finding is in contrast to many previous studies examining the effects of spates in streams (Lamberti et al. 1991; Angradi 1997; Bond & Downes 2003; Melo et al. 2003). There are at least three possible reasons for this finding. First, a large amount of variation was present in macroinvertebrate densities prior to the spate and thus, even with a decline in abundance after the spate, the result was not statistically significant. When examining individual groups of invertebrates, the average of many abundant groups declined after the spate (Table 3; Angradi 1997). One exception to this pattern was the increase in Chironomidae in pools after the spate. A second likely explanation is that the community was relatively resistant to this spate. Some organisms in the Kokosing River, such as the heptageniid mayflies, are well-adapted to high flow conditions and have adaptations for clinging to substrates, such as dorsoventrally flattened bodies and holdfast organs (Hora 1930). Heptageniids declined, but were still a large percentage of the riffle community after the spate. It is also likely that the spate was not strong enough to completely dislodge organisms. This spate was 22–23 times the average base flow for October, but at the highest discharge (22 $m^3$/s), was equal to the average

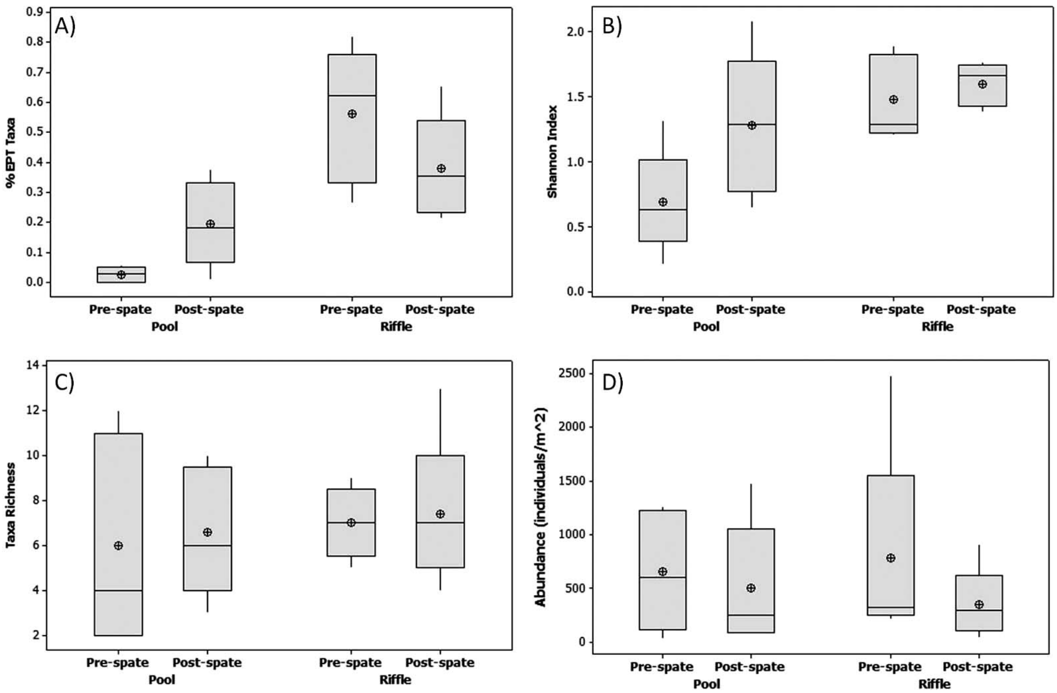


Figure 3.—% EPT taxa (A), diversity (B), taxa richness (C) and abundance (D) in five pools and five riffles in the Kokosing River before (18 October 2011) and after (26 October 2011) a spate event (N=20). For each response, circles represent the mean, horizontal lines show the median, gray boxes represent the interquartile range (IQR) and whiskers indicate values occurring within the upper ($3^{rd}$ quartile + 1.5*IQR) and lower ($1^{st}$ quartile + 1.5*IQR) limit.

base flow in some spring months and remained within the bankfull height of the Kokosing River (USGS 2011). A third explanation is that the community was relatively resilient to this spate and recovered quickly. Recolonization of disturbed habitat patches happened rapidly following this disturbance and was facilitated by habitat refugia and morphological, behavioral, and physiological traits of the organisms (Wallace & Anderson 1996; Lytle & Poff 2004). Angradi (1997) found that full recovery of macroinvertebrate density in Appalachian streams can take 4–6 months to occur and some invertebrate groups may not recover to pre-flood densities 22 months after the event (Mundahl & Hunt 2011). However, invertebrates in desert streams in the western United States recovered in 2–4 weeks (Fisher et al. 1982; Grimm & Fisher 1989), similar to Australian tropical rainforest streams (Rosser & Pearson 1995). Given that this post-spate sampling date was 5 days after peak flood discharge, the community did not have time to completely recover; however, some recovery had already started. This spate caused

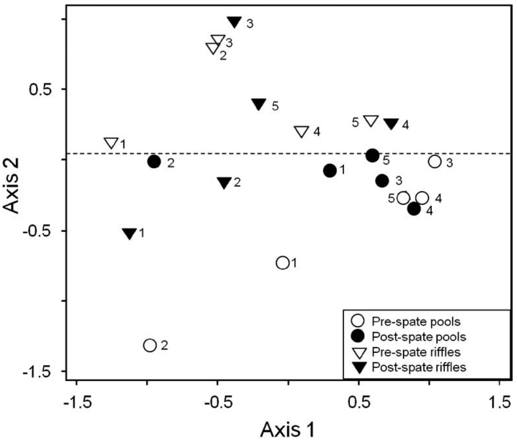


Figure 4.—NMDS ordination plot for relative abundance of macroinvertebrate taxa in riffles and pools before (18 October 2011) and after (26 October 2011) a spate event (N=20). Triangles represent riffles; circles represent pools. Open symbols indicate pre-spate conditions; closed symbols indicate post-spate conditions. Numbers correspond to sites in Fig. 1. Dotted line bisecting axis 2 separates riffle sites from pool sites before the spate, but not after the spate.

Table 3.—Mean abundance of macroinvertebrate taxa per m$^2$ (± 1 SE) of macroinvertebrate taxa before and after the spate in riffles and pools.

| Taxa | | Riffles | | Pools | |
|---|---|---|---|---|---|
| | | Pre-Spate | Post-Spate | Pre-Spate | Post-Spate |
| Ephemeroptera | Baetidae | 124 (61) | 20 (17) | – | – |
| | Caenidae | – | 4 (4) | – | – |
| | Ephemerellidae | 4 (4) | 2 (2) | 9 (9) | – |
| | Ephemeridae | – | 7 (7) | – | 22 (15) |
| | Heptageniidae | 64 (36) | 31 (15) | 7 (7) | – |
| | Leptophlebiidae | – | 2 (2) | – | – |
| | Oligoneuriidae | – | 7 (7) | – | – |
| Odonata | Gomphidae | – | – | 2 (2) | – |
| | Libellulidae | – | – | 2 (2) | – |
| | Unknown Anisoptera | – | – | – | 2 (2) |
| Plecoptera | Chloroperlidae | – | – | – | 4 (4) |
| | Perlidae | – | – | – | 7 (3) |
| | Perlodidae | 9 (6) | – | 4 (4) | – |
| | Unknown Plecoptera | 2 (2) | – | – | – |
| Megaloptera | Corydalidae | – | – | – | 2 (2) |
| Trichoptera | Hydropsychidae | 324 (240) | 64 (35) | 2 (2) | 4 (3) |
| | Hydroptilidae | – | 2 (2) | – | – |
| | Limnephilidae | – | – | 2 (2) | – |
| Lepidoptera | Pyralidae | 2 (2) | – | – | – |
| Coleoptera | Elmidae | 7 (3) | 24 (19) | 7 (3) | 4 (4) |
| | Psephenidae | – | 2 (2) | – | – |
| Diptera | Athericidae | – | 4 (4) | – | – |
| | Chironomidae | 78 (24) | 40 (15) | 244 (107) | 349 (240) |
| | Culicidae | – | 2 (2) | – | – |
| | Simuliidae | – | – | 2 (2) | – |
| | Tabanidae | – | – | – | 2 (2) |
| | Tipulidae | – | 2 (2) | – | – |
| Crustacea | Amphipoda | 2 (2) | – | 7 (7) | – |
| | Copepoda | – | – | – | 4 (4) |
| | Ostracoda | – | – | 2 (2) | 2 (2) |
| Chelicerata | Acari | 7 (7) | – | 4 (4) | 4 (3) |
| Gastropoda | Ancylidae | – | – | – | 7 (7) |
| | Lymnaeidae | – | – | 2 (2) | 2 (2) |
| | Physidae | – | 4 (3) | 4 (3) | 13 (13) |
| | Pleuroceridae | 142 (137) | 96 (87) | 331 (207) | 18 (9) |
| Bivalvia | *Corbicula fluminea* | – | – | 9 (6) | 2 (2) |
| Annelida | Oligochaeta | 11 (6) | 22 (9) | 16 (10) | 42 (17) |
| Platyhelminthes | Turbellaria | 4 (4) | 4 (4) | – | 2 (2) |
| Cnidaria | *Hydra* | – | – | – | 7 (7) |
| | TOTAL | 782 (430) | 342 (148) | 658 (250) | 502 (263) |

declines of some macroinvertebrate groups, but total abundance was not affected by a spate of this magnitude.

Even though macroinvertebrate abundance was not significantly affected, Shannon diversity slightly increased in both riffles and pools after the spate. Intermediate levels of disturbance are thought to create situations that yield maximum levels of diversity by reducing the abundance of strong competitors and creating space for pioneer species to reestablish (Connell 1978). In riffle habitat of the Kokosing River, this spate reduced the abundance of the dominant macroinvertebrates (i.e., Hydropsychidae and Baetidae; Table 3), potentially opening patches for less abundant taxa (e.g., Elmidae and Ephemeridae; Table 3). In pools the pattern was slightly different, with one of the two most dominant groups decreasing in abundance (i.e., Pleuroceridae), and the other dominant group increasing in abundance (i.e., Chironomidae). Regardless, many of the less abundant taxa increased, resulting in a more even distribution of taxa (Death & Winterbourn 1995). In contrast, other studies indicate that floods drastically reduced the richness (Bond & Downes 2003; Effenberger et al. 2008) or Simpson's diversity of macroinvertebrate communities (Death 2002). These conflicting findings can likely be explained by different disturbance regimes with greater reduction in macroinvertebrate abundance, species richness, and species diversity occurring with floods of greater magnitude or frequency.

Across habitat types, macroinvertebrate communities became more homogeneous after the spate. Taxa that served as indicators for riffle communities before the spate, declined after the spate. This included steep decreases in the two most dominant pre-spate riffle taxa (i.e., Hydropsychidae and Baetidae); however, there was little evidence that pools in the Kokosing River served as refugia for these dominant riffle organisms. No baetid mayflies were recovered in pools after the spate and only a few hydropsychid caddisflies were observed in this habitat throughout the study. Conversely, chironomids decreased in riffles after the spate and increased in pool samples. Chironomids might have used pools as refugia, but it is also possible that disturbed sediments uncovered chironomids that were previously buried. Brooks (1998) found evidence for the passive movement of chironomids from riffles to pools during a large flood. Brooks (1998) also reported mayflies in pools following a large flood, but that was not the case in the current study.

Negishi et al. (2002) found that pool taxa were most negatively affected by a flood, with taxa richness significantly decreasing. In that study, backwaters and inundated areas, instead of pools, acted as refugia for the recolonization of riffle habitat. The hyporheic zone could serve as a flow refugium for benthic invertebrates during times of flooding in the Kokosing River (Williams & Hynes 1974). While the hyporheic zone was not sampled in this study, some studies have concluded that it serves a major refugium for some benthic taxa, including *Gammarus* and cladocerans (Dole-Olivier et al. 1997). However, Palmer et al. (1992) found little evidence that the hyporheic zone was important as a refugium for benthic invertebrates.

Macroinvertebrate assemblages were more influenced by habitat differences than by the occurrence of a single spate in the Kokosing River. Shannon diversity and % EPT were always greater in riffles when compared to pools, confirming previous studies. A single spate caused reductions in dominant riffle taxa, which caused diversity to increase within riffles after the spate and homogenized taxa composition and evenness across two habitats after the spate. Macroinvertebrate assemblage structure in the Kokosing River is driven by habitat variables, but disturbances of this magnitude are likely to be important for maintaining diversity within different habitat types in this system.

## ACKNOWLEDGMENTS

Special thanks to Brittany Bianco, Bethany Blakely, Chad Carroll, Kandai Doi, Garrett Fruchey, Maggie Molnar, Emily Nebgen, and Josh Ryan for their assistance in collecting and sorting macroinvertebrates. Robert Verb assisted with water chemistry analyses. John Mager and Robert Verb provided constructive comments on earlier drafts and three anonymous reviewers strengthened the final draft of this manuscript. Carol and Wayne King at the Metzger Nature Center in Tuscawaras County, Ohio provided field accommodations and logistical support.

## LITERATURE CITED

Angradi, T.R. 1997. Hydrologic context and macroinvertebrate community response to floods in an Appalachian headwater stream. American Midland Naturalist 138:371–386.

Bond, N.R. & B.J. Downes. 2003. The independent and interactive effects of the fine sediment and flow on benthic invertebrate communities are characteristic of small upland streams. Freshwater Biology 48:455–465.

Brooks, S.S. 1998. Impacts of Flood Disturbance on the Macroinvertebrate Assemblage of an Upland Stream [PhD thesis]. Monash University, Clayton, Victoria 3168, Australia. 468 pp.

Connell, J.H. 1978. Diversity in tropical rain forests and coral reefs. Science 199:1302–1309.

Death, R.G. 2002. Predicting invertebrate diversity from disturbance regimes in forest streams. Oikos 97:18–30.

Death, R.G. & M.J. Winterbourn. 1995. Diversity patterns in stream benthic invertebrate communities: the influence of habitat stability. Ecology 76:1446–1460.

Dole-Olivier, M.J., P. Marmonier & J.L. Buffy. 1997. Response of invertebrates to lotic disturbance: is the hyporheic zone a patchy refugium? Freshwater Biology 37:257–276.

Dufrêne, M. & P. Legendre. 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecological Monographs 67:345–366.

Effenberger, M., J. Engel, S. Diehl & C.D. Matthaei. 2008. Disturbance history influences the distribution of stream invertebrates by altering microhabitat parameters: a field experiment. Freshwater Biology 53:996–1011.

Erman, N.A. & D.C. Erman. 1995. Spring permanence, *Trichoptera* species richness, and the role of drought. Journal of the Kansas Entomological Society 68:50–64.

Fisher, S.G., L.J. Gray, N.B. Grimm & D.E. Busch. 1982. Temporal succession in a desert stream ecosystem following a flash flooding. Ecological Monographs 52:93–110.

Grimm, N.B. & S.G. Fisher. 1989. Stability of periphyton and macroinvertebrates to disturbance by flash floods in a desert stream. Journal of the North American Benthological Society 8:293–307.

Hora, S.L. 1930. Ecology, bionomics and evolution of the torrential fauna, with special reference to the organs of attachment. Philosophical Transactions of the Royal Society of London, Series B 218: 171–282.

Hose, G., T. Walter & A. Brooks. 2007. Short-term colonization by macroinvertebrates of cobbles in main channel and inundated stream bank habitats. Hydrobiologia 592:513–522.

Hynes, H.B.N. 1958. The effect of drought on the fauna of a small mountain stream in Wales. Verhandlungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie 13: 826–833.

Kruskal, J.B. 1964. Nonmetric multidimensional scaling: a numerical method. Psychometrika 29: 115–129.

Lake, P.S. 2000. Disturbance, patchiness, and diversity in streams. Journal of the North American Benthological Society 19:573–592.

Lamberti, G.A., S.V. Gregory, L.R. Ashkenas, R.C. Wildman & K.M.S. Moore. 1991. Stream ecosystem recovery following a catastrophic debris flow. Canadian Journal of Fisheries and Aquatic Sciences 48:196–208.

Lancaster, J. & A.G. Hildrew. 1993. Flow refugia and the microdistribution of lotic macroinvertebrates. Journal of the North American Benthological Society 12:385–393.

Lytle, D.A. & N.L. Poff. 2004. Adaption to natural flow regimes. Trends in Ecology and Evolution 19: 94–100.

Mackay, R.J. 1992. Colonization by lotic macroinvertebrates: a review of processes and patterns. Canadian Journal of Fisheries and Aquatic Sciences 49:617–628.

Magurran, A.E. 2004. Measuring Biological Diversity. Wiley & Sons, Hoboken, New Jersey. 264 pp.

Mather, P.M. 1976. Computational Methods of Multivariate Analysis in Physical Geography. Wiley & Sons, London, England. 544 pp.

Matthaei, C.D., U. Uehlinger, E.I. Meyer & A. Frutiger. 1996. Recolonization of benthic invertebrates after experimental disturbance in a Swiss prealpine river. Freshwater Biology 35:233–248.

McCune, B. & J.B. Grace. 2002. Analysis of Ecological Communities. MjM Software, Gleneden Beach, Oregon, U.S.A.

McCune, B. & M.J. Mefford. 2011. PC-ORD. Multivariate analysis of ecological data, version 6.08. MjM Software, Gleneden Beach, Oregon, U.S.A.

Melo, A.S., D.K. Niyogi, C.D. Matthaei & C.R. Townsend. 2003. Resistance, resilience, and patchiness of invertebrate assemblages in native tussock and pasture streams in New Zealand after a hydrological disturbance. Canadian Journal of Fisheries and Aquatic Sciences 60:731–739.

Merritt, R.W., K.W. Cummins & M.B. Berg. 2008. An Introduction to the Aquatic Insects of North America, 4th ed. Kendall Hunt Publishing Co., Dubuque, Iowa. 1214 pp.

Mesa, L.M. 2010. Effect of spates and land use on macroinvertebrate community in neotropical Andean streams. Hydrobiologia 641:85–95.

Mundahl, N.D. & A.M. Hunt. 2011. Recovery of stream invertebrates after catastrophic flooding in southeastern Minnesota, USA. Journal of Freshwater Ecology 26:445–457.

Negishi, J.N., M. Inoue & M. Nunokawa. 2002. Effects of channelization on stream habitat in relation to a spate and flow refugia for macroinvertebrates in northern Japan. Freshwater Biology 47:1515–1529.

Ohio EPA (Environmental Protection Agency, Division of Surface Water). 2006. Methods for assessing habitat in flowing waters: using the qualitative habitat evaluation index (QHEI). Ohio EPA Bulletin EAS/2006-06-1, Groveport, Ohio. 26 pp.

Ohio EPA (Environmental Protection Agency, Division of Surface Water). 2010. Biological & water quality study of the Kokosing River and selected tributaries 2007. Ohio EPA Technical Report EAS/2010-05-09, Columbus, Ohio. 218 pp.

Palmer, M., A.E. Bely & K.E. Berg. 1992. Response of invertebrates to lotic disturbance: a test of the hyporheic refuge hypothesis. Oecologia 89:182–194.

Power, M.E., R.J. Stout, C.E. Cushing, P.P. Harper, F.R. Hauer, W.J. Matthews, P.B. Moyle, B. Statzner & I.R. Wais de Bagden. 1988. Biotic and abiotic controls in river and stream communities. Journal of the North American Benthological Society 7:456–479.

Reice, S.R. 1984. The impact of disturbance frequency on the structure of a lotic riffle community.

Verhandlungen des Internationalen Verein Limnologie 22:1906–1910.

Resh, V.H., A.V. Brown, A.P. Covich, M.E. Gurtz, H.W. Li, G.W. Minshall, S.R. Reice, A.L. Sheldon, J.B. Wallace & R.C. Wissmar. 1988. The role of disturbance in stream ecology. Journal of the North American Benthological Society 7: 433–455.

Resh, V.H. & J.K. Jackson. 1993. Rapid assessment approaches to biomonitoring using benthic macroinvertebrates. Pp. 195–223. *In* Freshwater Biomonitoring and Benthic Macroinvertebrates (D.M. Rosenberg & V.H. Resh, Eds.).Chapman & Hall, New York, New York.

Rosser, Z.C. & R.G. Pearson. 1995. Responses of rock fauna to physical disturbance in two Australian tropical rainforest streams. Journal of the North American Benthological Society 14: 183–196.

Slucher, E.R., E.M. Swinford, G.E. Larsen, G.A. Schumacher, D.L. Shrake, C.L. Rice, M.R. Caudill & R.G. Rea. 2006. Bedrock Geologic Map of Ohio. State of Ohio, Department of Natural Resources, Division of Geological Survey, Columbus, Ohio. 2 pp.

Smock, L.A., L.C. Smith, J.B. Jones & S.M. Hooper. 1994. Effects of drought and a hurricane on a coastal headwater stream. Archiv für Hydrobiologie 131:25–38.

Thorp, J.H., & A.P. Covich (Eds.). 2010, Ecology and Classification of North American Freshwater Invertebrates, 3rd ed. Elsevier Inc., Burlington, Massachusetts. 1021 pp.

USGS (United States Geological Survey). 2011. Kokosing River at Mount Vernon. At. http://nwis.waterdata.usgs.gov/oh/nwis/uv/?cb_00065=on&cb_00060=on&format=gif_default&period=&begin_date=2011-10-18&end_date=2011-10-27&site_no=03136500 (Accessed 9 January 2015).

Voshell, R.J. 2002. A Guide to Common Freshwater Invertebrates of North America. The McDonald & Woodward Publishing Company, Blacksburg, Virginia. 456 pp.

Waite, I.R., A.T. Herlihy, D.P. Larsen, N.S. Urquhart & D.J. Klemm. 2004. The effects of macroinvertebrate taxonomic resolution in large landscape bioassessments: an example from the Mid-Atlantic Highlands, USA. Freshwater Biology 49:474–489.

Wallace, B.J. & N.H. Anderson. 1996. Habitat, life history, and behavioral adaptations of aquatic insects. Pp. 41–73. *In* An Introduction to the Aquatic Insects of North America. (R.W. Merritt & K.W. Cummins, Eds.). Kendall/Hunt Publishing Company, Dubuque, Iowa.

Williams, D.D. & H.B.N. Hynes. 1974. The occurrence of benthos deep in the substratum of a stream. Freshwater Biology 4:233–256.

*Manuscript received 10 June 2014, revised 30 January 2015.*

2014. Proceedings of the Indiana Academy of Science 123(2):122–130

# RESULTS OF THE 2013 CONNER PRAIRIE BIODIVERSITY SURVEY, HAMILTON COUNTY, INDIANA

**Donald G. Ruch**[1]: Department of Biology, Ball State University, Muncie, IN 47306 USA

**Gail Brown**: Conner Prairie Interactive Historic Park Program Developer, 13400 Allisonville Road, Fishers, IN 46038 USA

**Robert Brodman**: Biology Department, Saint Joseph's College, Rensselaer, IN 47978 USA

**Brittany Davis-Swinford**: Naturalist, City of Indianapolis Department of Parks & Recreation, Ornithology Center, Eagle Creek Park, 6519 Delong Road, Indianapolis, IN 46278 USA

**Don Gorney**: Amos W. Butler Audubon Society, Indianapolis, IN 46280, USA

**Jeffrey D. Holland**: Department of Entomology, Purdue University, West Lafayette, IN 47907 USA

**Paul McMurray**: Indiana Department of Environmental Management, 100 North Senate Avenue, MC65-40-2 Shadeland, Indianapolis, IN 46204 USA

**Bill Murphy**: 7835 Tufton St., Fishers, IN 46038 USA

**Scott Namestnik**: Orbis Environmental Consulting, Senior Botanist, P.O. Box 10235, South Bend, Indiana 46680 USA

**Kirk Roth**: Corradino, LLC, 200 S. Meridian Street, Suite 330, Indianapolis, IN 46225 USA

**Stephen Russell**: The Hoosier Mushroom Co., PO Box 3094, Bloomington, IN 47402 USA

**Carl Strang**: Naturalist, Forest Preserve District of DuPage County, P.O. Box 5000, Wheaton, IL 60189-5000 USA

## INTRODUCTION

Conner Prairie is an interactive history park or a "living museum." Located 6 km north of Indianapolis in Fishers, Indiana, the 850 acres that presently comprise Conner Prairie have a unique place in Indiana history. The property has been witness to many of the changes Indiana's environment has undergone—from the glaciers that shaped much of the Hoosier landscape to the slow influx of humans over the past 12,000 years and the cultural changes they have made to the terrain.

The first biodiversity survey (commonly called a BioBlitz) of Conner Prairie was conducted on 8–9 June 2013. The results of the Conner Prairie BioBlitz have provided a greater understanding of the vast biological resources at the site. Further, the information gained by the event has and will continue to provide information on how to better conserve and interpret the natural setting. Lastly, the event has provided a unique snapshot on how human development impacts these isolated islands of natural habitat in an ever expanding suburban region. This manuscript will provide a brief history of Conner Prairie followed by a summary of the biodiversity survey and methods. For all of the information obtained at the BioBlitz, see the Indiana Academy of Science website at http://www.indianaacademyofscience.org/ (hover over Events | click BioBlitz Archives | click Conner Prairie BioBlitz).

## BRIEF HISTORY OF CONNER PRAIRIE

Conner Prairie traces its lineage to William Conner. Trader, interpreter, scout, community

---

[1] *Corresponding Author:* Donald G. Ruch, 765-285-8829 (phone), 765-285-8804 (fax), druch@bsu.edu.

leader, and entrepreneur, Conner came to central Indiana during the winter of 1800–1801 and soon fixed himself upon the land, including 200 acres of treeless "prairie," now encompassed in the museum complex. He lived there until moving to Noblesville, Indiana in 1837. During his 37 year tenure on the prairie, he raised two families, built the two-story brick home that is one of Conner Prairie's focal points, and helped shepherd the transition of Indiana from wilderness to settled state.

The land passed out of Conner family hands in 1871. Over the next six decades it was repeatedly bought and sold, becoming just another property with an ill-remembered heritage. Fortunately for history and historical preservation, the land, house and their accompanying heritage were purchased in 1934 by a man of vision who understood their importance, Eli Lilly. It was to be the first step in the shaping of Conner Prairie.

Mindful of its significance and crumbling condition, industrialist and philanthropist of history Lilly began a careful restoration of the Conner house immediately upon assuming ownership. Consulting experts, hiring contractors and sponsoring research, Lilly restored and furnished the home to a vision of what it may have been like when William Conner lived there. Lilly's understanding of the house's historic context led him to surround it with outbuildings of the period. Over the next few years he added a still house, spring house and loom house. A log cabin, barn and a recreated trading post were also added to the site, turning it into a nascent living history museum.

The land itself was not ignored. Carrying on another tradition, Lilly turned to agriculture and animal husbandry. Conner Prairie Farm became a showcase for the latest methods of raising crops and prize animals until it was phased out in the early 1970s. During this period, numerous barns, outbuildings, pastures, and fields dotted the landscape. Included in Lilly's changes was the addition of the levy surrounding William Conner's original treeless tract of floodplain along the White River.

Lilly, a great promoter of education, knew the value of Conner Prairie as a tool to inform the public about their shared history. He enthusiastically opened the site to the public. History-minded groups, individuals and countless schoolchildren were given tours and saw their heritage brought to life. Over the years Lilly sought ways to broaden the educational possibilities of Conner Prairie, calling it "one of the most important historic monuments in the State of Indiana." With this goal in mind, in 1964 Lilly transferred Conner Prairie to Earlham College, which continued to operate the farm and offer historic tours of the buildings and grounds. Conner Prairie explored various methods of interpreting the past for visitors. Regularly scheduled hours were established and added to the arranged visits. Special events like quilting bees and shows, craft demonstrations, and special holiday programs were added to the guided tours. Annual visitation increased from 2,800 in 1964 to over 28,000 in 1969.

As the ten-fold attendance increase indicated, there was great interest in the museum and its programs. By 1969 it was agreed that Conner Prairie was approaching a turning point. A decision had to be made about the site's future. Working groups comprised of Conner Prairie staff and the Conner Prairie Advisory Council concurred that expansion was needed to place the museum in the forefront of the burgeoning outdoor museum movement.

As a result, planning for the recreation of a typical early 19th century Indiana village began. Research into the period was conducted and historic buildings from all over Indiana were moved to Conner Prairie. The village, now 1836 Prairietown, opened formally in March 1974 with six major buildings. Like the small communities it represents, Prairietown has grown over time and now contains over twenty main structures, which serve as homes or workplaces for its historic residents.

Conner Prairie's other 800 acres have also undergone change. The present, modern Welcome Center (which replaced the barns and farmhouses that previously housed museum facilities) opened in 1988 and was remodeled in 1999. To ensure the Conner House would remain for future generations, a painstaking re-restoration and refurnishing of the home occurred from 1991 to 1993. Several other experiences have opened in the past 15 years, including The Lenape Indian Camp (opened in 2000), the 1859 Balloon Voyage (in 2009), Civil War Journey (in 2011), and new in 2013 was the Conner Prairie Nature Walk.

Conner Prairie's continuing commitment to excellence has long been recognized, both by its peers (the museum has received multiple

Table 1.—Summary of taxa observed during the Conner Prairie Biodiversity Survey 8-9 June 2013.

| Team | Leader | Taxa found/notes |
|---|---|---|
| Aquatic Macroinvertebrates | Paul McMurray | 34 [4 county records] |
| Beetles | Jeffrey Holland | 101 [26 families] |
| Birds | Don Gorney | 92 [6 state listed species] |
| Butterflies | Kirk Roth | 29 [8 not previously reported in county] |
| Fish | Robert Brodman | 3 [common species] |
| Fungi | Stephen Russell | 77 [earliest known report for 2 species of *Cantharellus* in Indiana] |
| Herpetofauna | Robert Brodman | 15 [4 county records] |
| Singing Insects | Carl Strang | 12 [5 singing insects, 7 others; first report of *Anaxipha vernalis* in Indiana; range expansion of 1 species] |
| Snail-killing Flies | Bill Murphy | 7 [1 county record] |
| Spiders | Brittany Davis-Swinford | 20 [all common species] |
| Vascular Plants | Scott Namestnik | 458 [150 potential county records; 8 state listed species] |

national awards from groups like the American Association for State and Local History and the American Association of Museums) and its approximately 350,000 visitors each year.

To learn more about Conner Prairie, the nation's finest outdoor living history museum, please visit the Conner Prairie Official Site at http://www.connerprairie.org/, the Fishers, Indiana website at http://fishers-indiana.funcityfinder.com/conner-prairie/ and Wikipedia at http://en.wikipedia.org/wiki/Conner_Prairie.

## SUMMARY OF RESULTS AND METHODS

The BioBlitz attracted over 40 scientists, naturalists, students, and others volunteering their time and expertise to make the event an overwhelming success. Food and lodging for the participants were provided through the generous support of Conner Prairie and The Indiana Academy of Science (IAS).

The 11 teams and their leaders reported 848 taxa (Table 1).

**Aquatic macroinvertebrates.**—Aquatic macroinvertebrates and adult Odonata (dragonflies and damselflies) were collected at a large pond located 0.6 km northwest of the Conner Prairie welcome center (39.98909 N, -86.032369 W). A D-frame aquatic dipnet with 500 µm mesh was used to sample aquatic macroinvertebrates from different aquatic habitats around the margin of the pond (i.e., emergent vegetation, sand, logs). Collected specimens were identified to lowest practical taxon by use of standard texts (Merritt et al. 2008; Thorp & Covich 2001). A total of 23 taxa were identified, representing five classes of invertebrates, 13 families, and at least 17 genera. These taxa are characteristic of lentic and slow-moving lotic bodies of water in this area. No new or unusual species were recorded. Adult odonates were collected from the shoreline around the pond by use of a large aerial net and identified using regional texts (Curry 2001; Glotzhober & McShaffrey 2002). A total of 11 species representing three families were recorded. Most of these species are common inhabitants of lentic waterbodies, although *Argia apicalis* and *A. moesta* are more commonly associated with lotic environments (such as the nearby White River). Four odonate species (*Argia moesta*, *A. tibialis*, *Ischnura posita*, and *Libellula incesta*) are new records for Hamilton County, Indiana (Abbot 2007). Representative voucher specimens of both aquatic macroinvertebrates and adult Odonata will be deposited in the Purdue Entomological Research Collection (PERC) at Purdue University.

**Beetles.**—Many of the beetles were collected at lights set up to attract beetles at night into the open areas between different forested habitats. These lights ran from approximately 9 PM until 2 AM and consisted of two sets of two UV lights, one 400 W mercury vapor light, and two 1000 W metal halide lights. Beetles were also collected by hand and by sweeping and beating vegetation. The complete effort totaled approximately 40 person-hours.

We found 101 species of beetles in 26 families. The level of diversity was slightly lower than expected for this level of collecting effort, but that was to be expected given the highly modified landscape surrounding Conner Prairie. However, we undoubtedly only captured a small proportion of the beetle species present. The most interesting occurrence during the survey was the spectacular density of Tricoptera (caddisflies) that were attracted to a metal halide light placed behind the large bandshell. This 1000 W light was reflected from the white surface and likely attracted caddisflies from a very large area, resulting in an extremely dense insect cover across most of the bandshell cover. Voucher specimens of most species were deposited in the Purdue Entomological Research Collection (PERC) at Purdue University. Some species not represented by vouchers at the PERC were retained in the personal collections of R. Michael Brattain and Robert Turnbow.

**Birds.**—The Bird Team had sufficient observers to cover all areas of the Conner Prairie property. The early June date for the Biodiversity Survey was ideal for detecting birds because it coincided with the period of peak breeding activity. Birds were identified by sight or by song or call note. Consequently, the survey was not limited to territorial or singing males, but this demography constituted the majority of records. In an attempt to capture as much baseline data as possible in this two-day survey, team members counted individual birds and noted any specific breeding activity by species. Bird diversity was found to be high, with a total of 92 species observed on or flying over the property. Approximately 90 percent of the species were presumed to be nesting on Conner Prairie property, with the remainder representing late migrants or birds that likely utilize the site for foraging only. Both forest and prairie habitats were important contributors to species diversity. Prairie areas produced most of the expected species, including Sedge Wren and Henslow's Sparrow, both listed as State Endangered. Four additional non-prairie species found on the survey are listed as State Special Concern, i.e., Bald Eagle, Red-shouldered Hawk, Common Nighthawk, and Hooded Warbler. One prairie species, Bobolink, was observed outside of property boundaries by only a few hundred meters.

**Butterflies (Fig. 1).**—A total of 295 butterflies of 27 species were detected during the BioBlitz. The most abundant species was the Cabbage White (*Pieris rapae*), with 170 individuals seen. This species may be expected to be common in Conner Prairie as a result of the abundance of mustard species, which are a common host plant. Additionally, farmers in the Pioneer Village noted that they were familiar with the "green worms" on their cabbage, which are very likely the larvae of this species.

Figure 1.—Silver-spotted Skipper (*Epargyreus clarus*). Photo taken by Kirk Roth.

Other butterfly species were observed to be benefitting from the Pioneer Village plantings. The flower gardens were frequented by several skipper species, including Silver-spotted (*Epagyreus clarus*), Zabulon (*Poanes zabulon*), and Peck's Skippers (*Polites peckius*). A second-instar Black Swallowtail larva was noted on fennel (*Foeniculum vulgare*) in one of the gardens. Several gardeners indicated that the larvae occur there every year that fennel is planted.

Butterfly numbers were low in the prairie areas. The few major nectar sources included patches of thistle (*Cirsium* sp.) or scattered Red Clover (*Trifolium pratense*). Few classic sources of prairie nectar, such as milkweeds (*Asclepias* sp.), mountain-mint (*Pycnanthemum* sp.), Wild Bergamot (*Monarda fistulosa*), Purple Coneflower (*Echinacea purpurea*), and others were noted to be in bloom. Eastern Tiger Swallowtail (*Papilio glaucus*) and Great Spangled Fritillary (*Speyeria cybele*) are normally common and conspicuous butterflies; they were notably absent from the count, possibly a result of the scarcity of favored nectar sources such as those above. Several woodland species were present in small numbers. The lone Northern Pearly-eye (*Lethe anthedon*) and Mourning Cloak (*Nymphalis antiopa*) were found in the south forested

Figure 2.—Spiny Softshell (*Apalone spinifera*); a Hamilton County record. Photo by J. Horton.

area. Most Eastern Comma (*Polygonia comma*) and Zabulon Skipper sightings were in the wooded White River floodplain. Summer Azures (*Celastrina neglecta*) were reliably found nectaring at blooming dogwood and scattered at forest edges. Most skippers were found by chance encounters in grassy areas rather than at nectar sources. Even though only a few individuals of skippers were observed, they represented nine different species.

The observations at the Conner Prairie BioBlitz include sightings of some species not listed for Hamilton County in Shull's (1987) or Belth's (2013) comprehensive books on the butterflies of Indiana. This lack of information probably resulted from a scarcity of sampling in Hamilton County, as many of these species are not uncommon in the state but are small or otherwise inconspicuous. The species not listed in Belth or Shull are Northern Pearly-eye (*Lethe anthedon*), Common Sootywing (*Pholisora catullus*), Zabulon Skipper (*Poanes zabulon*), Least Skipper (*Ancyloxypha numitor*), Delaware Skipper (*Anatrytone logan*), Dun Skipper (*Euphyes vestris*), Tawny-edged Skipper (*Polites themistocles*), and Crossline Skipper (*Polites origenes*). Belth included each of these species in maps of nearby Marion County, which is less than 6 km south of Conner Prairie.

**Fungi.**—Early June is nearing the end of a lull in the fungal world. The spring mushrooms are coming to an end, but the summer mushrooms have yet to fruit in abundance. That being said, Conner Prairie provided a fantastic species diversity for the time period. Two collectors spent a total of about 6 hours on the property collecting the listed species. The majority of the species encountered can be found commonly throughout much of the state. No specific genera were over-represented in numbers on the grounds. Of special note were two species of Chanterelles—*Cantharellus* "*cibarius*" and *C. minor*. All varieties of Chanterelles lack well defined, blade-like gills, which is one of the key defining features of the genus. While both of these edible species are fairly common, the dates on which they were observed during the BioBlitz were the earliest known by the team leader for Indiana. They most commonly begin presenting in mid to late July.

**Herpetofauna (Fig. 2) and fish.**—Amphibians and reptiles were surveyed by a combination of methods. Terrestrial and wetland habitats were sampled by visual searches and sample cover objects. Calling frogs were identified, and wetlands were sampled for larvae by use of dip nets. Turtles and larval amphibians were also sampled by use of turtle traps and minnow traps in wetlands, ponds, and the river. The complete effort totaled approximately 40 person-hours and 35 trap-days.

The herp team found a total of 150 herps of 15 species, including 37 reptiles representing eight species and 113 amphibians representing seven species. *Acris blanchardi* is a species of special concern in Indiana; during the last two to three decades, it has declined greatly throughout the northern half of its geographic range. The species was common at every wetland and pond surveyed at Conner Prairie. *Plestiodon fasciatus* was very common in most open terrestrial habitats. Four species [*Plestiodon fasciatus*, *Apalone spinifera* (Fig. 2), *Trachemys scripta elegans*, and *Plethodon cinereus*] represent new Hamilton County records. Minnow traps caught several species of fish, including Rock Bass (*Ambloplites rupestris*), Bluegill (*Lepomis macrochirus*), and Largemouth Bass (*Micropterus salmoides*).

Voucher specimens of *Plestiodon fasciatus* were deposited at the Indiana State Museum (INSM 71.2013.129). Voucher specimens for *Trachemys scripta elegans* (SJCZC R322) and *Plethodon cinereus* (SJCZC A350) were deposited in the Saint Joseph's College zoological collection in Rensselaer, Indiana. All other species were documented/vouchered by images and retained by Robert Brodman.

**Singing insects (Fig. 3).**—A total of 12 person-hours were spent searching for singing insects, mainly in the prairie area. Less than one hour was spent in forested areas, where the season was too early to expect members of this group. Methods mainly were walking the mowed lanes, looking and listening, with some time spent stalking and sweep-netting for the spring trig cricket, and a few checks of the beetle team's light stations after dark.

The timing of the Conner Prairie BioBlitz was early enough in the season so that the only adult singing insect species found were those that overwinter as nymphs. Three of these species are regarded as common (spring field cricket, green-striped grasshopper, and sulfur-winged grasshopper), although only one individual of the last species was observed. One locally distributed group of Roesel's katydid nymphs, found by the botany team, adds Conner Prairie to the known southern boundary of that species' range in Indiana. Roesel's katydid is a European insect that still is expanding its range from its introduction site in Québec, Canada. The most interesting find was a small cricket commonly heard singing in the prairie. This proved to be the spring trig, a species identified only by that common name and the temporary designation "*Anaxipha* n. sp. G" in the Singing Insects of North America website, hosted by the University of Florida. The species since has been named *Anaxipha vernalis* (Walker & Funk 2014). This apparently is the first observation of the species in Indiana, although in time it probably will prove to be widely distributed and common, at least in the southern part of the state.

Figure 3.—Green-striped grasshopper (*Chortophaga viridifasciata*). Photo by Carl Strang.

**Snail-killing [Sciomyzid] flies.**—Twelve individuals of seven species of Sciomyzidae (snail-killing flies) were found. Considering the scarcity of suitable habitat (standing water: marsh, swale, fen, bog, etc.) at the BioBlitz site, the number of species found was surprisingly high. A cold water seep west of White River produced *Tetanocera loewi* Steyskal, a new species of sciomyzid for Hamilton County. This is the southernmost Indiana record of this northern species; the previous southernmost record was from Tipton County. The four

Figure 4.—Fire Pink (*Silene virginica*). Photo by Scott Namestnik.

*Trypetoptera canadensis* (Macquart), a floodplain predator of pulmonate terrestrial snails, were found precisely where that species would be expected to occur — in the vernally flooded zone between the artificial levee and the natural sand dike along White River. The guild of species found indicated a healthy population in the floodplain and a possible glacial refuge along the seep.

**Spiders.**—Spiders were surveyed on Sunday, June 9, from 9 AM to 2 PM. A total of 19 spider species and 1 harvestman species were recorded. Restrooms, barns, prairie, ponds, and the attic of the China House were surveyed. If the BioBlitz had taken place a few weeks later, it is estimated that the spider count would have doubled.

**Vascular Plants (Fig. 4).**—Meander surveys following the methods of Goff et al. (1982) were conducted. Approximately 109 person-hours were spent conducting the survey. Additional time was spent identifying unknown plants in the laboratory.

A total of 458 vascular plant taxa (451 identified to at least the species level), 336 (73%) of which are native to Indiana, were observed during the two-day Conner Prairie BioBlitz. The vascular plant families represented by the most taxa were the Aster Family (Asteraceae, 55 taxa), the Grass Family (Poaceae, 49 taxa) and the Sedge Family (Cyperaceae, 40 taxa); the Sedge genus (*Carex*) was the best represented genus, with 34 taxa observed. A total of 150 potentially new species for Hamilton County, Indiana were documented. Eight species on the list of Indiana Endangered, Threatened, Rare, and Watch List species were noted: Wood's Stiff Sedge (*Carex woodii* Dewey [State Watch List]); Wild Sensitive Plant (*Chamaecrista nictitans* (L.) Moench [State Watch List]); Pink Turtlehead (*Chelone obliqua* L. var. *speciosa* Pennell & Wherry [State Watch List]); Ginseng (*Panax quinquefolius* L. [State Watch List]); White Pine (*Pinus strobus* L. [State Rare]); Great White Lettuce (*Prenanthes crepidinea* Michx. [State Watch List]); False Hellebore (*Veratrum woodii* J.W. Robbins ex Alph. Wood [State Watch List]); and Downy Yellow Violet (*Viola pubescens* Aiton [State Watch List]); plants listed as Watch List have enough known occurrences to have been removed from the Endangered, Threatened and Rare list and are no longer actively tracked by the Indiana Department of Natural Resources – Division of Nature Preserves. The White Pine (state rare) observed on the site was likely planted or an escape from a planting. The Wild Sensitive Plant (state watch list) observed on the site was likely introduced in the prairie creation seed mix.

The vascular plant communities at Conner Prairie consisted primarily of old field and planted tallgrass prairie. Agricultural field and developed/cultural areas also made up a large percentage of the property. Smaller portions of the property were comprised of upland forest, a pond in the upland forest, riverine woods, herbaceous floodplain, emergent wetland and pasture. With the exception of the upland forest and riverine woods, the plant communities at Conner Prairie were dominated by common early successional and disturbance-tolerant plant species. The riverine woods consisted of a mix of species common in floodplain communities in central Indiana, with few clear dominant species. The richest and most interesting plant community observed on the property was the Sugar Maple (*Acer saccharum* Marshall ssp. *saccharum*) dominated upland forest located at the south end of the site. Floristic Quality Assessment of the upland forest had a mean Coefficient of Conservatism (C) value of 3.3 and Floristic Quality Index (FQI) of 58.9. Areas with FQI values of 45 or greater are thought to possess natural area potential, though sites with mean C values less than 3.5 are not (Swink & Wilhelm 1994). In particular, the bluff above the White River and the adjacent steep slope provided unique habitat where several conservative plant species were observed. Shallow ravines and seepages along streams in the upland forest also were of interest. Overall, the mean C value calculated for the compiled inventory at Conner Prairie was 2.8, and the FQI was 60.0.

Numerous invasive species were identified. In the upland forest, invasive species of most concern included Tree-of-Heaven (*Ailanthus altissima* (Mill.) Swingle, rare), Garlic Mustard (*Alliaria petiolata* (M. Bieb.) Cavara & Grande, uncommon), Oriental Bittersweet (*Celastrus orbiculatus* Thunb., uncommon), Winged Euonymus (*Euonymus alatus* (Thunb.) Siebold, rare), Border Privet (*Ligustrum obtusifolium* Siebold & Zucc., uncommon), Common Privet (*Ligustrum vulgare* L., uncommon), Japanese Honeysuckle (*Lonicera japonica* Thunb., uncommon), Amur Honeysuckle (*Lonicera maackii* (Rupr.) Herder, uncommon), Honeysuckle (*Lonicera* L., uncommon), Reed Canary Grass (*Phalaris arundinacea* L., locally common/abundant), Multiflora Rose (*Rosa multiflora* Thunb., uncommon) and Common Periwinkle (*Vinca minor* L., locally common/abundant). Invasive species of most concern in the riverine woods included Tree-of-Heaven (rare), Garlic Mustard (common), Hungarian Brome (*Bromus inermis* Leyss., common), Winged Euonymus (uncommon), Dame's Rocket (*Hesperis matronalis* L., rare), Common Privet (rare), Reed Canary Grass (common), Golden Bamboo (*Phyllostachys aurea* Carrière ex A. Rivière & C. Rivière, locally common/abundant) and Multiflora Rose (uncommon). Hungarian Brome (common), Field Thistle (*Cirsium arvense* (L.) Scop., common) and Reed Canary Grass (abundant) posed the greatest ecological threat in the herbaceous floodplain area. Reed Canary Grass (uncommon) was of most concern in the emergent wetland community. Invasive species of concern in the old field/planted prairie areas included Hungarian Brome (locally common/abundant), Musk Bristle Thistle (*Carduus nutans* L., uncommon), Field Thistle (locally common/abundant), Bull Thistle (*Cirsium vulgare* (Savi) Ten., uncommon), Poison Hemlock (*Conium maculatum* L., rare), Autumn Olive (*Elaeagnus umbellata* Thunb., rare), Quack Grass (*Elymus repens* (L.) Gould, locally common/abundant), Yellow Sweet Clover (*Melilotus officinalis* (L.) Lam., uncommon), Reed Canary Grass (rare), Bradford Pear (*Pyrus calleryana* Decne., locally common/abundant), Multiflora Rose (rare) and Johnson Grass (*Sorghum halepense* (L.) Pers., common). Many of these same invasive species were observed in the pasture area, and although this area has no resemblance to a natural community, invasive species here provide a seed source for infestation into natural communities.

**Summary.**—To obtain a complete picture of the biodiversity found at Conner Prairie would require a long term seasonal survey. Nevertheless, this two-day survey in June revealed the remarkable species richness and the inherent value of this historic site. Highlight species reported included the Spiny Softshell turtle, Sedge Wren, Henslow's Sparrow, Zabulon Skipper, Roesel's Katydid, Elegant Stinkhorn fungus, Pink Turtlehead, and False Hellebore. Of the 15 species of reptiles and amphibians reported, three species of reptiles and one species of amphibian were new species records for Hamilton County. Of the 458 taxa of plants, 150 represent potentially new Hamilton County records, and eight species are on the Indiana Endangered, Threatened, Rare, or Watch List. Eight butterfly species had not been recorded previously from Hamilton County. Likewise, four records of aquatic macroinvertebrates were new for Hamilton County. Steve Russell, the mushroom team leader, said that "Conner Prairie provided a fantastic species diversity for the time period." Among the 92 species of birds observed, two were on the endangered list and four were species of special concern. As expected, the plant team found species diversity to be relatively low in the restored prairies. However, they found incredible species richness in the woodlands, especially in the woods at the southern end of the property that slopes down to the White River.

## LITERATURE CITED

Abbott, J.C. 2007. Odonata Central: an online resource for the distribution and identification of Odonata. Texas Natural Science Center, The University of Texas at Austin. At: http://www.odonatacentral.org (Accessed 10 July 2013).

Belth, J.E. 2013. Butterflies of Indiana – A Field Guide. Indiana University Press, Indianapolis, Indiana. 323 pp.

Curry, J.R. 2001. Dragonflies of Indiana. Indiana Academy of Science, Indianapolis, Indiana. 303 pp.

Glotzhober, R.C. & D. McShaffrey. 2002. The Dragonflies and Damselflies of Ohio. Bulletin of the Ohio Biological Survey, New Series 14: 1-364.

Goff, F.G., G.A. Dawson & J.J. Rochow. 1982. Site examination for threatened and endangered plant species. Environmental Management 6: 307-316.

Merritt, R.W., K.W. Cummins, & M.B. Berg (eds.). 2008, An Introduction to the Aquatic Insects of North America, 4th ed. Kendall/Hunt Publishing Company, Dubuque, Iowa. 1158 pp.

Shull, E.M. 1987. The Butterflies of Indiana. Indiana Academy of Science, Indianapolis, Indiana. 262 pp.

Swink, F. & G. Wilhelm. 1994. Plants of the Chicago Region, 4th ed. Indiana Academy of Science, Indianapolis, Indiana. 921 pp.

Thorp, J.H., & A.P. Covich (eds.). 2001. Ecology and Classification of North American Freshwater Invertebrates, 2nd ed. Academic Press, San Diego, California. 1056 pp.

Walker, T.J. & D.H. Funk. 2014. Systematics and acoustics of North American *Anaxipha* (Gryllidae: Trigonidiinae). Journal of Orthoptera Research 23: 1-38.

*Manuscript received 14 March 2015, revised 28 April 2015.*

2014. Proceedings of the Indiana Academy of Science 123(2):131–137

# A TWO YEAR POPULATION ECOLOGY STUDY OF PUTTYROOT ORCHID (*APLECTRUM HYEMALE* (MUHL. EX WILLD.) TORR.) IN CENTRAL INDIANA

**Megan E. Smith**[1] and **Alice L. Heikens**[2]: Department of Biology, Franklin College, 101 Branigin Boulevard, Franklin, IN 46131 USA

**ABSTRACT.** *Aplectrum hyemale*, puttyroot orchid, is a terrestrial, winter perennial found in rich, mesic forests throughout the Midwest as well as in Hougham Woods Biological Field Station (HWBFS) near Franklin in Johnson County, Indiana. This orchid overwinters as a single basal leaf that may produce a flowering shoot in spring. The size of the *Aplectrum* population at HWBFS remained relatively stable with 305 to 311 individuals during this 2012-2013 study. Only 2.9% of the plants flowered and only one plant produced fruits in 2012. No flowering or fruiting occurred in 2013. Plants that produced flowering shoots had basal leaves that were larger than the vegetative plants. However, basal leaf size was not correlated with the number of flowers per plant. It appears that weather, including the unusually warm spring and summer drought in 2012 and the dry spring in 2013, affected phenology and reproduction of *Aplectrum*.

**Keywords:** *Aplectrum hyemale*, puttyroot, Adam-and-Eve orchid, mesic woods, phenology

## INTRODUCTION

Puttyroot orchid, *Aplectrum hyemale*, is a winter perennial that is found throughout the eastern deciduous forest in mesic woods in much humus (Homoya 2012). The plant has a coefficient of conservatism of 7, indicating that it tolerates little disturbance (Rothrock 2004). The vegetative plant, a single basal leaf, emerges in fall, overwinters, and withers in May or June (Homoya 1993).

In contrast to many orchids, *Aplectrum* has relatively non-showy flowers that are somewhat camouflaged due to their dull coloration. In addition, the inflorescences emerge in May to June (Homoya 1993; Yatskievych 2000) as the basal leaves wither, making the plants somewhat inconspicuous to the casual observer. Similar to many orchids, *Aplectrum* plants often do not flower or fruit every year (Homoya 1993).

*Aplectrum*, which is found throughout Indiana especially in southern counties (Fig. 1), is reported for the first time in Johnson County. The plant received the common name of puttyroot from the mucilaginous substances in the corms that Native Americans and pioneers used as a paste to mend broken pottery (Correll 1950; Whiting & Catling 1986). It is also known as the Adam-and-Eve orchid because of the paired corms (Porcher & Rayner 2001).

In contrast to some of the large, showy orchids that have been extensively studied, there is a lack of information on *Aplectrum*, including fruiting phenology, frequency of flowering, and number and viability of seeds. The objectives of this research are: 1) to establish baseline information on the population size and location of individual *Aplectrum* plants at Hougham Woods Biological Field Station (HWBFS) in Johnson County, Indiana; 2) to determine the stability of population size and reproductive effort of *Aplectrum* at HWBFS by comparing the 2012 and 2013 data; 3) to assess whether leaf size is predictive of flowering; and 4) to explore possible impacts of weather variation on *Aplectrum* reproduction.

## METHODS

**Study site.**—HWBFS is a 12 ha relatively flat, mesic forest (dominant canopy species include *Acer saccharum*, *Fagus grandifolia*, and *Quercus* spp.) that was donated to Franklin College in 2006. The forest is located in Johnson County west of Franklin, Indiana in the Tipton Till Plain Section of the Central Till Plain Natural Region (Homoya et al. 1985). Soils are often neutral silt and silty clay loams

---

[1] Current address: Department of Biology, Ball State University, Muncie, Indiana 47306 USA.

[2] *Corresponding Author:* Alice L. Heikens, 317-738-8302 (phone), aheikens@franklincollege.edu.

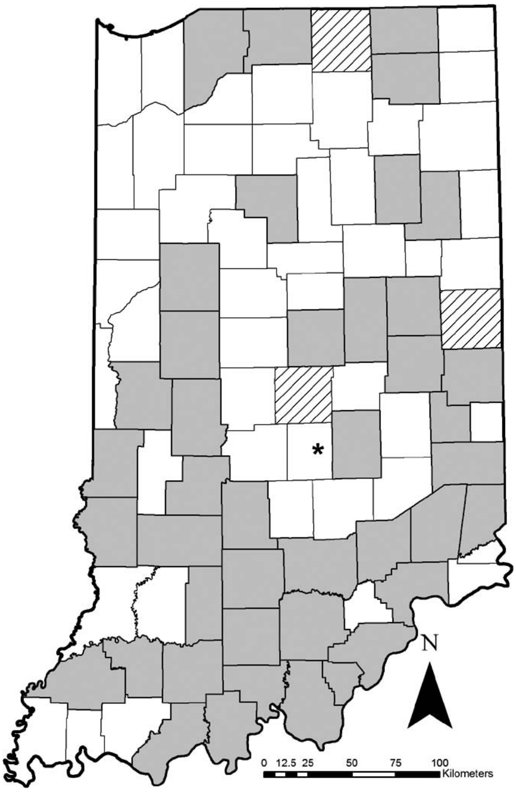


Figure 1.—Distribution of *Aplectrum hyemale* in Indiana. Shading indicates distribution from Homoya (1993), hashing indicates new records in Elkhart County (K. Yatskievych Pers. Comm.), Marion County (Homoya Pers. Comm.), and Randolph County (Ruch Pers. Comm.), and the star indicates the county record for Johnson County.

(Homoya et al. 1985). The forest is surrounded by agricultural fields and an industrial park, and has experienced past disturbances including selective cutting and wind throw. However, a few species with high coefficients of conservatism, such as *Fagus grandifolia* and *Epifagus virginiana* (Rothrock 2004), are found in the forest as well as one of Indiana's largest bur oaks.

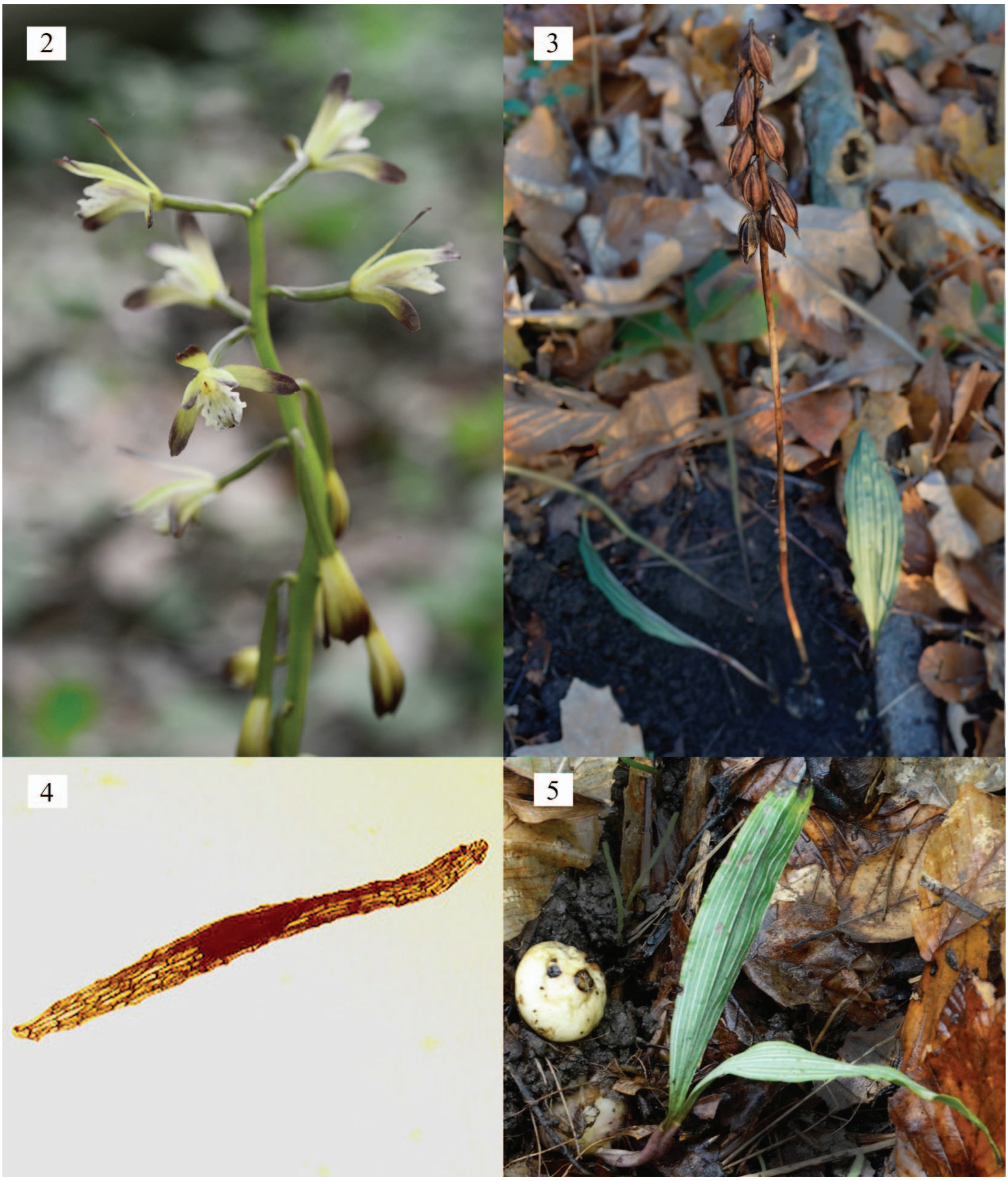
*Aplectrum* plants in HWBFS were marked using GPS in February, 2012 and March, 2013. Basal leaves were measured for length and width at the largest dimensions. To determine flowering and fruiting data, the plants were monitored once per week in spring of 2012, every other week in summer of 2012, and every other week in spring and summer of 2013. Length and weight of capsules and seeds on the one fruiting plant were obtained in 2012. Number of seeds/capsule was determined by weighing a measurable amount (0.3–1.2 mg) of seeds then counting them using a compound microscope. The total number of seeds/capsule was calculated using a proportion (number of counted seeds/weight of counted seeds = x number of seeds/total weight of seeds). Photo documentation (Friesner Herbarium at Butler University) was used to report *Aplectrum hyemale* as a county record for Johnson County because removing a specimen would alter the population size and prevent that specimen from possibly producing fruits.

Minitab 16 Statistical Software was used to perform two-sample t-tests or Mann-Whitney test when sample sizes were low. Pearson correlation was used to determine if the following correlations were significant: leaf size and the number of flowers/plant and capsule length and the number of seeds/capsule. Weather data were obtained from the National Weather Service station in Franklin, Indiana.

**Plant description.**—*Aplectrum hyemale* produces green, overwintering basal leaves with white parallel veins that extend from the base to the tip of the leaves (Homoya 1993). The lower surface is often light green but may have a purple tint (Homoya 1993). *Aplectrum* typically produces two corms but may occasionally have three or four interconnected corms (Fernald 1950). Each year, the younger of the two corms increases in size while the older corm gradually shrinks and sends its nutrients to the younger corm. The basal leaf emerges from the younger corm (Stevens & Dill 1942). The corms produce a sticky paste that contain 13.43% water, 29.65% mucilage, 55.92% starch, and traces of albumin (Stevens & Dill 1942).

Flowering stalks typically have 8-15 relatively non-showy greenish flowers with white to purple-brown tips (Fig. 2) (Homoya 1993; Yatskievych 1999). The three-lobed flowers are small, averaging 1.5 cm in length (Homoya 1993). Fruiting capsules (Fig. 3), which range from 1.5 to 3.0 cm long (Yatskievych 1999; Weakley et al. 2012), contain thousands of dust-like seeds (Fig. 4) that are easily wind dispersed (Stevens & Dill 1942; Case 1964).

The crane-fly orchid, *Tipularia discolor* (Pursh) Nutt., is similar to *Aplectrum* in that it is also a winter perennial with a single basal



Figures 2–5.—*Aplectrum hyemale*. 2. Flowering stalk. 3. Fruit. 4. Seeds (10 μm long). 5. Two basal leaves emerging from one corm. (Photos 2, 3, 5 by Renee Knight; photo 4 by Sarah Mordan-McCombs.)

leaf. However, *Tipularia* leaves lack white veins and have a dark purple undersurface (Homoya 1993). Because *Tipularia* may be found in second growth forests and areas that have been cultivated, it is more common than *Aplectrum* where their ranges overlap (Homoya 1993). In addition, *Tipularia* flowers later than *Aplectrum*, July to August verses May to June, and often occupies drier sites (Homoya 1993). By growing in winter when tree leaves are absent, these orchids do not compete with most plants for light. *Aplectrum*, which is capable of photosynthesizing under light snow cover and can photosynthesize at temperatures as low as

Table 1.—*Aplectrum hyemale* size and reproduction in 2012 and 2013 in Hougham Woods Biological Field Station in Johnson County, Indiana. Standard deviations are in parentheses. Length and width measurements are in cm. NA = no data due to no flowering. *Not all plants that produced flowering stalks flowered.

| Metrics | 2012 | 2013 |
|---|---|---|
| Number of basal leaves | 305 | 311 |
| Basal leaf length × width | 11.55 (2.51) × 5.33 (1.85) | 12.69 (3.23) × 4.42 (1.76) |
| Number of flowering shoots | 27 | 0 |
| Basal leaf length × width of plants with shoots | 13.76 (2.61) × 7.05 (2.36) | NA |
| Number of flowering plants* | 17 in May, 1 in August | 0 |
| Number of flowers/plant | 7.2 (4.0) | NA |
| Basal leaf length × width of plants with flowers | 14.21 (2.16) × 7.43 (1.99) | NA |
| Vegetative basal leaf length × width | 11.33 (2.40) × 5.16 (1.71) | NA |
| Basal leaf length × width of plants with shoots without flowers | 13.04 (3.43) × 6.29 (2.88) | NA |
| Number of capsules/plant | 13 | NA |
| Length of capsules | 2.85 (0.40) | NA |
| Number of seeds/capsule | 26,100 (6134) | NA |
| Length of seeds (μm) | 10 | NA |
| Seed weight (μg) | 2.05 (0.55) | NA |

4.5° C, reaches its maximum photosynthetic rate at 20-25° C (Adams 1970).

## RESULTS

In 2012, 305 basal leaves in three subpopulations were found at HWBFS (Table 1). In 2013, 311 leaves were found in approximately the same locations except for a new group of 10 plants that was found in the northeastern portion of the forest. In 2013, the basal leaves were significantly longer ($p < 0.001$) and more narrow ($p < 0.001$) than in 2012.

In 2012, 27 flowering shoots emerged in April with 17 of these shoots attaining floral anthesis in early May (Table 1). For unknown reasons, the other flowering stalks withered without flowering. *Aplectrum* had an average of 7.2 flowers per plant and a range of 1-14 flowers per inflorescence.

None of the spring flowering plants produced fruits. However, one orchid that flowered on May 9 with 12 flowers, bloomed a second time on August 21 with 13 flowers, and had mature capsules by early November. This lone orchid, which was located approximately 20 m from other *Aplectrum* plants, was the only plant to produce fruits in 2012. The 13 capsules produced by this plant averaged 2.85 cm in length and contained an average of 26,100 seeds per capsule (Table 1). The dust-like seeds were 10 μm long and weighed 2.1μg. In 2013, no flowering or fruiting occurred in the *Aplectrum* population at HWBFS.

There was a significant increase ($p < 0.001$ for length, $p < 0.001$ for width) in the size of basal leaves between flowering and non-flowering plants; however, there was no statistical increase in leaf size between plants that produced flowering stalks but did not flower and those that flowered ($p = 0.18$ for length, $p = 0.16$ for width). Also, there was no correlation between basal leaf length or width and the number of flowers per plant ($R^2 = 0.03$ and 0.02, respectively), or between capsule length and number of seeds per capsule ($R^2 = 0.25$).

In 2012, spring temperatures in central Indiana were much higher than average (Table 2). This was followed by an extreme summer drought (Table 3) in which only 8.9 cm of precipitation was received from May 1 to August 1 in comparison to the typical 37.1 cm (NWS 2014). However, August and September were much wetter than usual with central Indiana receiving almost twice the average rainfall for those months (NWS 2014). Spring 2013 was drier than normal with precipitation approximately 25% lower than average from March through June (Table 3).

## DISCUSSION

The *Aplectrum* population size remained relatively stable during this study although

Table 2.—Monthly average high temperatures in °C from 2011 to 2013 for Franklin, Indiana (NWS 2014). AVG = average.

| | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AVG | 2.2 | 4.4 | 10.6 | 17.2 | 22.8 | 27.8 | 29.4 | 28.9 | 25.6 | 18.9 | 11.7 | 3.9 |
| 2011 | −0.6 | 6.1 | 11.7 | 19.4 | 22.8 | 28.3 | 32.8 | 30.0 | 22.8 | 19.4 | 13.9 | 7.2 |
| 2012 | 5.6 | 7.8 | 19.4 | 18.9 | 27.2 | 30.0 | 35.0 | 30.6 | 24.4 | 17.2 | 11.7 | 7.8 |
| 2013 | 4.4 | 5.0 | 7.2 | 18.3 | 25.0 | 28.9 | 28.9 | 29.4 | 27.2 | 19.4 | 10.0 | 4.4 |

there was a slight increase in 2013. It appears that many of the 2012 plants survived the drought and emerged in 2013. These leaves, which were significantly longer but more narrow than the 2012 leaves, were comparable to sizes often reported (13.2 × 4.4 cm) (Gleason & Cronquist 1991; Homoya 1993; Yatskievych 1999).

In 2012, inflorescences emerged in late April, which is slightly earlier than Homoya (1993) reports of early to mid-May. The HWBFS plants bloomed the first week of May with most of the plants flowering by May 2, which is consistent with Homoya (1993) of early May to mid-June. In HWBFS, the *Aplectrum* basal leaves had withered by early May. The record-setting warm temperatures in March, 2012 (NWS 2014) may have contributed to *Aplectrum* developing flowering shoots slightly early and becoming dormant earlier than normal, as well as negatively impacting fruiting.

Consistent with Homoya (1993), few *Aplectrum* plants flowered in this study. However, *Aplectrum* usually has 8-15 flowers/stalk (Homoya 1993; Yatskievych 2000) but peduncles with only one flower were found in this study and the average number of flowers/inflorescence was lower than the typical range. Also, plants that produced flowering shoots had larger basal leaves than plants without shoots, but there was no significant difference in basal leaf size between plants that flowered and those that produced a flowering stalk that withered before flowering. Therefore, it appears that plant vigor, as indicated by leaf size, is correlated with peduncle production, regardless if flowers are produced. Apparently, a number of factors influence flowering because no flowering occurred in 2013 when the leaves were longer than in 2012. Perhaps the dry spring in 2013 negatively impacted flowering because inflorescences typically are produced in May (Homoya 1993). This coupled with the drought in 2012, may have resulted in the absence of flowering in 2013.

In this study, there was no correlation between leaf size and the number of flowers/plant. Because of the small sample size due to limited flowering in 2012 and the lack of flowering in 2013, additional research is needed to confirm that the number of flowers/inflorescence is not correlated with leaf size.

In 2012, one orchid flowered in May and again in August. The second flowering occurred after the first rains following the summer drought. According to herbarium records and published literature, there are no accounts of *Aplectrum* flowering twice in one year or of flowering occurring late in summer. Interestingly, this is the only plant to produce capsules in 2012. Although capsule length has not been reported for Indiana, the capsules found in HWBFS were longer than the range lengths of 1.5-2.5 cm reported for several other states (Radford et al. 1968; Yatskievych 1999; Smith 2012). However, Weakley et al. (2012) does report a capsule range (1-3 cm) that reaches the length of fruits in this study. The

Table 3.—Cumulative monthly precipitation (cm) from 2011 to 2013 for Franklin, Indiana (NWS 2014). AVG = average.

| | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AVG | 6.6 | 12.6 | 21.4 | 32.4 | 46.7 | 58.5 | 69.6 | 78.5 | 86.5 | 94.8 | 104.5 | 113.9 |
| 2011 | 3.5 | 15.4 | 25.7 | 54.0 | 68.9 | 86.2 | 86.4 | 89.2 | 104.8 | 112.0 | 127.2 | 138.8 |
| 2012 | 9.1 | 11.8 | 19.8 | 26.1 | 33.2 | 33.3 | 35.0 | 42.5 | 57.6 | 63.7 | 65.3 | 70.1 |
| 2013 | 9.9 | 13.2 | 16.4 | 24.7 | 31.3 | 42.6 | 46.0 | 54.3 | 60.3 | 71.2 | 75.1 | 90.0 |

seeds, described as dust-like and numerous (Stevens & Dill 1942; Homoya 1993), were linear (Fig. 4), adhered to many surfaces, and clumped in water. Although the correlation between capsule size and number of seeds/ capsule was not significant, there was a small sample size due to the low fruiting rate in 2012 and absence of fruiting in 2013.

Lauzer et al. (2007) determined that the seed coat in *Aplectrum* is resistant to water, but that water imbibition is needed for germination. They also determined that external mechanisms, including such factors as frost and soil microorganisms, are needed to scarify the seed coat (Lauzer et al. 2007). The new subpopulation discovered in 2013 may have been a result of sexual reproduction. However, it is unknown if these plants had been dormant for a year or more or had been overlooked previously.

In 2013, several plants with two distinct leaves and petioles were observed emerging from a single corm (Fig. 5). Although most botanists describe *Aplectrum* as having one basal leaf (Gleason & Cronquist 1991; Homoya 1993; Yatskievych 2000), in the Great Plains, *Aplectrum* occasionally has been observed with two leaves (McGregor et al. 1986). In addition, in this study, several plants with three corms were observed. This does not appear to be common because few floras indicate that more than two corms may form (Fernald 1950; Radford et al. 1968). Interestingly, the orchid that bloomed twice in 2012 had three corms. The mucilaginous substances in the corms absorb and store water, which is especially important in winter when water is often limited by the cold conditions (Stevens & Dill 1942) as well as during droughts.

In conclusion, the *Aplectrum* population at HWBFS was relatively stable for the two years of this study even with the abnormal weather in 2012 that impacted the phenology of the species. Only 2.9% of plants flowered in this study and the only plant that produced fruit did so at an unusual time in autumn. Flowering plants were found to have larger leaves than vegetative plants, but leaf size was not correlated with the number of flowers per plant. Also, plants that flowered did not have significantly larger leaves than plants that produced a flowering stalk that withered before flowering. The presence of more than 300 individuals of a relatively conservative species is one indication that HWBSF is a moderately high-quality forest. Because *Aplectrum* is a conserved species, it may be possible to help determine the quality of HWBFS by monitoring the *Aplectrum* population.

## ACKNOWLEDGMENTS

This research was funded by the Franklin College Endowed Undergraduate Field Biology Research Scholarship and a Franklin College Undergraduate Research Grant. The authors greatly appreciate the GIS assistance provided by Dr. Benjamin O'Neal and the statistical assistance of Dr. John Boardman. The field assistance of Alissa Allen, Ashley Bay, Roger Cochrane, Wanda Gaines, Kimberly Holzbog, Alysa Hopkins, Kevin Kreuzman, Cassie Rainesalo, Allison Stropes, Brittany Wehmiller, Spencer Wesche, and Emily Whitsitt is greatly appreciated.

## LITERATURE CITED

Adams, M.S. 1970. Adaptations of *Aplectrum hyemale* to the environment: effects of preconditioning temperatures on net photosynthesis. Bulletin of the Torrey Botanical Club 97: 219–224.

Case, F.W. 1964. Orchids of the Western Great Lakes Region. Cranbook Institution of Science, Bloomfield Hills, Michigan. 147 pp.

Correll, D.S. 1950. Native Orchids of North America. Chronica Botanica Co., Waltham, Massachusetts. 399 pp.

Fernald, M.L. 1950. Gray's Manual of Botany. Dioscorides Press, Portland, Oregon. 486 pp.

Gleason, H.A. & A. Cronquist. 1991. Manual of the Vascular Plants of Northeastern United States and Adjacent Canada, 2nd edition. New York Botanical Garden, New York, New York. 933 pp.

Homoya, M.A., D.B. Abrell, J.R. Aldrich & T.P. Post. 1985. The natural regions of Indiana. Proceedings of the Indiana Academy of Science 94: 245–268.

Homoya, M.A. 1993. Orchids of Indiana. Indiana University Press, Bloomington, Indiana. 276 pp.

Homoya, M.A. 2012. Wildflowers and ferns of Indiana forests: a field guide. Indiana University Press, Bloomington, Indiana. 442 pp.

Lauzer, D., S. Renaut, M. St-Arnaud & D. Barabe. 2007. In vitro germination, protocorm development, and plantlet acclimatization of *Aplectrum hyemale*. Journal of the Torrey Botanical Society 134: 344–348.

McGregor, R.L., T.M. Barkley, R.E. Brooks & E.K. Schofield. 1986. Flora of the Great Plains. University Press of Kansas, Lawrence, Kansas. 1402 pp.

NWS (National Weather Service). 2014. At: http://weather.noaa.gov (Accessed 14 April 2014).

Porcher, R.D. & D.A. Rayner. 2001. A Guide to Wildflowers of South Carolina. University of South Carolina Press, Columbia, South Carolina. 551 pp.

Radford, A.E., H.E. Ahles & C.R. Bell. 1968. Manual of the Vascular Flora of the Carolinas. The University of North Carolina Press, Chapel Hill, North Carolina. 353 pp.

Rothrock, P.E. 2004. Floristic Quality Assessment in Indiana: the Concept, Use, and Development of Coefficients of Conservatism. Final report for ARN A305–4–53 EPA Wetland Program Development Grant CD975586-01. 96 pp.

Smith, W.R. 2012. Native Orchids of Minnesota. University of Minnesota Press, Minneapolis, Minneapolis. 254 pp.

Stevens, W.C. & F.E. Dill. 1942. *Aplectrum spicatum* in a Kansas woodland. Kansas Academy of Science 45:138–151.

Weakley, A. S, J.C. Ludwig & J.F. Townsend. 2012. Flora of Virginia. BRIT Press, Fort Worth, Texas. 1554 pp.

Whiting, R.E. & P.M. Catling. 1986. Orchids of Ontario, an Illustrated Guide. CanaColl Foundation, Ottawa, Canada. 169 pp.

Yatskievych, G. 1999. Steyermark's Flora of Missouri, Vol. 1. The Missouri Botanical Garden Press, St. Louis, Missouri. 991 pp.

Yatskievych, K. 2000. Field Guide to Indiana Wildflowers. Indiana University Press, Bloomington, Indiana. 357 pp.

*Manuscript received 12 September 2014, revised 24 November 2014.*

2014. Proceedings of the Indiana Academy of Science 123(2):138–160

# BACON'S SWAMP – GHOST OF A CENTRAL INDIANA NATURAL AREA PAST

**Rebecca W. Dolan**[1]: Friesner Herbarium, Butler University, Indianapolis, IN 46208 USA

**ABSTRACT.** Bacon's Swamp was identified in the 1920s as a ca. 12 ha glacial kettle lake bog system at the southernmost limits of these habitats in Indiana. Located just 9.6 km from the center of Indianapolis, the site was all but destroyed in the mid-20th century by urban expansion. Prior to habitat conversion at the site, Bacon's Swamp was a frequent location for Butler University ecology class field trips and student research projects. Herbarium specimens and published inventory records allow for analysis of the historical vegetation of Bacon's Swamp using modern techniques. Floristic Quality Assessment applied to these historical records reveals Bacon's Swamp was a regionally significant natural area, with a native Floristic Quality Index (FQI) value of 60 and a mean native Conservation Coefficient value of 4.2. Little of this unusual, high-quality habitat remains. A 2010 botanical inventory at the site documents decline in habitat with the loss of species that have a fidelity to high-quality habitat, with a corresponding drop in FQI to 20 and the addition of invasive non-native plants. Re-analysis of Bacon's Swamp historical flora supports the view that it was a significant wetland natural area and floristically unique in Central Indiana.

**Keywords:** Bacon's Swamp, Butler University, historical botany, urban flora, wetlands

## INTRODUCTION

Rare habitats and high-quality natural areas are often lost as cities grow and urbanization spreads out from the core to engulf surrounding land. Habitat can be directly lost through land use conversion and fragile ecological communities can be degraded through indirect effects that result in habitat alteration via processes such as fragmentation, spread of invasive species and altered drainage patterns (Dolan et al. 2011a, 2011b). Often only local historical knowledge remains with no physical record of species formerly present. Occasionally, lost natural areas have been the focus of historical scientific study prior to major disturbance (e.g., Tamarack Bog, Noble Co., IN (Swinehart & Starks 1994) and Cabin Creek Raised Bog, Randolph Co., IN (Ruch et al. 2013). When this happens, re-examination of the records and application of modern techniques of analysis can allow for a better appreciation of the quality and features of lost habitats. Additionally, these data can often be used to guide restoration efforts.

The opportunity existed to explore Bacon's Swamp, an ~12 ha glacial kettle lake bog system near the southernmost limits of these habitats in Central Indiana that has been nearly destroyed. Due to the unique composition of the swamp and its proximity to researchers and students in the Botany Department of Butler University, the site was a living lab – the focus of research papers, ecology class projects, honor's and master's projects, field trips, and specimen collection in the 1920s and 1930s (Fig. 1).

This paper compiles species lists from published literature records and herbarium specimens deposited in Butler University's Friesner Herbarium to examine and quantify the quality of the historical vegetation of Bacon's Swamp and its significance to the flora of the region using Floristic Quality Assessment, a tool developed in the early years of the twenty-first century. In addition, the site, which is fewer than 9.6 km from the center of downtown Indianapolis, was revisited in 2010 to assess the vegetation currently present.

## METHODS

**Study site.**—Bacon's Swamp was named after an early owner whose property was reportedly a stop on the Underground Railroad. The swamp was the focus of local lore, rumored in the early twentieth century to be bottomless (Roettger 1994). During the first half of the twentieth century, the swamp was a prominent natural area known for its unusual plants and diversity of birds and other wildlife and as a good spot for duck hunting.

---

[1] *Corresponding author:* Rebecca W. Dolan, 317-940-9413 (phone), 317-940-9519 (fax), rdolan@butler.edu.

Figure 1.—Stanley Cain's inaugural undergraduate Plant Ecology class at Butler University visits Bacon's Swamp in 1928. From left to right: Stanley Oren, unknown student, Rex Daubermire, and Alice Phillips. Photo courtesy of Rex Daubermire. Oren, Daubermire, and Phillips subsequently earned Ph.D.s in plant ecology at other universities.

Surrounding fields were in agriculture at this time. Development pressure intensified after World War II as the area surrounding Bacon's Swamp was converted from agriculture to housing. Long viewed as an "attractive nuisance," public outcry led to the swamp being drained and filled in the 1950s following the drowning deaths of several children. Some plans to save the area as a nature preserve and park had been discussed since the 1930s, but were never put in place (Roettger 1994). In the 1980s a senior living community was built on the site. The former bog area of Bacon's Swamp was dredged to form a lake. The former swamp habitat in the northern part is now in private hands and the wetlands in that area have also been dredged to form a lake. Aerial photos of the site from 1941-2014 document the changes (Figs. 2–5).

The origin of this unusual Central Indiana habitat is attributed to glacial melt from the retreating Early Wisconsin sheet ca. 20,000 year ago creating a kettle, or depression, formed by a glacial ice block that became a lake when the ice melted. The site then succeeded into a peatland that early researchers referred to as a bog, noting much peat and *Sphagnum* at the site, with cores showing a depth of sediment up to 11.9 m in the southern portion (Engelhardt 1959). Bogs were defined by Potzger (1934) as sites where the water table is at or near the surface and the soil is organic and formed *in situ,* while swamps were defined as sites with the water table above ground and the soil is inorganic or "of a humus nature." More recent interpretation would apply this definition of bogs to peatlands in general, of which bogs are a type (Swinehart 1997). Bacon's Swamp is likely the southernmost location of a kettle lake in Indiana and perhaps the Midwest (Otto 1938). These formations are most common in the Northern Lakes Natural Region, located 160 km to the north (Casebere 1997).

Cores into the peat of Bacons' Swamp reveal the succession of upland flora characteristic of regional post-glacial plant communities. Pollen in the deepest level, 6.1–9.8 m, was dominated by *Picea* and *Abies* with *Pinus, Larix* and *Salix-Populus* in low frequencies (Otto 1938). Mid-level cores revealed a rapid increase in *Pinus.* Top layers showed *Quercus* in high frequency, along with *Carya* and increases in *Acer* and *Fagus*, the beech-maple climax for Central Indiana (Otto 1938; Engelhardt 1959).

Bacon's Swamp is located in Marion County, Indiana and is bordered by 54th St. and Kessler

Figures 2-5.—Aerial photographs illustrating the change of Bacon's Swamp through time. 2. 1941 (top left). 3. 1959. 4. 1986. 5. 2014 (bottom right).

Blvd. on the north and south and by College Ave. and Keystone Ave. on the east and west (T 16 N, R 3 E, Sec. 6; with latitude and longitude at the center 39°51'17"N, 86°07'40"W; Fig. 6).

Marion County is in the Central Till Plain Natural Region (Homoya et al. 1985) of Indiana. This is a region of gently rolling terrain comprised of Wisconsin era glacial till deposits, often in excess of 30 m deep. General Land Office Survey records witness trees from 1820-1822 and soil survey records indicate that Marion County was 98% forested in pre-European settlement times (Barr et al. 2002). Mesic beech-maple forest covered 76% of the county, growing over an undissected plain of Wisconsin glacial till with small areas of oak-hickory forest on drier ridges. Wetlands, including ponds, bogs, marshes, and fens, are estimated to have made up approximately one percent of the original land cover (Barr et al. 2002).

The geology of Marion County is Carboniferous limestone covered by deposits of glacial drift 15-30 m deep. Soils at Bacon's Swamp were reported by Cain (1928) to be Miami black clay loam. The most recent USGS soil maps for Marion County only list cut and fill for the site (Sturm & Gilbert 1978). In the 1920s, corings revealed Bacon's Swamp was lined with a nearly impenetrable layer of fine compact blue silt at a depth in places of "only a few inches" (Cain 1926). Acidity of the cores varied vertically. The surface layer of the cores, down to a depth of 2.4 m, was raw *Sphagnum* peat with a pH of 5.9 (Otto 1938). Middle depths (2.4–7.0 m) were composed of sedge peat that was slightly acidic, while lower levels were alkaline (pH 7.3) due to groundwater soaking through limestone bedrock and to

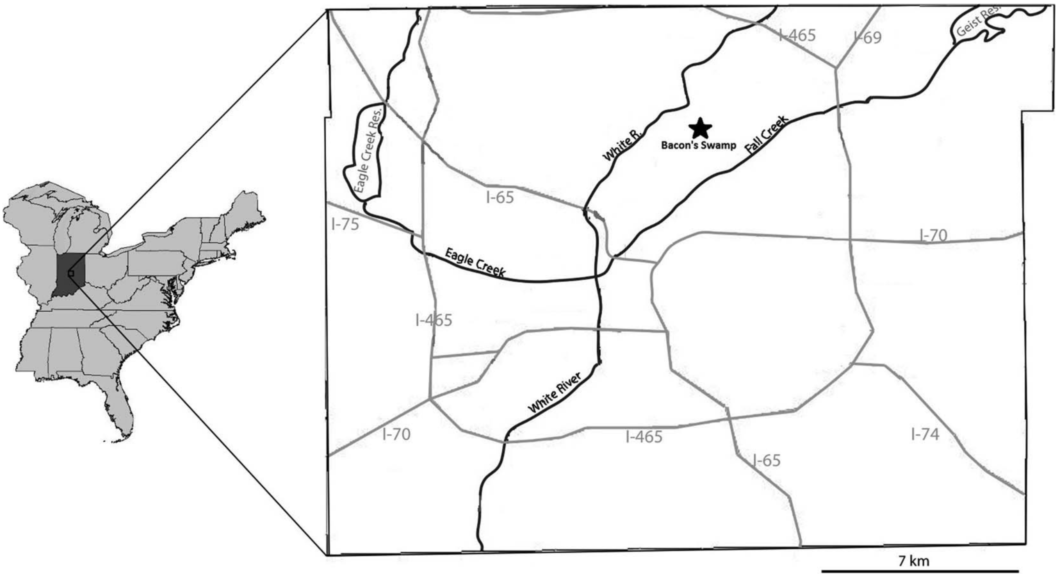


Figure 6.—Map illustrating the location of Marion County and the location of Bacon's Swamp within the county.

surface runoff. A layer of marl was present at the bottom of the basin (Otto 1938).

In the late 1920s, the site consisted of wetlands and surrounding upland forest (Fig. 7). Ecologists at the time identified the following plant zones or communities (Cain 1928; Phillips 1929). A wet meadow dominated by *Calamagrostis canadensis* occurred in the center of the site. *Dulichium arundinaceum, Juncus canadensis, Thelypteris palustris* var. *pubescens* and *Triadenum virginicum* were also present (Cain 1928; Phillips 1929). The wet meadow generally had 20–38 cm of standing water with scattered patches of *Typha* and open water with hydrophytes. *Sphagnum* and islands of *Decodon verticillatus* occurred along the meadow-mat next to the open water. It was surrounded by the deepest water present at the site, a "moat" 5–10 cm deep and 38–51 m wide. *Cephalanthus occidentalis* grew here, along with areas dominated by *Polygonum* spp. The moat was surrounded by a *Salix nigra* zone that graded into swamp forest dominated by *Acer rubrum*, *Fraxinus nigra, F. profunda, Nyssa sylvatica, Quercus bicolor, Q. palustris*, *Populus deltoides and Ulmus rubra*. Herbaceous plants included *Carex crinita*, *Onoclea sensibilis* and *Saururus cernuus*. The swamp forest transitioned to an upland beech-maple forest.

Cain (1928) and Phillips (1929) also identified a small area in the west-central portion of Bacon's Swamp as a fen. It was a site with few shrubs and no shade. Species present there included *Apios tuberosa, Asclepias incarnata, Eupatorium perfoliatum, Lobelia cardinalis, L. siphilitica, Lycopus uniflorus* and *Penthorum sedoides.* Soils were unlike the acid soils found elsewhere in the swamp; they contained sandy soil washed in from the adjacent upland, had widely fluctuating water levels, and a neutral pH (Cain 1928).

Cain (1928) posited that the concentric zonation of the vegetation represented stages of plant succession. He acknowledged the interest and assistance of Henry Cowles, University of Chicago, whose seminal paper (Cowles 1899) was the first published on the concept.

A final interesting piece of history relating to Bacon's Swamp is that it was the site of the first use of aerial photography to assist in ecological mapping (Cain 1926). Stanley Cain used pictures shot from 1524 m (5000 ft) to map zonation of plant communities in the swamp (Fig. 7). He felt the technique had great promise to assist ecologists in visualizing areas where the vegetation was too dense to traverse and topological maps did not exist. He noted that as airplanes became more numerous and available to people outside the military, that airplane photography would have great applicability to the burgeoning field of ecology. Cain was a Butler student and then professor who became an eminent ecologist,

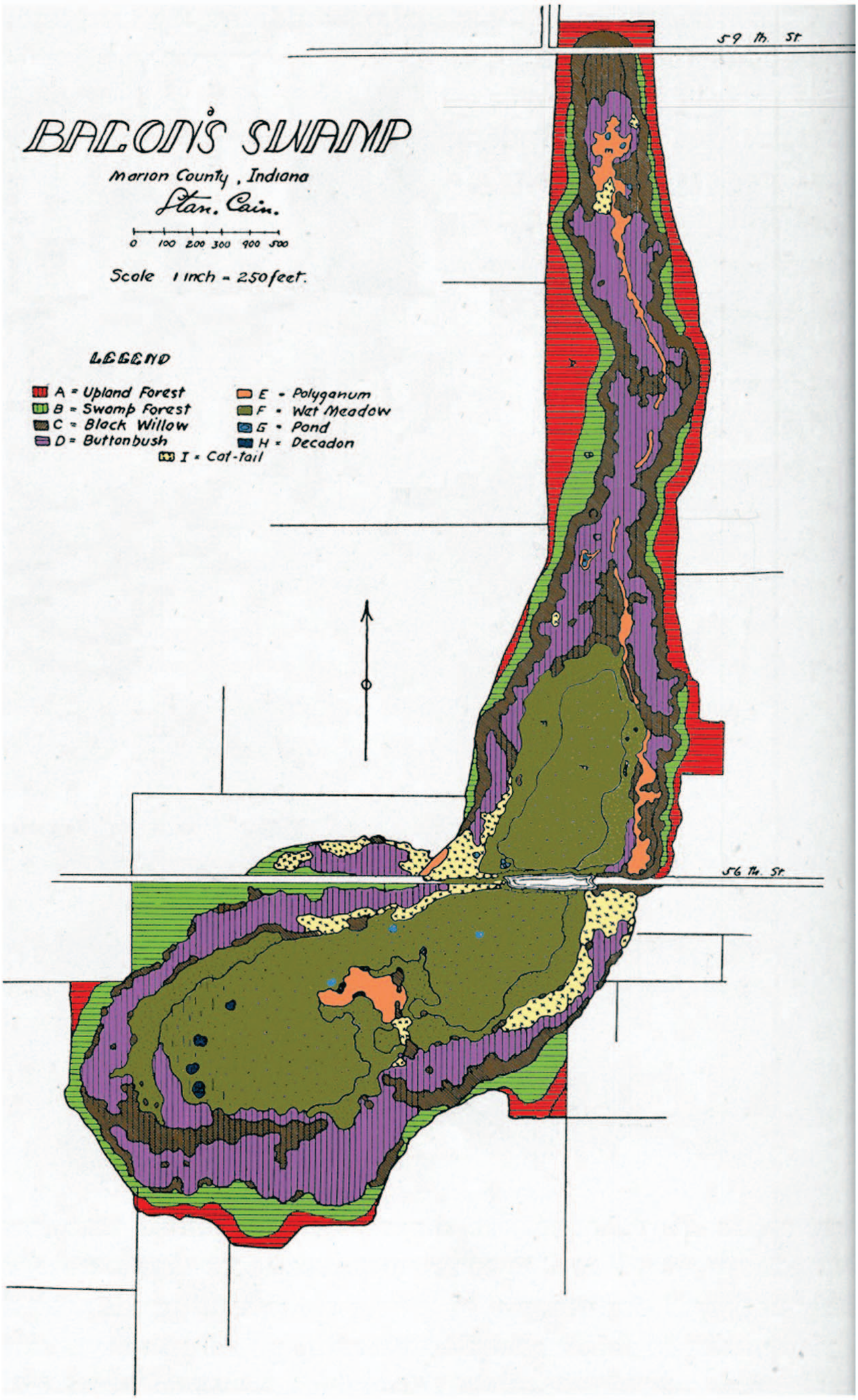


Figure 7.—Zonation of plant associations at Bacon's Swamp. Colorized version of map originally published in the Proceedings of the Indiana Academy of Science by Cain (1926).

elected President of the Ecological Society of America, and a member of the National Academy of Science.

**Data analysis.**—Two sources of information were used to establish a record of the historical flora of Bacon's Swamp. In 1929, Alice Phillips published a paper in the Butler University Botanical Studies that listed plants growing at Bacon's Swamp (Phillips 1929). Her goal was to categorize plants found in different microhabitats into Raunkiaer life-forms and to examine patterns. She lists 156 different taxa from six different plant associations/communities. A second source of historical records for Bacon's Swamp was specimens collected at the site that have been deposited in the Friesner Herbarium (BUT) of Butler University. A completed database of label information for all ca. 47,000 BUT sheets collected in Indiana allowed for identifying records that mention Bacon's Swamp in the location or habitat fields. In total 292 sheets of 138 different taxa collected from 1921-1935 were identified, suggesting the area was frequently botanized and collected. Most are plants noted by Phillips, but there are additions, and not all plants noted by Phillips have vouchers at BUT.

Species lists were compiled from the historical sources, matching older names with current nomenclature. To quantify the quality of vegetation at Bacon's Swamp and to allow comparison with other sites, I used Floristic Quality Assessment (Swink & Wilhelm 1994). Coefficients of Conservatism (C values) were used to quantify species' fidelity to high quality habitats and, therefore, tolerance of disturbance, as an indicator of overall floristic quality. C values were chosen for analysis of our data because they are comprehensive for the plants in the study area, provide a numerical value for species' behavior and can be used to make statistical comparisons between sites and through time. C values rank native species (those thought to have been present before European settlement) from 0-10 based on fidelity to high quality habitats, with higher numbers indicating greater preference for high quality habitat and less tolerance of disturbance. Because fidelity to high quality habitats can vary across species' ranges, we used C values developed specifically for the Indiana flora by Rothrock (2004).

Mean Coefficient of Conservatism (MC) and Floristic Quality Index (FQI) values were calculated using Floristic Quality Assessment software (Wilhelm & Masters 2004) separately for historical and recent species lists for Bacon's Swamp. All MC values reported are for native species only. FQI is calculated as FQI = $\Sigma(C_i)/\sqrt{}\ (N_{native})$, where C = the Coefficient of Conservatism of plant species i and $N_{native}$ = the total number of native species occurring in the community being evaluated. Nomenclature followed Rothrock (2004), which is based largely on the Flora of North America (2008).

Finally, in July of 2010, I visited the site with Paul Rothrock (then at Taylor University), Kay Yatskievych (Missouri Botanical Garden), and students to inventory current vegetation in what remains of Bacon's Swamp. We focused on plants in and around the borders of the remaining wetland area. Vouchers were not collected.

## RESULTS

A total of 268 taxa was reported for Bacon's Swamp (Appendix 1). The two historical sources yielded 228 different plants, the recent inventory yielded 66, 40 of which were not reported for the site in the past. Many prominent plants from historical reports, including *Calamagrostis canadensis*, a main component of the former wet meadow, were not seen in the recent survey, while others, like *Cephalanthus occidentalis*, previously prominent in the moat, remained (Appendix 1).

Historically, native perennial forbs (37.0%), trees (18.3%) and shrubs (12.3%) were the most common growth forms. Recent surveys show a similar pattern of physiognomy of the vegetation, with the exception of an increase in the percentage of annual forbs, which doubled in frequency from 8.2%–16.7% (Appendix 1).

MC based for historical records was 4.2, with a native FQI of 60.2 (Table 1). The recent inventory indicated greatly reduced habitat integrity, with values of 2.6 and 19.9, respectively. In the historical record, 16.0% (35 of 219) of plants had C values in the range of 7–10. Only one plant, *Quercus bicolor*, with a C value of 7, was in this range in the recent study. Values of 9 and 10 are indicative of species restricted to remnant landscapes that appear to have suffered very little post-settlement trauma (Rothrock & Homoya 2005). *Comarum palustre*, C = 9, and the following C = 10 species were present in the historical

Table 1.—Total species, percent native, native Mean Coefficient of Conservatism (MC), and native Floristic Quality Index (FQI) for historical and recent vegetation at Bacon's Swamp. BUT = Friesner Herbarium of Butler University.

| | Phillips | BUT | Total historical | Recent |
|---|---|---|---|---|
| Total Species | 158 | 138 | 219 | 66 |
| % Native | 96.8 | 86.2 | 91.8 | 86.4 |
| MC | 4.5 | 4.1 | 4.2 | 2.6 |
| FQI | 54.5 | 45.1 | 60.0 | 19.9 |

flora of Bacon's Swamp: *Acorus americanus, Dulichium arundinaceum, Symphyotrichum laeve* and *Triadenum virginicum.*

No plants currently recognized as threatened or endangered were found at Bacon's Swamp during historical or recent studies. In historical surveys, almost 92 percent of plants were native. The recent survey recorded 86%. Although relatively few non-native species have been recorded at Bacon's Swamp, some are considered invasive. Five of the seven recent non-natives have invasive ranks of "high" (IISC 2012): *Euonymus fortunei, Iris pseudacorus, Lythrum salicaria, Phalaris arundinacea* and *Rosa multiflora*. *Typha × glauca* is ranked as "caution" (IISC 2012).

Three plants recorded for Bacon's Swamp by Phillips (1929), *Iris versicolor, Salvinia natans* and *Spiraea salicifolia,* are not currently documented to grow in Indiana (BONAP 2014; USDA 2014; K. Yatskievych, Pers. Com.)

Of the six community associations detailed by Phillips (1929), plants found in the moat and in the wet meadow had the highest MC, with values over 5 (Table 2). The upland habitat surrounding the wetland complex has the highest FQI. Species numbers for some associations are low, and geographic size of association areas would have varied, limiting strength of interpretation. Comparison of historical and recent inventories (Appendix 1) reveals species have been lost about equally from all associations identified by Phillips (1929) and that habitat alternation at the site has greatly impacted all areas.

## DISCUSSION

Analysis of historical data for Bacon's Swamp with Floristic Quality Assessment confirms the impression of early 20th century botanists that the site was a significant natural area. If its 1920's vegetation was present today, Bacon's Swamp would be regionally significant. The total historical flora had an FQI over 60. Sites with FQI values greater than 50 are considered to be of "paramount importance" from a regional perspective (Swink & Wilhelm 1994). Bacon's Swamp's historical FQI puts it in the lower 1/3 of 17 high-quality Indiana natural areas reviewed in Ruch et al. (2013), but in the range of values for the two wetland complexes they report on, IMI WC and Bennett WC, in Henry County.

An analysis of Marion County's flora based on records before 1940 found only 14 plants out of over 700 taxa recorded had C values of 10, with seven having C values of 9 (Dolan et al. 2011a). Plants in this range are indicative of "species restricted to remnant landscapes that appear to have suffered very little post-settlement trauma" (Rothrock 2004). Of the five found historically at Bacon's Swamp – *Acorus americanus*, *Comarum palustre, Dulichium arundinaceum, Symphyotrichum leave*, and *Triadenum virginicum* – vouchers are present at BUT for all but the final two. Four of these

Table 2.—Total species, percent native, native Mean Coefficient of Conservatism (MC), and native Floristic Quality Index (FQI) values for species in plant associations identified by Phillips (1929) at Bacon's Swamp.

| | Upland | Lowland | Moat | Wet meadow | Fen | Aquatic |
|---|---|---|---|---|---|---|
| Total Species | 105 | 18 | 9 | 15 | 16 | 7 |
| % Native | 96.2 | 94.4 | 100.0 | 100.0 | 100.0 | 100.0 |
| MC | 4.4 | 4.6 | 5.2 | 5.4 | 4.3 | 4.4 |
| FQI | 43.8 | 19.2 | 15.7 | 20.9 | 17.3 | 11.7 |

species are not known to have occurred elsewhere in Marion County (Deam 1940) and may be extirpated from the county due to the loss of Bacon's Swamp. These records highlight the unusual nature of the habitat at Bacon's Swamp relative to the rest of the county.

While overall site quality can be inferred from the presence of individual high quality species, mean Coefficient of Conservatism values offer a more integrated view of the flora present at a site. Bacon's Swamp's historical MC of 4.2 ranks it among the highest values for a site in the county. Dolan et al. (2011b) present native MC values based on recent inventories of 14 natural areas in Marion County. These sites had an average MC of 3.7. Only three had values over 4.0; two sites had MC of 4.5, and one of 4.4. C values for the best natural sites in the Central Till Plain of central Indiana are in the low 4 range, lower than other regions of the state, due to a limited number of high quality species. As noted by Rothrock & Homoya (2005), this region is home to few rare, threatened or endangered species, likely due to the relative homogeneity of natural communities and the presence of few specialized edaphic habitats.

Both historical and recent records for Bacon's Swamp contain a small number of non-natives, 8% and 14%, respectively. Fourteen percent of species growing outside of cultivation in Indiana in 1940 were non-native (Deam 1940). Recent estimates put the percentage at 31% (K. Yatskievych, Pers. Com.) statewide. Dolan et al. (2011b) found 19.3% in city parks with natural area remnants. Although the recent Bacon's Swamp inventory was completed in only a single day and likely underestimates the true number of non-natives, five highly invasive non-natives were identified. These plants will contribute to further degradation of the ecological integrity of the site.

Bacon's Swamp was described as a bog by early researchers based on the presence of peat, *Sphagnum*, and acidic free-standing water. Bogs in the Northern Lakes Region of Indiana are characterized additionally by the presence of a distinctive suite of ericaceous shrubs including *Andromeda glaucophylla*, *Chamaedaphne calyculata*, and *Vaccinium macrocarpon*, along with carnivorous plants such as *Sarracenia* (Homoya et al. 1985; Casebere 1997). None of these plants are known from Bacon's Swamp. Their geographic range is typically limited to northern Indiana. However, several species historically found at Bacon's Swamp are disjunct from their mainly northern Indiana ranges (e.g., *C. palustre* and *T. virginicum*).

Analysis of the historical records of plants at Bacon's Swamp revealed three species that have not been documented for the state. Two are known from adjacent states (USDA, 2014) and could occur in Indiana. *Iris versicolor* occurs in Michigan, Ohio, Illinois and Kentucky. *Spiraea salicifolia* is documented for Michigan and Kentucky. Their historical records from Bacon's Swamp may be misdeterminations (Kay Yatskevych, Pers. Com.). *Iris versicolor* has been misidentified due to omissions in Gray's Manual, 7th ed. (Fernald & Robinson 1908), the reference used by Phillips (1929). *Iris virginica* var. *shrevei*, seen at Bacon's Swamp in the recent inventory and collected at the site in 1931, 1933, and 1936 and now deposited at BUT, would key out to *I. veriscolor* using that guide and may be the taxon Phillips identified. *Spiraea salicifolia* is a primarily European species that readily hybridizes with native species, producing many intermediate forms that can be difficult to key out.

The historical listing of *Salvinia natans* for Bacons' swamp is also problematic to interpret without a voucher specimen. No *Salvinias* have been definitively documented outside of cultivation in Indiana or surrounding states and it is a distinctive genus that would be unlikely to be misidentified. Phillips' (1929) taxonomic source for the historical inventories at Bacon's swamp, Gray's Manual, 7th ed. (Fernald & Robinson, 1908), lists only *Salvinia natans* Pursh., which is now considered an illegitimate name (MOBOT 2014), so it is not clear to which species the plant found at Bacon's Swamp should be referred (Kay Yatskevych, Pers. Com.). *Salvinia natans* (L.) All. is a legitimate name for a plant that is known only from New York and Massachusetts, according to the USDA's Plants Database (USDA 2014). It is possible the plant reported as *S. natans* was actually the liverwort *Ricciocarpus natans* L. Corda, which is common in similar wetland habits (P. Rothrock & A. Swinehart, Pers. Com.), although Cain (1928) does reference *Ricca fluitans* L. as being present at Bacon's Swamp, so he was aware of liverworts occurring there.

With the exception of the fern, a record for Indiana would not be a significant range expansion for these plants, so it may be that Bacon's Swamp was the historical home to state records. However, without vouchers deposited in herbaria to document these reports, it is not possible to examine a specimen to confirm correct identification.

The 2010 inventory, although limited to a single day and likely missing spring ephemerals and other out-of-season species, showed reduced habitat quality with marked reductions in FQI and Mean C compared to historical flora at the site and the presence of invasive non-native species. As early as the 1920s, evidence of habitat degradation due to drainage, fire, and agriculture were noted to be affecting Bacon's Swamp. An attempt to build 56th Street (Figs. 2-5) across the swamp in 1914 resulted in a paved road that sank when the peat on which it was built compressed. Construction of the road made a rectangular pond in the center of the swamp. Otto (1938) noted that 10 years before his study, Bacon's Swamp held water throughout the year and flooded to shallow lake stage in spring and fall. The thick growth of *Cephalanthus* in the moat and free-standing water provided protected habitat for migratory birds, reptiles, and amphibians. Small areas of living *Sphagnum* were present (Cain 1928). By 1936 the water table at the site had lowered, causing most of the swamp to dry out, perhaps due to tilling of surrounding land for agriculture and the effects of a drain installed at the north end. In late summer, dried grasses and sedges promoted fires that sometimes ignited peat (Otto 1938). Otto also noted the swamp forest on the northern edge of the swamp had been recently cut and cleared to "reclaim" the land, although the trees were too small to be of commercial value. He noted increases in wet meadow and decreases in *Sphagnum* which he attributed to the nearly annual fires.

Re-examination of the historical flora of Bacon's Swamp confirms that it was a high-quality site of regional significance based on FQA. Alkaline soils characteristic of Bacon's Swamp in its prime, together with its bog/wet meadow conditions, are unlikely to be recreated or replicated elsewhere in the county. However, the high-quality species that were once present at Bacon's Swamp and are now extirpated from the county could be targeted for use in wetland restorations in Marion County. This would allow these now lost elements of the county's flora to be recovered. With its absence of ericads, Bacon's Swamp might not be categorized as a bog by today's standards, but whatever its habitat classification, it was a unique site for Central Indiana. In a region that has lost over 85% of its historic wetlands (Ruch et al. 2013), Bacon's Swamp is an especially significant loss.

## ACKNOWLEDGMENTS

Paul Rothrock and Kay Yatskievych provided plant identification during the recent inventory at Bacon's Swamp. Paul, Kay and Tony Swinehart provided very helpful review comments for this manuscript. Butler undergraduate Brandon Euen prepared Figures 2–6 and colorized Figure 7. Their assistance is greatly appreciated. This paper is dedicated to the early faculty of the Botany Department at Butler University, whose contributions to the understanding of Indiana flora are still being appreciated today.

Appendix 1.—Plants of Bacon's Swamp, Indianapolis, Indiana. Non-native species are in uppercase letters. Recent refers to plants present during a July, 2010 survey, BUT refers to specimens in the Friesner Herbarium of Butler University, Phillips refers to all plants reported by Phillips (1929). Plant associations (Upland, Lowland, Moat, Wet Meadow, Fen, Aquatic) are from Phillips (1929). C is Coefficient of Conservation based on Rothrock (2004). For physiognomy, Nt = native, Ad = adventive or non-native, P = perennial, A = annual, B = biennial, H = herbaceous, W = woody.

| Scientific name | Recent | BUT | Phillips | Lowland | Upland | Moat | Wet meadow | Fen | Aquatic | Physiognomy | C |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Acer rubrum* L. var. *rubrum* | | | x | x | | | | | | Nt Tree | 5 |
| *Acer saccharinum* L. | x | | | | | | | | | Nt Tree | 1 |
| *Acer saccharum* Marshall ssp. *saccharum* | | | x | | x | | | | | Nt Tree | 6 |
| *Acer saccharum* Marshall ssp. *nigrum* (Michx. f.) Desmarais | | | x | | x | | | | | Nt Tree | 4 |
| *Acorus americanus* (Raf.) Raf. | | x | | | | | | | | Nt P-Forb | 10 |
| *Actaea pachypoda* Elliott | | | x | | x | | | | | Nt P-Forb | 7 |
| *Aesculus glabra* Willd. | | | x | | x | | | | | Nt Tree | 5 |
| *Agastache nepetoides* (L.) Kuntze | | | x | | x | | | | | Nt P-Forb | 4 |
| *Agastache scrophulariifolia* (Willd.) Kuntze | | x | | | | | | | | Nt P-Forb | 4 |
| *Ageratina altissima* (L.) R.M. King & H. Rob. | | x | | | | | | | | Nt P-Forb | 2 |
| *Agrimonia gryposepala* Wallr. | | x | | | | | | | | Nt P-Forb | 2 |
| *AGROSTIS GIGANTEA* Roth | | x | | | | | | | | Ad P-Grass | NA |
| *Alisma subcordatum* Raf. | | x | | | | | | | | Nt P-Forb | 2 |
| *Alopecurus aequalis* Sobol. | | x | | | | | | | | Nt P-Grass | 6 |
| *Amaranthus tuberculatus* (Moq.) D. Sauer | x | | | | | | | | | Nt A-Forb | 1 |
| *Ambrosia artemisiifolia* L. var. *elatior* (L.) Descourtils | | x | | | | | | | | Nt A-Forb | 0 |
| *Ambrosia trifida* L. | x | x | | | | | | | | Nt A-Forb | 0 |
| *Apios americana* Medik. | | | x | | | | | x | | Nt H-Vine | 3 |
| *Apocynum cannabinum* L. | x | | | | | | | | | Nt P-Forb | 2 |
| *Arisaema dracontium* (L.) Schott | | x | x | | x | | | | | Nt P-Forb | 5 |

Appendix 1.—Continued.

| Scientific name | Recent | BUT | Phillips | Lowland | Upland | Moat | Wet meadow | Fen | Aquatic | Physiognomy | C |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Arisaema triphyllum* (L.) Schott | | | x | | x | | | | | Nt P-Forb | 4 |
| *Asarum canadense* L. | | x | x | | x | | | | | Nt P-Forb | 5 |
| *Asclepias incarnata* L. | x | x | x | | | | | x | | Nt P-Forb | 4 |
| *Asimina triloba* (L.) Dunal | | | x | | x | | | | | Nt Tree | 6 |
| *BARBAREA VULGARIS* W.T. Aiton | | x | | | | | | | | Ad B-Forb | NA |
| *Bidens bipinnata L.* | | x | | | | | | | | Nt A-Forb | 0 |
| *Bidens connata* Muhl. ex Willd. | x | | | | | | | | | Nt A-Forb | 2 |
| *Bidens coronata* (L.) Fisch. ex Steud | | x | x | | | | | x | | Nt A-Forb | 5 |
| *Bidens frondosa* L. | x | | | | | | | | | Nt A-Forb | 1 |
| *Boehmeria cylindrica* (L.) Sw. | x | | | | | | | | | Nt P-Forb | 3 |
| *Botrychium virginianum* (L.) Sw. | | x | x | | x | | | | | Nt Fern | 4 |
| *Calamagrostis canadensis* (Michx.) P. Beauv. | | | x | | | | x | | | Nt P-Grass | 5 |
| *Calystegia sepium* (L.) R. Br. | x | | | | | | | | | Nt P-Forb | 1 |
| *Camassia scilloides* (Raf.) Cory | | x | | | x | | | | | Nt P-Forb | 5 |
| *Campanulastrum americanum* L. | | x | | | | | | | | Nt A-Forb | 4 |
| *Campsis radicans* (L.) Bureau | | | x | | x | | | | | Nt W-Vine | 1 |
| *CAPSELLA BURSA-PASTORIS* Medik. | | x | x | | | | | | | Ad A-Forb | NA |
| *Cardamine concatenata* (Michx.) O. Schwarz | | x | x | | x | | | | | Nt P-Forb | 4 |
| *Carex blanda* Dewey | | x | | | | | | | | Nt P-Sedge | 1 |
| *Carex crinita* Lam. | | x | x | x | | | | | | Nt P-Sedge | 8 |
| *Carex cristatella* Britton | x | | | | | | | | | Nt P-Sedge | 3 |
| *Carex frankii* Kunth | x | | | | | | | | | Nt P-Sedge | 2 |
| *Carex granularis* Muhl. ex Willd. | x | | | | | | | | | Nt P-Sedge | 2 |

Appendix 1.—Continued.

| Scientific name | Recent | BUT | Phillips | Lowland | Upland | Moat | Wet meadow | Fen | Aquatic | Physiognomy | C |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Carex hyalinolepis* Steud. | | | x | | | | x | | | Nt P-Sedge | 3 |
| *Carex laxiflora* Lam. | | | x | | x | | | | | Nt P-Sedge | 7 |
| *Carex stipata* Muhl. ex Willd. var. *stipata* | x | x | | | | | | | | Nt P-Sedge | 2 |
| *Carex tribuloides* Wahlenb. var. *tribuloides* | x | | | | | | | | | Nt P-Sedge | 5 |
| *Carex vulpinoidea* Michx. | x | | | | | | | | | Nt P-Sedge | 2 |
| *Carpinus caroliniana* Walter | | | x | | x | | | | | Nt Tree | 3 |
| *Carya cordiformis* (Wangenh.) K. Koch | | | x | | x | | | | | Nt Tree | 5 |
| *Carya ovata* (Mill.) K. Koch | | | x | | x | | | | | Nt Tree | 4 |
| *Celtis occidentalis* L. | x | | x | | x | | | | | Nt Tree | 3 |
| *Cephalanthus occidentalis* L. | x | x | x | | | x | x | | | Nt Shrub | 5 |
| *Cercis canadensis* L. | | | x | | x | | | | | Nt Tree | 3 |
| *Circaea lutetiana* L. ssp. *canadensis* (L.) Asch & Magnus | | x | | | | | | | | Nt P-Forb | 2 |
| *Claytonia virginica* L. | | x | x | | x | | | | | Nt P-Forb | 2 |
| *Collinsonia canadensis* L. | | x | | | | | | | | Nt P-Forb | 8 |
| *Comarum palustre* L. | | x | x | | | | x | | | Nt P-Forb | 9 |
| *Cornus drummondii* C.A. Mey. | x | | | | | | | | | Nt Shrub | 2 |
| *Cornus florida* L. | | | x | | x | | | | | Nt Tree | 4 |
| *Cornus obliqua* Raf. | | x | x | | x | x | | | | Nt Shrub | 5 |
| *Cornus sericea* L. | | x | | | | | | | | Nt Shrub | 4 |
| *Corylus americana* Walter | | x | | | | | | | | Nt Shrub | 4 |
| *Cyperus strigosus* (Nees) Steud. | x | | | | | | | | | Nt P-Sedge | 0 |
| *Cystopteris protrusa* (Weath.) Blasdell | | x | x | | x | | | | | Nt Fern | 4 |

Appendix 1.—Continued.

| Scientific name | Recent | BUT | Phillips | Lowland | Upland | Moat | Wet meadow | Fen | Aquatic | Physiognomy | C |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Decodon verticillatu*s (L.) Elliott | | x | x | | | | x | | | Nt Shrub | 8 |
| *Desmodium canadense* (L.) DC. | | | x | | | | | x | | Nt P-Forb | 3 |
| *Dicentra canadensis* (Goldie) Walp. | | | x | | x | | | | | Nt P-Forb | 7 |
| *Dicentra cucullaria* (L.) Bernh. | | x | x | | x | | | | | Nt P-Forb | 6 |
| *Dichanthelium acuminatum* (Sw.) Gould & C.A. Clark | | x | | | | | | | | | |
| ssp. *implicatum* (Scribn.) Gould & C.A. Clark | | | | | | | | | | Nt P-Grass | 2 |
| *DIGITARIA ISCHAEMUM* (Schreb.) Muhl. | | x | | | | | | | | Ad A-Grass | 0 |
| *Dulichium arundinaceum* (L.) Britton | | x | x | | | | x | x | | Nt P-Sedge | 10 |
| *Eclipta prostrata* (L.) L. | x | | | | | | | | | Nt A-Forb | 3 |
| *Eleocharis erythropoda* Steud. | x | | | | | | | | | Nt P-Sedge | 2 |
| *Eleocharis obtusa* (Willd.) Schult. | | x | | | | | | | | Nt A-Sedge | 3 |
| *Eleocharis palustris* Britton | | x | | | | | | | | Nt P-Sedge | 8 |
| *ELEUSINE INDICA* (L.) Gaertn. | | x | | | | | | | | Ad A-Grass | NA |
| *Elymus villosus* Muhl. ex Willd. | | x | | | | | | | | Nt P-Grass | 4 |
| *Enemion biternatum* Raf. | | | x | | x | | | | | Nt P-Forb | 5 |
| *Epifagus virginiana* (L.) W.P. Barton | | x | x | | x | | | | | Nt P-Forb | 8 |
| *Equisetum hyemale* L. ssp. *affine* (Engelm.) A.A. Eaton | | | x | | x | | | | | Nt Fern | 2 |
| *ERAGROSTIS CILIANENSIS* (All.) Vignlo ex Janch. | | x | | | | | | | | Ad A-Grass | NA |
| *Eragrostis hypnoides* (Lam.) Britton, Sterns & Poggenb. | | x | | | | | | | | Nt A-Grass | 3 |
| *Erigenia bulbosa* (Michx.) Nutt. | | | x | | x | | | | | Nt P-Forb | 5 |

Appendix 1.—Continued.

| Scientific name | Recent | BUT | Phillips | Lowland | Upland | Moat | Wet meadow | Fen | Aquatic | Physiognomy | C |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Erythronium albidum* Nutt. | | | x | | x | | | | | Nt P-Forb | 3 |
| *Erythronium americanum* Ker Gawl. | | x | x | | x | | | | | Nt P-Forb | 5 |
| *Euonymus atropurpurea* Jacq. | | x | x | | x | | | | | Nt Shrub | 5 |
| *EUONYMUS FORTUNEI* (Turcz.) Hand.-Mazz. | x | | | | | | | | | Ad Shrub | NA |
| *Euonymus obovata* Nutt. | | | x | | x | | | | | Nt Shrub | 7 |
| *Eupatorium perfoliatum* L. | | x | | | | | | | | Nt P-Forb | 5 |
| *Euthamia graminifolia* (L.) Nutt. | | x | x | | | | | x | | Nt P-Forb | 4 |
| *Eutrochium purpureum* (L.) E.E. Lamont var. *purpureum* | | x | | | | | | | | Nt P-Forb | 3 |
| *Fagus grandifolia* Ehrh. | | | x | | x | | | | | Nt Tree | 8 |
| *Fraxinus americana* L. | x | | x | | x | | | | | Nt Tree | 4 |
| *Fraxinus nigra* Marshall | | | x | x | x | | | | | Nt Tree | 7 |
| *Fraxinus pennsylvanica* Marshall var. *lanceolata* (Borkh.) Sarg. | x | | x | | x | | | | | Nt Tree | 1 |
| *Fraxinus pennsylvanica* Marshall var. *pennsylvanica* | | | x | | x | | | | | Nt Tree | 3 |
| *Fraxinus profunda* (Bush) Bush | | | x | x | | | | | | Nt Tree | 8 |
| *Fraxinus quadrangulata* Michx. | | | x | | x | | | | | Nt Tree | 7 |
| *Galium aparine* L. | | | x | | x | | | | | Nt A-Forb | 1 |
| *Geranium maculatum* L. | | x | x | | x | | | | | Nt P-Forb | 4 |
| *Geum canadense* Jacq. | x | | | | | | | | | Nt P-Forb | 1 |
| *Geum vernum* (Raf.) Torr. & A. Gray | | x | x | | x | | | | | Nt P-Forb | 1 |
| *Gleditsia triacanthos* L. | | | x | | x | | | | | Nt Tree | 1 |

Appendix 1.—Continued.

| Scientific name | Recent | BUT | Phillips | Lowland | Upland | Moat | Wet meadow | Fen | Aquatic | Physiognomy | C |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Glyceria septentrionalis* Hitchc. | | x | | | | | | | | Nt P-Grass | 7 |
| *Glyceria striata* (Lam.) Hitchc. | x | x | | | | | | | | Nt P-Grass | 4 |
| *Gratiola neglecta* Torr. | | x | | | | | | | | Nt A-Forb | 4 |
| *Gratiola virginiana* L. | | | x | | x | | | | | Nt A-Forb | 4 |
| *Gymnocladus dioica* (L.) K. Koch | | | x | | x | | | | | Nt Tree | 4 |
| *Heuchera americana* L. | | x | x | | x | | | | | Nt P-Forb | 7 |
| *Hybanthus concolor* (T.F. Forst.) Spreng. | | | x | | x | | | | | Nt P-Forb | 6 |
| *Hydrastis canadensis* L. | | | x | | x | | | | | Nt P-Forb | 7 |
| *Hydrophyllum appendiculatum* Michx. | | x | x | | x | | | | | Nt P-Forb | 6 |
| *Hydrophyllum macrophyllum* Nutt. | | | x | | x | | | | | Nt P-Forb | 7 |
| *Hydrophyllum virginianum* L. | | | x | | x | | | | | Nt P-Forb | 4 |
| *Ilex verticillata* (L.) A. Gray | | x | x | | | x | | | | Nt Shrub | 8 |
| *Impatiens capensis* Meerb. | x | | x | x | | | | | | Nt A-Forb | 2 |
| *IRIS PSEUDACORUS* L. | x | | | | | | | | | Ad P-Forb | NA |
| *Iris versicolor* L. | | | x | | | | | x | | Nt P-Forb | |
| *Iris virginica* L. var. *shrevei* (Small) E.S. Anderson | x | x | | | | | | | | Nt P-Forb | 5 |
| *Juglans nigra* L. | | x | x | | x | | | | | Nt Tree | 2 |
| *Juncus canadensis* J. Gay | | x | x | | | | x | | | Nt P-Forb | 7 |
| *Lactuca canadensis* L. | | x | | | | | | | | Nt B-Forb | 2 |
| *Leersia oryzoides* (L.) Sw. | x | | | | | | | | | Nt P-Grass | 2 |
| *Lemna minor* L. | x | | x | | | | | | x | Nt A-Forb | 3 |
| *Lemna trisulca* L. | | | x | | | | | | x | Nt A-Forb | 6 |

Appendix 1.—Continued.

| Scientific name | Recent | BUT | Phillips | Lowland | Upland | Moat | Wet meadow | Fen | Aquatic | Physiognomy | C |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *LEONURUS CARDIACA* L. |  | x |  |  |  |  |  |  |  | Ad P-Forb | NA |
| *Lindera benzoin* (L.) Blume |  |  | x |  | x |  |  |  |  | Nt Shrub | 5 |
| *Lindernia dubia* (L.) Pennell var. *dubia* | x |  |  |  |  |  |  |  |  | Nt A-Forb | 3 |
| *Liquidambar styraciflua* L. | x |  |  |  |  |  |  |  |  | Nt Tree | 4 |
| *Liriodendron tulipifera* L. |  |  | x | x |  |  |  |  |  | Nt Tree | 4 |
| *Lobelia cardinalis* L. |  | x | x |  |  |  |  | x |  | Nt P-Forb | 4 |
| *Lobelia siphilitica* L. |  | x | x |  |  |  |  | x |  | Nt P-Forb | 3 |
| *Luzula echinata* (Small) F.J. Herm. |  | x |  |  |  |  |  |  |  | Nt P-Forb | 6 |
| *Luzula multiflora* (Ehrh.) Lej. |  | x | x |  | x |  |  |  |  | Nt P-Forb | 6 |
| *Lycopus americanus* Muhl. ex W.P.C. Barton | x |  |  |  |  |  |  |  |  | Nt P-Forb | 3 |
| *Lycopus uniflorus* Michx. |  | x | x |  |  |  |  | x |  | Nt P-Forb | 5 |
| *LYSIMACHIA NUMMULARIA* L. | x |  |  |  |  |  |  |  |  | Ad P-Forb | NA |
| *Lythrum alatum* Pursh |  | x |  |  |  |  |  |  |  | Nt P-Forb | 5 |
| *LYTHRUM SALICARIA* L. | x |  |  |  |  |  |  |  |  | Ad P-Forb | NA |
| *MACLURA POMIFERA* (Raf.) C.K. Schneid. |  |  | x |  | x |  |  |  |  | Ad Tree | NA |
| *Maianthemum racemosum* (L.) Link |  | x | x |  | x |  |  |  |  | Nt P-Forb | 4 |
| *MEDICAGO SATIVA* L. ssp. *SATIVA* |  | x |  |  |  |  |  |  |  | Ad P-Forb | NA |
| *Menispermum canadense* L. |  |  | x |  | x |  |  |  |  | Nt W-Vine | 3 |
| *Mentha arvensis* var. *villosa* L. |  | x |  |  |  |  |  |  |  | Nt P-Forb | 4 |
| *Mimulus ringens* L. |  | x |  |  |  |  |  |  |  | Nt P-Forb | 4 |
| *Morus rubra* L. |  | x | x |  | x |  |  |  |  | Nt Tree | 4 |
| *Muhlenbergia schreberi* J.F. Gmel. |  | x |  |  |  |  |  |  |  | Nt P-Grass | 0 |
| *NEPETA CATARIA* L. |  | x | x |  | x |  |  |  |  | Ad P-Forb | NA |

Appendix 1.—Continued.

| Scientific name | Recent | BUT | Phillips | Lowland | Upland | Moat | Wet meadow | Fen | Aquatic | Physiognomy | C |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Nuphar advena* (Aiton) W.T. Aiton | | | x | | | | | | x | Nt P-Forb | 6 |
| *Nyssa sylvatica* Marshall | | x | x | x | | | | | | Nt Tree | 5 |
| *Oenothera biennis* L. | | x | | | | | | | | Nt B-Forb | 0 |
| *Onoclea sensibilis* L. | | x | x | x | x | | | | | Nt Fern | 4 |
| *ORNITHOGALUM UMBELLATUM* L. | | x | | | | | | | | Ad P-Forb | NA |
| *Osmorhiza longistylis* (Torr.) DC. | | | x | | x | | | | | Nt P-Forb | 3 |
| *Ostrya virginiana* (Mill.) K. Koch | | | x | | x | | | | | Nt Tree | 5 |
| *Panicum dichotomiflorum* Michx. | | x | | | | | | | | Nt A-Grass | 0 |
| *Parthenocissus quinquefolia* (L.) Planch. | | | x | | x | | | | | Nt W-Vine | 2 |
| *Penthorum sedoides* L. | | x | x | | | | | x | | Nt P-Forb | 2 |
| *Persicaria amphibia* (L.) Gray var. *emersa* (L.) Delarbre | | x | x | | | | x | | | Nt P-Forb | 4 |
| *Persicaria hydropiperoides* Michx. | x | x | x | | | | x | | | Nt P-Forb | 3 |
| *Persicaria pensylvanica* (L.) M. Gómez | | x | | | | | | | | Nt A-Forb | 0 |
| *Persicaria sagittata* (L.) H. Gross | | x | x | | | | x | x | | Nt A-Forb | 4 |
| *PERSICARIA VULGARIS* Webb & Moq. | x | | | | | | | | | Ad A-Forb | NA |
| *PHALARIS ARUNDINACEA* L. | x | | | | | | | | | Ad P-Grass | NA |
| *Phlox divaricata* L. | | x | x | | x | | | | | Nt P-Forb | 5 |
| *Photinia floribunda* (Lindl.) K.R. Roberston & J.B. Phipps | | | x | | | x | | | | Nt Shrub | 8 |
| *Photinia melanocarpa* (Mich.) K.R. Robertson & J.B. Phipps | | x | | | | | | | | Nt Shrub | 8 |
| *Phryma leptostachya* L. | | | x | | x | | | | | Nt P-Forb | 4 |
| *Phyla lanceolata* (Michx.) Greene | x | | | | | | | | | Nt P-Forb | 2 |

Appendix 1.—Continued.

| Scientific name | Recent | BUT | Phillips | Lowland | Upland | Moat | Wet meadow | Fen | Aquatic | Physiognomy | C |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Phytolacca americana* L. | | | x | | x | | | | | Nt P-Forb | 0 |
| *Pilea pumila* (L.) A. Gray | x | | | | | | | | | Nt A-Forb | 2 |
| *Platanus occidentalis* L. | x | | x | | x | | | | | Nt Tree | 3 |
| *Podophyllum peltatum* L. | | | x | | x | | | | | Nt P-Forb | 3 |
| *Polemonium reptans* L. | | x | x | | x | | | | | Nt P-Forb | 5 |
| *Polygonatum biflorum* (Walter) Elliott | | | x | | x | | | | | Nt P-Forb | 4 |
| *Populus deltoides* W. Bartram ex Marshall | x | | x | x | | | | | | Nt Tree | 1 |
| *Populus grandidentata* Michx. | | | x | | x | | | | | Nt Tree | 4 |
| *Prunus nigra* Aiton | | | x | | x | | | | | Nt Tree | 8 |
| *Prunus serotina* Ehrh. | | | x | | x | | | | | Nt Tree | 1 |
| *Prunus virginiana* L. | | | x | | x | | | | | Nt Shrub | 3 |
| *Pseudognaphalium obtusifolium* (L.) Hillard & B.L. Burtt | | x | | | | | | | | Nt B-Forb | 2 |
| *Ptelea trifoliata* L. var. *trifoliata* | | | x | | x | | | | | Nt Shrub | 4 |
| *Quercus alba* L. | | x | x | | x | | | | | Nt Tree | 5 |
| *Quercus bicolor* Willd. | x | x | x | x | | | | | | Nt Tree | 7 |
| *Quercus macrocarpa* Michx. | | | x | | x | | | | | Nt Tree | 5 |
| *Quercus muehlenbergii* Engelm. | | x | x | | x | | | | | Nt Tree | 4 |
| *Quercus palustris* Münchh. | | | x | x | | | | | | Nt Tree | 3 |
| *Quercus rubra* L. | | | x | | x | | | | | Nt Tree | 4 |
| *Quercus velutina* Lam. | | | x | | x | | | | | Nt Tree | 4 |
| *Ranunculus abortivus* L. | | | x | x | | | | | | Nt A-Forb | 0 |
| *Ranunculus flabellaris* Raf. | | x | x | | | | | | x | Nt P-Forb | 7 |

Appendix 1.—Continued.

| Scientific name | Recent | BUT | Phillips | Lowland | Upland | Moat | Wet meadow | Fen | Aquatic | Physiognomy | C |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Ranunculus recurvatus* Poir. |  |  | x | x |  |  |  |  |  | Nt A-Forb | 5 |
| *Rhus glabra* L. |  | x | x |  | x |  |  |  |  | Nt Shrub | 1 |
| *Ribes cynosbati* L. |  |  | x |  | x |  |  |  |  | Nt Shrub | 4 |
| *Rorippa palustris* (L.) Besser ssp. *fernaldiana* (Butters & Abbe) Jonsell | x |  |  |  |  |  |  |  |  | Nt A-Forb | 2 |
| *ROSA MULTIFLORA* Thunb. | x |  |  |  |  |  |  |  |  | Ad Shrub | NA |
| *Rosa palustris* Marshall |  | x | x |  |  | x | x |  |  | Nt Shrub | 5 |
| *Rubus allegheniensis* Porter | x | x | x |  | x |  |  |  |  | Nt Shrub | 2 |
| *Rubus hispidus* L. |  | x | x |  |  |  |  | x |  | Nt Shrub | 6 |
| *Rubus occidentalis* L. |  | x | x |  | x |  |  |  |  | Nt Shrub | 1 |
| *RUMEX ACETOSELLA* L. |  | x |  |  |  |  |  |  |  | Ad P-Forb | NA |
| *RUMEX OBTUSIFOLIUS* L. |  | x |  |  |  |  |  |  |  | Ad P-Forb | NA |
| *Rumex verticillatus* L. | x | x |  |  |  |  |  |  |  | Nt P-Forb | 5 |
| *Sagittaria latifolia* Willd. | x | x | x |  |  |  |  | x | x | Nt P-Forb | 3 |
| *Salix discolor* Muhl. |  |  | x |  |  | x | x |  |  | Nt Tree | 3 |
| *Salix eriocephala* Michx. |  | x | x |  |  | x | x |  |  | Nt Shrub | 4 |
| *Salix interior* Rowlee | x | x |  |  |  |  |  |  |  | Nt Shrub | 1 |
| *Salix nigra* Marshall | x | x | x | x |  |  |  |  |  | Nt Tree | 3 |
| *Salix sericea* Marshall |  | x | x |  | x | x |  |  |  | Nt Shrub | 6 |
| *Salvinia natans* (L.) All. |  |  | x |  |  |  |  |  | x | Nt P-Fern |  |
| *Sambucus nigra* L. ssp. *canadensis* (L.) R. Bolli | x | x | x |  | x |  |  |  |  | Nt Shrub | 2 |
| *Sanguinaria canadensis* L. |  | x | x |  | x |  |  |  |  | Nt P-Forb | 5 |
| *Saururus cernuus* L. |  | x | x | x |  |  |  | x |  | Nt P-Forb | 4 |

Appendix 1.—Continued.

| Scientific name | Recent | BUT | Phillips | Lowland | Upland | Moat | Wet meadow | Fen | Aquatic | Physiognomy | C |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Scirpus cyperinus* (L.) Kunth |  | x | x |  |  |  | x | x |  | Nt P-Sedge | 4 |
| *Scrophularia marilandica* L. |  | x |  |  |  |  |  |  |  | Nt P-Forb | 5 |
| *Scutellaria incana* Biehler |  | x |  |  |  |  |  |  |  | Nt P-Forb | 4 |
| *Scutellaria lateriflora* L. | x |  |  |  |  |  |  |  |  | Nt P-Forb | 4 |
| *SETARIA PUMILA* (Poir.) Roem. & Schult. |  | x |  |  |  |  |  |  |  | Ad A-Grass | NA |
| *Silene antirrhina* L. |  | x |  |  |  |  |  |  |  | Nt A-Forb | 0 |
| *Sium suave* Walter | x | x | x |  |  |  |  | x |  | Nt P-Forb | 5 |
| *Smilax glauca* Walter |  | x |  |  |  |  |  |  |  | Nt W-Vine | 4 |
| *Smilax rotundifolia* L. |  |  | x |  | x |  |  |  |  | Nt W-Vine | 3 |
| *Smilax tamnoides* L. |  |  | x |  | x |  |  |  |  | Nt W-Vine | 4 |
| *SOLANUM DULCAMARA* L. | x | x | x | x | x |  |  |  |  | Ad W-Vine | 0 |
| *Solidago caesia* L. |  | x |  |  |  |  |  |  |  | Nt P-Forb | 7 |
| *Solidago canadensis* L. var. *canadensis* |  | x |  |  |  |  |  |  |  | Nt P-Forb | 0 |
| *Spiraea alba* Du Roi |  | x |  |  |  |  |  |  |  | Nt Shrub | 4 |
| *Spiraea salicifolia* L. |  |  | x |  |  | x | x |  |  | Nt Shrub |  |
| *Spirodela polyrhiza* (L.) Schleid. | x |  |  |  |  |  |  |  |  | Nt A-Forb | 5 |
| *Stellaria pubera* Michx. |  | x | x |  | x |  |  |  |  | Nt P-Forb | 7 |
| *Stylophorum diphyllum* (Michx.) Nutt. |  |  | x |  | x |  |  |  |  | Nt P-Forb | 7 |
| *Symphyotrichum cordifolium* (L.) G.L. Nesom |  | x |  |  |  |  |  |  |  | Nt P-Forb | 5 |
| *Symphyotrichum laeve* (L.) Á. Löve & D. Löve |  |  | x |  | x |  |  |  |  | Nt P-Forb | 10 |
| *Symphyotrichum lanceolatum* (Willd.) G.L. Nesom | x |  |  |  |  |  |  |  |  | Nt P-Forb | 3 |
| *Symphyotrichum lateriflorum* (L.) Á. Löve & D. Löve | x |  |  |  |  |  |  |  |  | Nt P-Forb | 3 |

Appendix 1.—Continued.

| Scientific name | Recent | BUT | Phillips | Lowland | Upland | Moat | Wet meadow | Fen | Aquatic | Physiognomy | C |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Symphyotrichum pilosum* (Willd.) G.L. Nesom var. *pilosum* |  | x |  |  |  |  |  |  |  | Nt P-Forb | 0 |
| *Teucrium canadense* L. var. *canadense* | x |  |  |  |  |  |  |  |  | Nt P-Forb | 3 |
| *Thalictrum thalictroides* (L.) A.J. Eames & B. Boivin |  |  | x |  | x |  |  |  |  | Nt P-Forb | 7 |
| *Thelypteris palustris* Schott var. *pubescens* (G. Lawson) Fernald |  | x | x |  |  |  | x |  |  | Nt Fern | 7 |
| *Toxicodendron radicans* (L.) Kuntze ssp. *radicans* | x |  | x |  | x |  |  |  |  | Nt W-Vine | 1 |
| *Tradescantia subaspera* Ker Gawl. | x | x |  |  |  |  |  |  |  | Nt P-Forb | 4 |
| *Triadenum virginicum* (L.) Raf. |  |  | x | x | x |  |  |  |  | Nt P-Forb | 10 |
| *TRIFOLIUM PRATENSE* L. |  | x |  |  |  |  |  |  |  | Ad P-Forb | NA |
| *Trillium recurvatum* L.C. Beck |  |  | x |  | x |  |  |  |  | Nt P-Forb | 4 |
| *Trillium sessile* L. |  |  | x |  | x |  |  |  |  | Nt P-Forb | 4 |
| *Triodanis perfoliata* (L.) Nieuwl. |  | x |  |  |  |  |  |  |  | Nt A-Forb | 2 |
| *Typha latifolia* L. |  |  | x |  |  |  |  |  | x | Nt P-Forb | 1 |
| *TYPHA* × *GLAUCA* Godr. | x |  |  |  |  |  |  |  |  | Ad P-Forb | NA |
| *Ulmus americana* L. |  |  | x |  | x |  |  |  |  | Nt Tree | 3 |
| *Ulmus rubra* Muhl. |  | x | x | x |  |  |  |  |  | Nt Tree | 3 |
| *URTICA DIOICA* L. ssp. *DIOICA* |  | x |  |  |  |  |  |  |  | Ad P-Forb | NA |
| *VERBASCUM THAPSUS* L. |  | x |  |  |  |  |  |  |  | Ad B-Forb | NA |
| *Verbena urticifolia* L. var. *urticifolia* | x |  |  |  |  |  |  |  |  | Nt P-Forb | 3 |
| *Vernonia gigantea* (Walter) Trel. ex Branner & Coville | x | x |  |  |  |  |  |  |  | Nt P-Forb | 2 |
| *Viburnum lentago* L. |  |  | x |  | x |  |  |  |  | Nt Shrub | 5 |

Appendix 1.—Continued.

| Scientific name | Recent | BUT | Phillips | Lowland | Upland | Moat | Wet meadow | Fen | Aquatic | Physiognomy | C |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Viburnum prunifolium* L. |  | x |  |  |  |  |  |  |  | Nt Shrub | 4 |
| *VIOLA BICOLOR* Pursh |  | x | x |  | x |  |  |  |  | Ad A-Forb | NA |
| *Viola pubescens* Aiton |  | x |  |  |  |  |  |  |  | Nt P-Forb | 5 |
| *Viola sororia* Willd. |  | x | x |  | x |  |  |  |  | Nt P-Forb | 1 |
| *Viola striata* Aiton |  | x | x |  | x |  |  |  |  | Nt P-Forb | 4 |
| *Vitis aestivalis* Michx. var. *bicolor* Deam |  |  | x |  | x |  |  |  |  | Nt W-Vine | 4 |
| *Vitis vulpina* L. | x |  |  |  |  |  |  |  |  | Nt W-Vine | 3 |
| *Wolffia columbiana* H. Karst. |  |  | x |  |  |  |  |  | x | Nt A-Forb | 5 |
| *Woodsia obtusa* Torr. |  |  | x |  | x |  |  |  |  | Nt Fern | 4 |
| *Zanthoxylum americanum* Mill. |  | x | x |  |  | x |  |  |  | Nt Shrub | 3 |
| *ZEA MAYS* L. |  | x |  |  |  |  |  |  |  | Ad A-Grass | NA |

## LITERATURE CITED

Barr, R.C., B.E. Hall, J.A. Wilson, C. Souch, G. Lindsey, J.A. Bacone, R.K. Campbell & L.P. Tedesco. 2002. Documenting changes in the natural environment of Indianapolis-Marion County from European settlement to the present. Ecological Restoration 20:37–46.

BONAP (Biota of North America Program). 2014. Biota of North America Program, Chapel Hill, North Carolina. At: http://bonap.org (Accessed on 9 September 2014).

Cain, S.A. 1926. Airplane photography and ecological mapping. Proceedings of the Indiana Academy of Science 36:269–251.

Cain, S.A. 1928. Plant succession and ecological history of a central Indiana swamp. Botanical Gazette 86:384–401.

Casebere, L.A. 1997. Half land, half water: The Northern Lakes Region. Pp. 203–208, *In*: The Natural Heritage of Indiana. (M.T. Jackson, Ed.). Indiana University Press: Bloomington, Indiana.

Cowles, H.C. 1899. The ecological relations of the vegetation on the sand dunes of Lake Michigan. Part I.–Geographical relations of the dune floras. Botanical Gazette 27:95–117.

Deam, C.C. 1940. Flora of Indiana. Department of Conservation, Division of Forestry: Indianapolis, Indiana. 1236 pp.

Dolan, R.W., M.E. Moore & J.D. Stephens. 2011a. Documenting effects of urbanization on flora using herbarium records. Journal of Ecology 99: 1055–1063.

Dolan, R.W., J.D. Stephens & M.E. Moore. 2011b. Living *more than* just enough for the city: persistence of high–quality vegetation in natural areas in an urban setting. Diversity 3:611–627; doi: 10.3390/d3040611 – published online 3 October 2011.

Engelhardt, D.W. 1959. A comparative pollen study of two early Wisconsin bogs in Indiana. Proceedings of the Indiana Academy of Science 69: 110–119.

Fernald, B.L. & M.L. Robinson. 1908. Gray's New Manual of Botany, 7th ed. A Handbook of the Flowering Plants and Ferns of the Central and Northeastern United States and Adjacent Canada. American Book Company, New York, New York. 664 pp.

Flora of North America. 2008. Welcome to the Flora of North America Web Site. At: http://floranorthamerica.org/ Accessed on 3 September 2014.

Homoya, M.A., D.B. Abrell, J.R. Aldrich & T.W. Post. 1985. Natural Regions of Indiana. Proceedings of the Indiana Academy of Science 94: 245–268.

IISC (Indiana Invasive Species Council). 2012. Official IISC Invasive Plant List. Purdue University, West Lafayette, Indiana. At: http://www.entm.purdue.edu/iisc/invasiveplants.php (Accessed 1 August 2014).

MOBOT (Missouri Botanical Garden). 2014. Tropicos. St. Louis, Missouri. At: http://tropicos.org (Accessed on 1 September 2014).

Otto, J.H. 1938. Forest succession in the southern limits of early Wisconsin glaciation as indicated by a pollen spectrum from Bacon's Swamp, Marion County, Indiana. Butler University Botanical Studies 4:93–116.

Phillips, A. 1929. Life–forms and biological spectra of the flora of Bacon's Swamp, Indiana. Butler University Botanical Studies 1:41–53.

Potzger, J.E. 1934. A notable case of bog formation. American Midland Naturalist 15:567–580.

Roettger, A.A. 1994. Bacon's Swamp. Pp. 286–287, *In*: The Encyclopedia of Indianapolis. (D.J. Bodenhamer & R.D. Barrows, Eds.). Indiana University Press: Bloomington, Indiana.

Rothrock, P.E. 2004. Floristic quality assessment in Indiana: the concept, use, and development of Coefficients of Conservatism. Final Report for ARN A305–4–53 Floristic Quality Assessment Grant CD975586–01, Environmental Protection Agency Wetland Program Development Grant.

Rothrock, P.E. & M.A. Homoya. 2005. An evaluation of Indiana's floristic quality assessment. Proceedings of the Indiana Academy of Science 114:9–18.

Ruch, D.G., B.G. Torke, K.S. Badger, J.E. Taylor, B.H. Hess & P.E. Rothrock. 2013. The vascular flora and vegetational communities of Cabin Creek Raised Bog, Randolph County, Indiana. Castanea 78:290–311.

Sturm, R.H. & R.H. Gilbert. 1978. Soil Survey of Marion County, Indiana. United States Department of Agriculture, Soil Conservation Service. 63 pp.

Swinehart, A.L. 1997. The development and ecology of peatlands in Indiana. Ph.D. Thesis. Purdue University, Department of Forestry and Natural Resources, West Lafayette, IN.

Swinehart, A.L. & G.S. Starks. 1994. A record of the natural history and anthropogenic senescence of an Indiana Tamarack bog. Proceedings of the Indiana Academy of Science 103:225–239.

Swink, F. & G. Wilhelm. 1994. Plants of the Chicago Region, 4th ed. Indiana Academy of Science: Indianapolis, Indiana. 932 pp.

USDA, NRCS. 2014. The plants national database. Baton Rouge, Louisiana. At: http://plants.usda.gov (Accessed on 15 September 2014).

Wilhelm, G. & L. Masters. 2004. Floristic Quality Assessment and computer applications. Conservation Design Forum. Elmhurst, Illinois.

*Manuscript received 22 October 2014, revised 16 December 2014.*

2014. Proceedings of the Indiana Academy of Science 123(2):161–178

# THE VASCULAR FLORA AND VEGETATIONAL COMMUNITIES OF DUTRO WOODS NATURE PRESERVE, DELAWARE COUNTY, INDIANA

**Donald G. Ruch**[1], **Kemuel S. Badger, John E. Taylor** and **Samantha Bell**: Department of Biology, Ball State University, Muncie, IN 47306, USA

**Paul E. Rothrock**: Indiana University, Deam Herbarium, Smith Research Center, Indiana University, Bloomington, IN 47408, USA

**ABSTRACT.** Owned by the Red-tail Land Conservancy, Dutro Woods Nature Preserve (DWNP) is a 6.8 ha (16.7 acres) site located on State Road 32 in west-central Muncie, Indiana, Delaware County. An inventory of the vascular flora indicates that the urban site harbors considerable plant diversity with 240 taxa representing 164 genera and 63 families. Of the 240 taxa, 136 (57%) are native and 104 (43%) are non-native (exotic). The percent of non-native taxa is high when compared to other studies in east-central Indiana (typically between 18–25%). Thirty species represent Delaware County Records. In addition, seven species documented at DWNP are reported for the first time in Delaware County; however, they are not considered county records since they have not naturalized at the site. *Tilia cordata* represents a state record. No species occur on the IDNR list of endangered, threatened, or rare plants. The 12 families containing approximately 62% of the documented species are Asteraceae (31 spp.), Poaceae (27 spp.), Cyperaceae (16 spp.), Rosaceae (16 spp.), Fagaceae (eight spp.), Liliaceae (eight spp.), Polygonaceae (eight spp.), Brassicaceae (seven spp.), Fabaceae (seven spp.), Lamiaceae (seven spp.), Caprifoliaceae (five spp.), and Caryophyllaceae (five spp.). No species of the Ranunculaceae were observed. A physiognomic analysis reveals that the native species consist of 42 woody species, 65 herbaceous vines or forbs, 27 graminoids, and two ferns. Of the 104 exotics, 26 are woody, 61 are herbaceous vines or forbs, and 17 are grasses. The flora at DWNP is predominately low fidelity (low C-value), i.e., 87.9% (211 spp.) of the taxa have C-values $\leq 3$, and only 4.6% (11 taxa) have C-values $\geq 5$. For native species only, the FQI = 25.0 and the mean Coefficient of Conservatism (mean C) is 2.2. For all species FQI = 18.6 and the mean C = 1.2. These numbers suggest that DWNP lacks or has not returned to remnant natural quality. The high percentage of non-native species is discussed from the standpoint of secondary succession at the site since the early 1980s.

**Keywords:** Floristic quality index (FQI), county records, vascular plants, flora – Indiana, old-field flora

## INTRODUCTION

Unlike other sites previously inventoried in east-central Indiana, Dutro Woods Nature Preserve (DWNP) has experienced extensive human exploitation, being the site of Ernst Nursery until the early 1980s. Two previous study sites, which have experienced considerable, but much less, human impact, are Munsee Woods Nature Preserve (FQI = 55.0; mean C = 3.2) formerly known as Camp Munsee, a girl scout camp (Prast et al. 2014), and Mississinewa Woods (FQI = 46.2; mean C = 3.0), a floodplain woodland with a former hay field and trails (Ruch et al. 2012). Despite the negative impact of human activity at these sites on the floral communities, the FQIs of both sites suggest that they are of nature preserve quality possessing some noteworthy remnants of natural heritage of the region.

After conducting a visual examination of DWNP in the fall of 2012 and late winter of 2013, it was evident that human activities of the former nursery had severely impacted the floral communities to the extent that remnant natural quality was likely lacking. Nonetheless, the research team decided to study DWNP with the overall goal of documenting the floristic recovery of an urban site in the intermediate term (ca. 30 years). It was a further goal to validate the performance of Floristic Quality Assessment within a diverse, but compromised community. As with previous studies, the analysis included (1) an inventory of the vascular flora; (2)

---

[1] *Corresponding Author:* Donald G. Ruch, 765-285-8829 (phone), 765-285-8804 (fax), druch@bsu.edu.

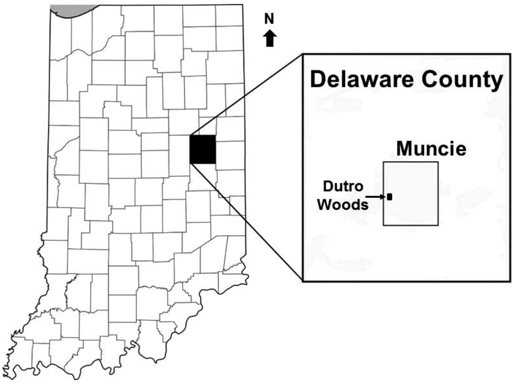


Figure 1.—Map indicating the location of Dutro Woods Nature Preserve in west-central Muncie, Delaware County (right), and the location of Delaware County within the state of Indiana (left). The site is on the south side of State Road 32.

determination of floristic quality metrics; (3) description of the various habitats and floral dominance for each; and (4) identification of areas of special concern (e.g., areas with rare or threatened plants, if any. Based on the finding of this study, information for long term resource management of the site has already been discussed with Barry Banks, Executive Director of the Red-tail Land Conservancy.

## SITE DESCRIPTION AND HISTORY

Formerly the site of Ernst Nursery until the early 1980s, Dutro Woods Nature Preserve (DWNP) is a 6.8 ha (16.7 acres) site located in west-central Muncie, Indiana, on State Road 32 (Fig. 1). The latitude and longitude at the corner of SR 32 and Proctor Road is 40$^0$10’51” N and 85$^0$26’33” W with an elevation of 287 m (942 ft). The property is bordered on the north and west by roads, on the south by tracks of the Norfolk Southern Railroad (RR), and on the east by land formerly belonging to the nursery. No creeks run across the property.

DWNP was purchased by the Red-tail Land Conservancy (RTLC) in January 2012 using funds provided by Goeff and Josephine Fox. The current site represents the western half of the old nursery. The RTLC purchased the eastern 15.3 acres from the DaSilva family in early 2015, following the completion of this project. A study conducted by Creek Run LLC, Montpelier, Indiana, determined the ground water was contaminated and recommended that the RTLC dig no deeper than 1 m (Barry Banks, Executive Director RTLC, pers. comm.). Lastly, when the nursery closed, apparently all shrubs and small trees were removed/bulldozed from the northern half of the property. The remains of this vegetation are seen as a long woody debris pile running the length of the site along the border of the woodland. Today, the site primarily consists of a successional shrubby old-field and a honeysuckle-Siberian elm dominated woodland.

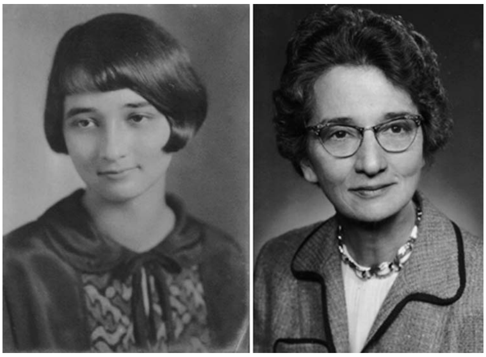


Figure 2.—Photographs of Ms. Ruth Dutro: high school senior photograph (left) and 1964 (right).

The site is named in honor of Ms. Ruth Dutro (Fig. 2). Ms. Dutro was a naturalist and a former biology teacher at Burris Laboratory School at Ball State University from 1942–1972. Josephine Fox and the Ernst family daughters were good friends and former students of Ms. Dutro.

The major habitat types of DWNP are shown in Fig. 3. There are two roadside fields each having distinctly different vegetation. The old-field along State Road 32 is mowed by the City of Muncie. Although regularly mowed in the past, the old-field along Proctor Road is now in succession and is dominated by shrubs, especially the southern two-thirds. A narrow old-field runs the length of the property along the RR tracks. This field frequency experiences disturbance by humans. First, a power line runs parallel to the RR tracks, and the power company periodically removes or cuts back any woody vegetation. Second, Norfolk Southern sprays herbicide along the RR tracks each year. The northern half of the property, which was apparently bulldozed to remove woody vegetation when the nursery closed, is now a shrubby old-field (IHAPI 2011). The southern half of the property, which was open woodland previously, is currently thick honeysuckle woodland with some trees, especially

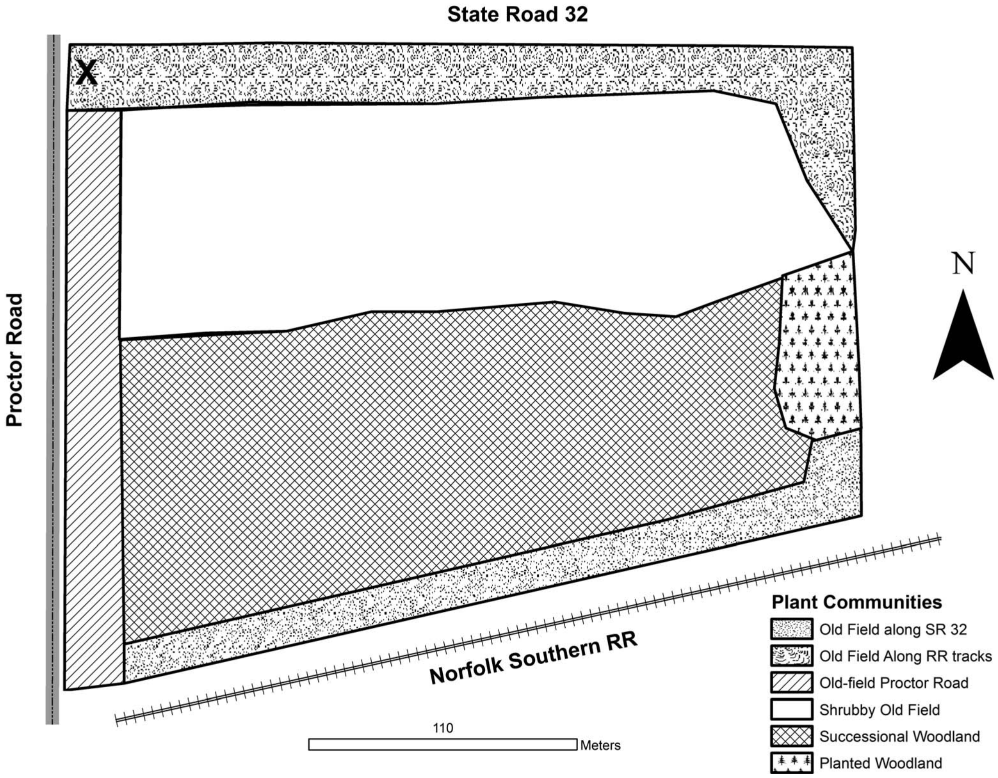


Figure 3.—Diagram illustrating the distribution of the major habitat types in Dutro Woods Nature Preserve, Delaware County, Indiana. The **X** marks the latitude and longitude coordinates given in the Site Description and History section.

*Ulmus pumila* (IHAPI 2011). Lastly, the eastern fifth of the woodland is "planted" woodland, a site where the nursery planted trees for sale. The planted woodland is devoid of honeysuckle.

DWNP lies near the northern border of the Tipton Till Plain Section or the New Castle Till Plains and Drainageways, of the Central Till Plain Region of Indiana (Homoya et al. 1985; Hedge 1997; IUPUI 2013). DWNP occurs in the Upper White River Watershed (USGS Cataloging Unit 05120201, EPA 2009). The west fork of the White River, which runs parallel to the northern border, lies approximately 480 m north of the site.

DWNP is comprised primarily of silt loam. The majority of the site consists of Wawaka Silt Loam, which is characterized as 0–2% slope and well drained. The southeastern quarter of the site consists of Crosley Silt Loam, which is characterized as 0–2% slope and somewhat poorly drained with no flooding or ponding (WWS 2013).

## METHODS

During the 2013 growing season [April through September], a foray every seven to ten days was made into the study area, a total of 21 trips. Forays were made into every major habitat type and efforts were 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 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 USDA Plants Database (USDA 2013). The Floristic Quality Index (FQI) for DWNP was determined using the program developed by the Conservation Design Forum in conjunction with Rothrock (2004). For this study, all exotic species, whether naturalized or not, were included in FQI calculations. 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 exotic. 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.] An 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). Potential Delaware County plant species records were determined from the following sources: the Indiana Natural Heritage Data Center's records for Delaware County [this is the same plant list in the computer database of Keller et al. (1984)], the USDA Plant database (2013), Overlease & Overlease (2007), the species listed at Munsee Woods Nature Preserve (Prast et al. 2014), and Ginn Woods (Ruch et al. 1998, 2004),

## RESULTS

The vascular flora documented at DWNP is listed in Appendix 1. The flora consists of 240 taxa representing 164 genera and 63 families. Of the 240 documented taxa, 136 taxa (57%) are native and 104 taxa (43%) are non-native. The 12 families containing 62% of the documented species are Asteraceae (31 species), Poaceae (27 species), Cyperaceae (16 species), Rosaceae (16 species), Fagaceae (eight species), Liliaceae (eight species), Polygonaceae (eight species), Brassicaceae (seven species), Fabaceae (seven species), Lamiaceae (seven species), Caprifoliaceae (five species), and Caryophyllaceae (five species). One interesting observation, no species of the Ranunculaceae were found at the site. A physiognomic summary of the flora discloses that 28.3% taxa are trees (38), shrubs (22), and woody vines (8), 52.5% of the taxa are herbaceous forbs (126), and vines (1), 18.3% are graminoids (27 grasses and 17 sedges), and > 1% are ferns (2) (Table 1, Appendix 1).

The Floristic Quality Indices (FQI) and the mean Coefficients of Conservatism (mean C) clearly specify the quality of the preserve (Table 2). The mean C of all taxa reveals the flora at DWNP consists predominately of low fidelity (low C-value) species (Appendix 1). The highest rated natives are *Quercus shumardii* and *Carex planispicata* (C = 7) and *Carex conjuncta* and *Dryopteris carthusiana* (C = 6). Only eleven species, 4.6% of all taxa, have a C-value ≥ 5. In contrast, 134 species have a C = 0 (104 exotics and 29 native species), 26 species have a C = 1, 20 species have a C = 2, 32 species have a C = 3, and 18 species have a C = 4. Thus, 95.4% of the documented flora at DWNP is categorized with C-values ≤ 4.

Accounting for 43% of the taxa, exotic species have considerably higher visual abundances than the native species. All of the native taxa with high visual abundances or widespread distributions are representatives of the low fidelity species categories (C ≤ 4), thus indicting a notable history of disturbance. Some exotic shrubs, especially *Lonicera* spp., grow so densely that large areas of the site, such as woodland on the southern half of the property and many locations in the shrubby old-field, have little or no other shrubs or herbaceous ground cover. Herbaceous exotic species are found in abundance in all habitats on the property, especially in all old-fields (Fig. 2, Appendix 1). For native species only, the FQI = 25.0 and the mean C is 2.2 (Table 2). If exotic species are included, the FQI drops nearly seven units (or 26% of its value) and the mean C falls by 1.0 unit (nearly 50% of its value) (Table 2). Such substantial change in both metrics clearly suggests that the exotics are having a significant negative impact on the native flora. While exotic shrubs made up only a small percentage (5.4%, 13 species) of the total number of species (Table 1), they have the highest visual abundances and largest negative impact at the site. The exotic shrub and small tree species with the highest visual abundances are *Ailanthus altissima*, *Lonicera × bella*, *L. maackii*, *L. morrowii*, *Malus* spp. (flowering crabapples), *Morus alba*, *Pyrus calleryana*, *Rosa multiflora*, and *Ulmus pumila* (Appendix 1).

Thirty species documented at DWNP are reported for the first time in the county and represent new Delaware County records (Table 3, Appendix 1). If any of these species

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

| | Native species summary | | Exotic species summary | |
|---|---|---|---|---|
| | Number | % of Total | Number | % of Total |
| # of species | 136 | 56.5% | 104 | 43.5% |
| Tree | 26 | 10.8% | 12 | 5.0% |
| Shrub | 9 | 3.7% | 13 | 5.4% |
| W-Vine | 7 | 2.9% | 1 | 0.4% |
| H-Vine | 1 | 0.4% | 0 | 0.0% |
| P-Forb | 44 | 18.3% | 26 | 10.9% |
| B-Forb | 6 | 2.5% | 16 | 6.7% |
| A-Forb | 14 | 5.9% | 19 | 7.9% |
| P-Grass | 8 | 3.4% | 10 | 4.3% |
| A-Grass | 2 | 0.8% | 7 | 2.9% |
| P-Sedge | 16 | 6.6% | 0 | 0.0% |
| A-Sedge | 1 | 0.4% | 0 | 0.0% |
| Fern | 2 | 0.8% | 0 | 0.0% |

were originally planted, they have naturalized and are spreading. Additionally, there are seven other species at DWNP that have not been previously reported from Delaware County. These are not being reported as county records because these have not naturalized nor are they spreading. Six of the seven are non-native species and include *Acer platanoides*, *Ginkgo biloba*, *Picea pungens*, *Pinus sylvestris*, *Quercus phellos*, and *Viburnum recognitum*. The native species is *Crataegus phaenopyrum* (Yatskievych, pers. comm.). *Tilia cordata* represents a state record (Yatskievych, pers. comm.). Lastly, none of the species documented at DWNP occur on the Indiana Department of Natural Resources list of endangered, threatened, or rare plants (IDNR 2013).

## DESCRIPTONS OF THE MAJOR HABITATS

This preserve encompasses several habitats, each with rather distinct plant communities (Fig. 3). Since there is no current management of the site, the different communities have resulted from past and, to some extent current, human use and intervention. The major habitats occurring at DWNP include the roadside old-fields, the old-field along the RR tracks, the successional shrubby old-field in the northern half of the site, the woodland in the southern half of the site, a "planted" woodland, i.e., a site used by the former nursery to grow woody species for sale, and a woody debris pile along the entire length between the shrubby old-field and woodland.

Table 2.—Floristic Quality summary for the vascular flora documented at Dutro Woods Nature Preserve, Delaware County, Indiana. Mean C = mean Coefficient of Conservation, FQI = Floristic Quality Index, Total species = native plus non-native species.

| | Species count | Mean C | FQI |
|---|---|---|---|
| Native species | 135 | 2.2 | 25.0 |
| Total species | 239 | 1.2 | 18.6 |

**Roadside old-fields.**—There are two roadside fields, each having a distinctive flora. The field along State Road 32 (SR 32), mowed by the City of Muncie once or twice a year, is dominated by grasses and herbs. The field along Proctor Road was manicured in the past, but it is now a successional old-field, most of which is dominated by shrubs. *Old-field along SR 32:* This field is dominated by graminoids. The common to abundant species of grasses include *Agrostis gigantea*, *Poa pratensis,* and

Table 3.—List of Delaware County records documented at Dutro Woods Nature Preserve. Non-native species are in capital letters.

Species

*AGROSTIS GIGANTEA*
*AMARANTHUS RETROFLEXUS*
*Andropogon virginicus*
*ARTEMISIA VULGARIS*
*ASPARAGUS OFFICINALIS*
*BROMUS COMMUTATUS*
*BROMUS ARVENSIS*
*Carex aggregata*
*CHLORIS VERTICILLATA*
*Cyperus esculentus* var. *leptostachyus*
*DRABA VERNA*
*Eupatorium altissimum*
*Eupatorium serotinum*
*FALLOPIA CONVOLVULUS*
*GERANIUM DISSECTUM*
*HEMEROCALLIS FULVA*
*Hypericum prolificum*
*Juniperus virginiana*
*Liquidambar styraciflua*
*Panicum capillare*
*Paspalum setaceum*
*Phalaris arundinacea*
*PLANTAGO MAJOR*
*PYRUS CALLERYANA*
*Rudbeckia triloba* var. *triloba*
*SILENE NOCTIFLORA*
*Solidago altissima*
*TILIA CORDATA*
*TORILIS ARVENSIS*
*Viola palmata*

*Schedonorus arundinaceus*. Other less frequent grasses include *Elymus repens*, *Phalaris arundinacea* (in the ditch), and *Phleum pratense*. Abundant sedges include *Carex leavenworthii*, and in the ditch both *Cyperus esculentus* var. *leptostachyus* and *Eleocharis obtusa*. Also, *Juncus tenuis* is abundant and widespread. The most common herbs are *Apocynum cannabinum*, *Daucus carota*, *Erigeron annuus*, *Securigera varia*, *Sisyrinchium angustifolium*, *Solidago altissima*, *Symphyotrichum pilosum*, *Toxicodendron radicans* ssp. *negundo*, *Vernonia gigantea*, and *Veronica serpyllifolia*. In the ditch along the road, *Acalypha rhomboidea* and *Bidens frondosa* were common. *Old-field along Proctor Road:* Visually, this field is dominated by shrubs. The most abundant species is *Lonicera maackii*; other common shrubs include *Acer negundo*, *Morus alba*, *Populus deltoides*, and *Rosa multiflora*. Between the shrubs are many graminoid species which are common to abundant including *Carex blanda*, *C. davisii*, *C. grisea*, *Chloris verticillata*, *Digitaria sanguinalis*, *Paspalum setaceum*, *Poa pratensis*, *Schedonorus arundinaceus*, and *Tridens flavus*. The most common herbaceous plants in this field include *Barbarea vulgaris*, *Cichorium intybus*, all *Cirsium* spp., *Daucus carota*, *Erigeron annuus*, *Medicago lupulina*, *Plantago lanceolata*, *Polygonatum biflorum* var. *biflorum*, and *Veronica arvensis*. This field is the only location for *Euonymus atropurpureus* and *Gaura biennis*, both rare at the site.

**Old-field along the RR tracks.**—This old-field lies between the woodland and the RR tracks along the extreme southern edge of the property. The field is impacted by humans in two ways. First, the RR sprays herbicide along the tracks annually. Second, a power line runs through the field parallel to the RR tracks, and the power company periodically trims/removes wood vegetation. As a result of these human interventions, this old-field is an "exotic species paradise." Woody species occurring at this site that are common to abundant include *Ailanthus altissima*, *Gleditsia triacanthos*, *Lonicera maackii*, *Morus alba*, *Toxicodendron radicans* ssp. *negundo*, and *Vinca minor* (a very large colony at the eastern end). *Carex grisea* is the only sedge common along the tracks. Although several grasses occur here, none are widespread or especially common. Grasses with the highest frequency are *Bromus inermis*, *Muhlenbergia schreberi*, *Panicum capillare*, *Poa pratensis*, and *Setaria faberi*. Exotic herbaceous plants common to abundant in this field include *Alliaria petiolata*, *Allium vineale*, *Artemisia vulgaris*, *Barbarea vulgaris*, *Brassica nigra*, *Cirsium arvense*, *C. vulgare*, *Conium maculatum*, *Geranium dissectum*, *Glechoma hederacea*, *Lamium purpureum*, *Leonurus cardiaca*, *Lepidium campestre*, *Nepeta cataria*, *Saponaria officinalis*, *Taraxacum officinale*, *Thlaspi arvense*, *Verbascum thapsus*, and *Veronica arvensis*. Native herbaceous species in this field include *Ambrosia artemisiifolia* var. *elatior*, *Cirsium discolor*, *Conyza canadensis*, *Fallopia scandens*, *Oxalis dillenii*, *Phytolacca americana*, *Solidago altissima*, and *S. canadensis* var. *canadensis*. Except for *C. discolor*, all the native herbaceous species common to abundant in this old-field have a C-value = 0. The woodland edge of the field is lined with large *Ulmus pumila*, the largest having a dbh (diameter at breast height) = 146.6 cm. At the base of this tree is a large colony of *Fallopia japonica*.

**Successional shrubby old-field.**—When the nursery closed, the northern half of the property was cleared by bulldozing all shrubs and small trees to the border of the open woodlands. Currently, there is a woody debris pile along the entire length between this field and woodland. Following the removal of the woody vegetation, the field was left fallow and today is a shrubby old-field undergoing secondary succession. The single most abundant plant in this large field is *Toxicodendron radicans* ssp. *negundo* forming a "carpet" over the site. The most visual and abundant woody vegetation includes *Cornus drummondii*, *Fraxinus americana*, *F. pennsylvanica* seedlings, *Hypericum prolificum*, *Lonicera* spp., *Malus* spp. (crabapples), *Morus alba*, *Pyrus calleryana*, *Quercus* spp., *Rosa setigera*, *Ulmus americana*, *U. pumila*, *Vitis riparia*, and *V. vulpina*. Between the shrubs, the two most abundant grasses are *Poa pratensis* and *Schedonorus arundinaceus*. Several sedges are common to abundant, including *Carex aggregata*, *C. leavenworthii*, and *C. granularis*. Also, the rush *Juncus tenuis* is extremely abundant and widespread. Although many species of herbs occur in the field, most are infrequent and found only in localized areas. The few herbs that are common to abundant and widespread include *Dipsacus fullonum*, *Geum laciniatum* var. *trichocarpum*, *G. vernum*, *Prunella vulgaris*, *Solidago altissima*, *Veronica serpyllifolia*, and *Viola sororia*.

*Woody debris pile:* Plant species occurring within the pile include those typical of both the successional woodland and the shrubby old-field. Nevertheless, growing in the soil between the logs is one robust plant of *Dryopteris carthusiana*. This plant is approximately 45–50 m from Proctor Road and the fronds bore sori.

**Successional woodland.**—This community occurs along the southern half of the property. When the nursery closed, this was an open woodland with few shrubs. However, over the years, *Lonicera maackii* has invaded and now grows so thickly that most of the woodland has no herbaceous cover. Tree species in this woodland include *Acer saccharinum*, *Celtis occidentalis*, *Fraxinus americana*, *F. pennsylvanica*, *Juglans nigra*, *Morus alba*, *Populus deltoides* (western end), *Prunus serotina*, *Ulmus americana*, and *U. pumila*. Vines include *Menispermum canadense* and *Toxicodendron radicans* ssp. *negundo*. Herbaceous plants grow where breaks in the honeysuckle occur and include *Allium canadense*, *Fallopia japonica*, *Geum canadense*, *G. vernum*, *Poa trivialis*, *Symphyotrichum lateriflorum* var. *lateriflorum*, *Tovara virginiana*, and *Viola sororia*. The majority of the herbaceous plants occur in the eastern half of this woodland.

**"Planted" woods.**—The small woodland area occurs at the eastern end of the larger woodland and was used by the former nursery to grow woody species for sale. Woody species occurring in this site include *Acer platanoides*, *Ginkgo biloba*, *Liquidambar styraciflua*, *Philadelphus inodorus*, *Quercus shumardii*, and *Tilia cordata*. The most notable ground cover under the rows of trees is *Allium canadense* and *Vinca minor*. In the southwest corner of these this woodland is a large colony of *Carex jamesii*. This is the only site that this sedge occurs on the property.

## DISCUSSION

Swink & Wilhelm (1994) state, "Plant species, through millennia, have become adapted to the specific combinations of biotic and abiotic factors, processes, and floral and faunal interactions uniquely characterizing the site they inhabit. An area with a long history of biome-level stability, such as characterized most of the presettlement landscape in the Midwest, will almost always support a diverse assemblage of conservative species in self-replicating, interactive arrays." With rapid changes to a site/habitat, the established specific combinations of biotic and abiotic factor and processes no longer exist. The result is a significant reduction in conservative plants and an increase in the number of both less conservative native plants and non-native invasive plants suitable to the new habitat. This shift in flora is often proportional to the severity of change to the habitat (Swink & Wilhelm 1994). Although the native FQI is 25.0 at DWNP, when all species are included the FQI drops to 18.6. Similarly, the native mean C is 2.2, but when all species are included the mean C drops to 1.2. These metrics clearly illustrate the high percentage of exotic and low-fidelity native species ($C \leq 4$, 95.4%) at the site. If a site has an FQI less than 20, then that site essentially has no significance from a natural area perspective (Rothrock & Homoya 2005; Swink & Wilhelm 1994). Clearly, the anthropogenic impact for over half a century significantly devalued the floristic quality of this property. Because no studies of the flora prior to the nursery are available, the full extent of the decline is unknown.

Since the close of the nursery in the early 1980s, the site has undergone continued succession. The southern half of the property adjacent to the railroad tracks, which was open woodland with some manicured fields and was not bulldozed, has developed into woodland heavily dominated by *Lonicera maackii* and *Ulmus pumila*, both exotic species. The northern half of the property along SR 32, which was bulldozed, has essentially undergone secondary old-field succession (that is, succession due to a catastrophic event that reduced an already established ecosystem (Kimmins 2004; IHAPI 2011). With this type of succession, the first plants to appear are annuals and biennials which have long-lived seeds and the ability to use available resources quickly to grow and reproduce. Within a few years perennial grasses and herbs begin to replace the initial species (Monk 1983). After approximately ten years, shrubs start to become dominant. Eventually shade-tolerant tree seedlings appear, and with time the site will become woodland (Quarterman 1957; Root & Wilson 1973; Kimmins 2004). The northern half of DWNP is currently in the dominant shrub stage of succession with *Cornus drummondii* and *Fraxinus pennsylvanica* seedlings, both low C-value natives, and *Lonicera* spp. and *Morus alba* abundant.

The results of old-field succession today, particularly in urban areas such as Muncie, differ from 50 or 100 years ago due to the high number of non-native species introduced to the United States over the past half century

(Bargeron et al. 2008; USDA 2014). Many of these non-native species are invasive and inhibit the establishment of native species (e.g., Collier et al. 2002; Davis et al. 2005). Typically, the percent of exotic species documented in inventories conducted in east-central Indiana, regardless of the size of the site, is between 18 to 26% (Rothrock et al. 1993; Rothrock 1997; Ruch et al. 1998, 2002, 2004, 2007, 2008a, b, 2009, 2010, 2012; Stonehouse et al. 2003; Tungesvick 2011). Exotics might be expected to comprise 1/3 of post-agricultural communities (Stover & Marks 1998). At DWNP exotic species compose 43% of the documented species. The most plausible explanation for the remarkable number of exotics is the reservoir of available propagules in combination with intense anthropogenic impact. The combination provided open habitat for invasive species while reducing competition from the native species.

The Indiana Invasive Species Council (IISC) has been creating a list of invasive plant species for the state using a science-based assessment program. Currently, the list contains 120 species including their invasive rank, i.e., high, medium, or caution, for most species (IISC 2013). Of the 104 exotic taxa occurring at DWNP, twenty-one have a high invasive rank, such as *Ailanthus altissima, Alliaria petiolata, Artemisia vulgaris, Conium maculatum, Dipsacus fullonum, Fallopia japonica, Lonicera* spp., *Rosa multiflora*, and *Securigera varia*. Additionally, nine species have a medium invasive rank, such *as Glechoma hederacea, Melilotus* spp., *Pastinaca sativa, Schedonorus arundinaceus, Ulmus pumila*, and *Vinca minor*. Many of the exotic species at DWNP are remnants of the nursery, such as *Ginkgo biloba*, *Hypericum prolificum*, *Malus* spp., *Philadelphus inodorus*, *Picea* spp., *Quercus phellos*, *Tilia cordata*, and *Viburnum* spp.

In summary, DWNP is a site which lacks remnant natural quality due to intense human activity associated with the former nursery. When the nursery closed, conditions were apparently ideal for the invasion of exotic species and for the exotics left on the site by the nursery to expand. As a result, nearly half of the plant taxa documented are non-native species. However, with considerable effort and resources, DWNP could be transformed into a high quality site. Barry Banks and Josie Fox are both committed to achieving this. We have recommended, at least for the shrubby fields, that they develop some quality prairies.

## ACKNOWLEDGMENTS

The authors wish to thank the Indiana Academy of Science (IAS) and the Department of Biology at Ball State University for financial support of this research project. Support from the IAS was through the Winona Welch Award for Botanical Biodiversity Research. We also wish to thank the Board of Directors of the Red-tail Land Conservancy, and especially Barry Banks, Executive Director, for permission to conduct the study. We thank Michael Szajewski, Archivist for Digital Development and University Records, University Libraries, Ball State University, for providing materials and photographs of Ms. Ruth Dutro. Likewise, we thank Doug Peters, Ms. Dutro's grandnephew, and his wife Dana for providing materials and photographs. We express our appreciation to Kay Yatskievych and Mary Damm for their critical evaluation of the manuscript. Lastly, we express our sincere gratitude to Samantha Melling, a former Ball State University student, for her invaluable assistance in the herbarium.

## APPENDIX 1

## CATALOG OF VACULAR FLORA AT DUTRO WOODS, DELAWARE COUNTY, INDIANA

(Arranged alphabetically by family)

Listed are voucher specimens for all species documented at Dutro Woods. Nomenclature follows the USDA Plants Database (USDA 2014). Each species report contains the following information: (1) current scientific name based on the USDA Plants Database; (2) current taxonomic synonyms, if appropriate; (3) common name(s), based primarily on Gleason & Cronquist (1991), Swink & Wilhelm (1994), and Yatskievych (2000); (4) typical habitat(s) within the study site; (5) a visual estimate of its relative abundance; (6) its coefficient of conservatism (C-value) for Indiana (Rothrock 2004); and (7) 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.

All non-native (exotic) species are in capital letters. (Exotics that were planted and have not naturalized are also listed in capital letters.) Potential Delaware County records are indicated by a pound-symbol (#) in parentheses immediately preceding a species. Species were deemed unreported for Delaware County, and hence considered a county record, if they did not appear in Deam (1940), the computer database of Keller et al. (1984) and Keller (1986), Overlease & Overlease (2007), Prast et al. 2014, Ruch et al. (1998, 2004), or the USDA Plant Database (USDA 2014). (The database of plants developed by Keller et al. (1984) contains the same plant list for Delaware County as does the Indiana Natural Heritage Data Center, IDNR.). There are 30 Delaware County records. Lastly, no species documented at Dutro Woods occur on the Indiana Department of Natural Resources list of endangered, threatened or rare plants (IDNR 2013).

## DIVISION POLYPODIOPHYTA

### Ferns

### Dryopteridaceae (Wood Fern Family)

*Dryopteris carthusiana* (Vill.) H.P. Fuchs; SYN: *Dryopteris spinulosa* (O.F. Müll.) Watt; Toothed or Spinulose Wood-Fern, Spinulose Shield-Fern; Border between woodland and shrubby field; Rare; C = 6; BSUH 18843.

*Onoclea sensibilis* L.; Sensitive Fern; Shrubby old-field, east end; Rare; C = 4; BSUH 18762.

## DIVISION GINKGOOPHYTA

### Ginkgo

### Ginkgoaceae (Ginkgo Family)

*GINKGO BILOBA* L.; Ginkgo, Maidenhair Tree; Planted woodland; Rare, one tree; C = 0; BSUH 18718.

## DIVISION CONIFEROPHYTA

### Conifers

### Cupressaceae (Redwood or Cypress Family)

*Juniperus virginiana* L. var. *virginiana*; Eastern Red Cedar; Shrubby old-field; Rare; C = 2; BSUH 18813.

### Pinaceae (Pine Family)

*PICEA ABIES* (L.) Karst.; Norway Spruce; Shrubby old-field; Several trees, planted not naturalized; C = 0; BSUH 18706, 18746.

*PICEA PUNGENS* Engelm.; (Colorado) Blue Spruce; Shrubby old-field; Two trees, planted not naturalized; C = 0; BSUH 18717.

*PINUS SYLVESTRIS* L.; Scotch or Scots Pine; Shrubby old-field; Several trees, planted not naturalized; C = 0; BSUH 18792.

## DIVISION MAGNOLIOPHYTA

### Angiosperms

### Aceraceae (Maple Family)

*Acer negundo* L. var. *negundo*; Boxelder, Ash-Leaved Maple; Shrubby old-field and woodland; Infrequent; C = 1; BSUH 18660.

*ACER PLATANOIDES* L.; Norway Maple; Rare; Planted woodland; C = 0; BSUH 18719.

*Acer rubrum* L. var. *rubrum*; Red Maple; Rare, one tree, planted; Shrubby old-field, west end; C = 5; BSUH 18659.

*Acer saccharinum* L.; Silver Maple; Woodland; Infrequent; C = 1; BSUH 18664, 18793.

*Acer saccharum* Marshall var. *saccharum*; Sugar Maple; Woodland; Infrequent; C = 4; BSUH 18663.

### Amaranthaceae (Amaranth Family)

*AMARANTHUS RETROFLEXUS* L.; Redroot, Rough Green Amaranth; Old-field along RR track; Infrequent; C = 0; BSUH 18782.

### Anacardiaceae (Cashew Family)

*Toxicodendron radicans* (L.) Kuntze ssp. *negundo* (Greene) Gillis; Common or Eastern Poison Ivy; All habitats; Extremely abundant; C = 1; BSUH 18808, 18811.

### Apiaceae (Carrot Family)

*CONIUM MACULATUM* L.; Poison Hemlock; Old-field along RR track; Abundant; C = 0; BSUH 18819.

*DAUCUS CAROTA* L.; Wild Carrot, Queen Anne's-Lace; Old-field and roadside along S. Proctor Road; Common; C = 0; BSUH 18642.

*PASTINACA SATIVA* L.; Wild Parsnip; Old-field along RR track; Infrequent but locally abundant; C = 0; BSUH 18803.

*Sanicula canadensis* L. var. *canadensis*; Canadian Black-Snakeroot, Canada Sanicle; Woodland; Rare; C = 2; BSUH 18645.

*TORILIS ARVENSIS* (Huds.) Link ssp. *ARVENSIS*; Field or Spreading Hedge-Parsley; Old-field along RR track; Infrequent; C = 0; BSUH 18638.

### Apocynaceae (Dogbane Family)

*Apocynum cannabinum* L.; (American) Indian Hemp, Dogbane; Old-field along SR 32; Infrequent; C = 2; BSUH 18814.

*VINCA MINOR* L.; Common Periwinkle, Myrtle; Edge of planted woods and old-field along RR track; Rare but locally abundant; C = 0; BSUH 18711, 18712, 18713.

### Asclepiadaceae (Milkweed Family)

*Asclepias incarnata* L. ssp. *incarnata*; Swamp Milkweed; Old-field along SR 32; Rare, one clump; C = 4; BSUH 18626.

*Asclepias syriaca* L.; Common Milkweed; Old-field along RR track; Infrequent; C = 1; BSUH 18688.

### Asteraceae (Aster Family)

*Achillea millefolium* L. var. *occidentalis* DC.; Common or Western Yarrow; Old-field along SR 32, western-end; Rare; C = 0; BSUH 18806.

*Ambrosia artemisiifolia* L. var. *elatior* Descourt.; SYN: *Ambrosia elatior* L.; Common or Annual Ragweed; Old-field along RR track; Abundant; C = 0; BSUH 18751.

*Ambrosia trifida* L. var. *trifida*; Great or Giant Ragweed; Old-field along SR 32; C = 0; BSUH 18756.

*ARCTIUM MINUS* (Hill) Bernh.; Common or Lesser Burdock; Old-field along RR tract; Infrequent; C = 0; BSUH 18734.

*ARTEMISIA VULGARIS* L.; SYN: *Artemisia vulgaris* L. var. *vulgaris*; Mugwort, Common Wormwood; Old-field between planted woods and RR track and old-field along RR tract; Abundant; C = 0; BSUH 18727, 18770, 18772.

*Bidens frondosa* L.; Common or Devil's Beggar's-Ticks; Ditch in old-field along SR 32; Common; C = 1; BSUH 18779.

*CICHORIUM INTYBUS* L.; Chicory; Old-field and roadside along S. Proctor Road; Common; C = 0; BSUH 18651.

*CIRSIUM ARVENSE* (L.) Scop.; Canada Thistle; Old fields along S. Proctor Road and the RR track; Abundant; C = 0; BSUH 18735, 18810.

*Cirsium discolor* (Muhl. ex Willd.) Spreng.; Field or Pasture Thistle; Old-fields along the RR tract and S. Proctor Road; Abundant; C = 3; BSUH 18750.

*CIRSIUM VULGARE* (Savi) Ten.; Bull Thistle; Old-field along the RR tract and S. Proctor Road; Common; C = 0; BSUH 18755.

*Conyza canadensis* (L.) Cronquist var. *canadensis*; SYN: *Erigeron canadensis* L.; Horseweed, Muleweed; Old-field along RR track; Abundant; C = 0; BSUH 18628.

*Erigeron annuus* (L.) Pers.; Eastern Daisy, Annual Fleabane, Whitetop; Old-field along S. Proctor Road; Common; C = 0; BSUH 18802.

*Erigeron philadelphicus* L. var. *philadelphicus*; Common, Marsh, or Philadelphia Fleabane; Old-field along SR 32 and northern side of shrubby old-field; Infrequent; C = 3; BSUH 18590.

*Eupatorium altissimum* L.; Tall Boneset, Tall Thoroughwort; Old-field along S. Proctor Road; Infrequent; C = 1; BSUH 18764.

*Eupatorium serotinum* Michx.; Late Boneset, Late-Flowering Thoroughwort; Old-field along SR 32; Infrequent; C = 0; BSUH 18765.

*Heliopsis helianthoides* (L.) Sweet var. *helianthoides*; False Sunflower, Smooth Oxeye; Shrubby old-field; Infrequent; C = 4; BSUH 18682.

*Lactuca canadensis* L.; Wild or Canada Lettuce; Old-field along RR track; Infrequent; C = 2; BSUH 18752.

*LACTUCA SERRIOLA* L.; SYN: *Lactuca scariola* L.; Prickly Lettuce; Old-field along RR track; Rare; C = 0; BSUH 18733.

*LEUCANTHEMUM VULGARE* Lam.; SYN: *Chrysanthemum leucanthemum* L. var. *pinnatifidum* Lecoq & Lamotte, *Leucanthemum vulgare* Lam. var. *pinnatifidum* (Lecoq & Lamotte) Moldenke; Ox-Eye Daisy; Old-field along S. Proctor Road; Rare; C = 0; BSUH 18650.

*MATRICARIA DISCOIDEA* DC.; SYN: *Matricaria matricarioides* auct. non (Less.) Porter; Pineapple-Weed, Disc Mayweed; Roadside along S. Proctor Road; Rare; C = 0; BSUH 18624.

*Rudbeckia triloba* L. var. *triloba*; Three-Lobed Coneflower, Brown-Eyed Susan; Old-field along RR track; Rare; C = 3; BSUH 18776.

*Solidago altissima* L.; SYN: *Solidago canadensis* L. var. *scabra* Torr. & A. Gray; Tall or Canada Goldenrod; Old-fields; Abundant; C = 0; BSUH 18722, 18763, 18768.

*Solidago canadensis* L. var. *canadensis*; Canada Goldenrod; Old-field along SR 32; Common; C = 0; BSUH 18775.

*SONCHUS ASPER* (L.) Hill; Spiny Sow-Thistle; Old-field along RR track; Infrequent; C = 0; BSUH 18565, 18637.

*Symphyotrichum lanceolatum* (Willd.) G.L. Nesom ssp. *lanceolatum* var. *lanceolatum*; SYN: *Aster simplex* Willd., *Aster lanceolatus* Willd. ssp. *simplex* (Willd.) A.G. Jones; White Panicle Aster; Woodland, especially eastern-end; Infrequent; C = 3; BSUH 18777.

*Symphyotrichum lateriflorum* Á. Lőve & D. Lőve var. *lateriflorum*; SYN: *Aster lateriflorus* (L.) Britton; Goblet, Calico, or Side-Flowering Aster; Woodlands, especially eastern-end; Common; C = 3; BSUH 18778, 18780.

*Symphyotrichum novae-angliae* (L.) G.L. Nesom; SYN: *Aster novae-angliae* L.; New England Aster; Old-field along SR 32; Infrequent; C = 3; BSUH 18767.

*Symphyotrichum pilosum* (Willd.) G.L. Nesom var. *pilosum*; SYN: *Aster pilosus* Willd.; Heath or Hairy White Old-Field Aster, Goodbye-Meadow; Old-field along SR 32; Abundant; C = 0; BSUH 18766.

*TARAXACUM OFFICINALE* Weber ssp. *OFFICINALE*; Common Dandelion; Old-field; Common; C = 0; BSUH 18693.

*TRAGOPOGON LAMOTTEI* Rouy; SYN: *Tragopogon pratensis* L.; Showy or Common

Goat's-Beard, Jack-go-to-Bed-at-Noon; Roadside and field along S. Proctor Road; Infrequent; C = 0; BSUH 18714.

*Vernonia gigantea* (Walter) Trel. ssp. *gigantea*; SYN: *Vernonia altissima* Nutt.; Tall or Giant Ironweed; Old-field along SR 32 and shrubby old-field; Infrequent; C = 2; BSUH 18631.

### Bignoniaceae (Trumpet-Creeper Family)

*Catalpa speciosa* (Warder) Warder ex Engelm.; Northern Catalpa; Shrubby old-field; Rare; C = 0; BSUH 18583.

### Boraginaceae (Borage Family)

*Hackelia virginiana* (L.) I.M. Johnst.; Stickseed, Beggars-Lice; Woodland and old-field along RR track; Infrequent but locally common; C = 0; BSUH 18630.

### Brassicaceae (Mustard Family)

*ALLIARIA PETIOLATA* (M. Bieb.) Cavara & Grande; SYN: *Alliaria officinalis* Andrz. ex M. Bieb.; Garlic Mustard; Woodland and old-field in southeast corner; Abundant; C = 0; BSUH 18701.

*BARBAREA VULGARIS* W.T. Aiton; (Garden) Yellow Rocket, Bitter Winter Cress; Old-fields along S. Proctor Road and the RR track; Abundant; C = 0; BSUH 18694.

*BRASSICA NIGRA* (L.) W.D.J. Koch; Black Mustard; Old-field along RR track; abundant; C = 0; BSUH 18685.

*DRABA VERNA* L.; SYN: *Erophila verna* (L.) Besser; Early Whitlow-Grass, Spring Draba; Roadside along S. Proctor Road; Infrequent; C = 0; BSUH 18702.

*HESPERIS MATRONALIS* L.; Dame's-Rocket; Old-fields along S. Proctor Road and RR track; Common; C = 0; BSUH 18602.

*LEPIDIUM CAMPESTRE* (L.) W.T. Aiton; Field Peppergrass or Pepperweed, Cow Cress; Old-field along RR track and roadside on S. Proctor Road; Common, locally abundant; C = 0; BSUH 18848.

*THLASPI ARVENSE* L.; Field Pennycress; Old-field along RR track; Common; C = 0; BSUH 18707.

### Campanulaceae (Bellflower Family)

*Lobelia siphilitica* L. var. *siphilitica*; Great Blue Lobelia; Edge of planted woods; Rare; C = 3; BSUH 18771.

### Caprifoliaceae (Honeysuckle Family)

*LONICERA × BELLA* Zabel; Showy Fly Honeysuckle; Shrubby old-field; Common; C = 0; BSUH 18678.

*LONICERA MAACKII* (Rupr.) Herder; Amur Bush Honeysuckle; All habitats; Abundant; C = 0; BSUH 18574.

*LONICERA MORROWII* A. Gray; Morrow's Honeysuckle; Shrubby old-field; Common; C = 0; BSUH 18679, 18680.

*Sambucus nigra* L. ssp. *canadensis* (L.) R. Bolli; SYN: *Sambucus canadensis* L.; American Black Elderberry, Common Elderberry; Old-field along RR track, eastern-end; Infrequent but locally common; C = 2; BSUH 18801.

*VIBURNUM OPULUS* L. var. *OPULUS*; Guelder-Rose, European Highbush Cranberry; Shrubby old-field and woodland; Infrequent; C = 0; BSUH 18598.

*VIBURNUM RECOGNITUM* Fernald; SYN: *Viburnum dentatum* L. var. *lucidum* Aiton; Smooth or Southern Arrow-Wood; Shrubby old-fields and borders; Infrequent; C = 0; BSUH 18581, 18816.

### Caryophyllaceae (Pink Family)

*ARENARIA SERPYLLIFOLIA* L.; Thyme-Leaved Sandwort; Roadside and old-field along S. Proctor Road; Infrequent; C = 0; BSUH 18805.

*CERASTIUM FONTANUM* Baumg. ssp. *VULGARE* (Hartm.) Greuter & Burdet; SYN: *Cerastium vulgatum* L.; Mouse-Ear Chickweed, Big Chickweed; Old-fields along RR track and S. Proctor Road; Rare; C = 0; BSUH 18580.

*SAPONARIA OFFICINALIS* L.; Soapwort, Bouncing-Bet; Old-field along RR track; Infrequent but locally common; C = 0; BSUH 18686.

*Silene antirrhina* L.; Sleepy Catchfly, Sleepy Silene; Old-field along S. Proctor Road; Infrequent; C = 0; BSUH 18834.

*SILENE LATIFOLIA* Poir. ssp. *ALBA* (Mill.) Greuter & Burdet; SYN: *Silene pratensis* (Raf.) Gren. & Godr., *Lychnis alba* Mill.; Evening, White, or Bladder Campion; Old-field along RR track; Rare; C = 0; BSUH 18566, 18567.

*SILENE NOCTIFLORA* L.; Night-Flowering Catchfly or Silene; Old-field along RR track; Rare; C = 0; BSUH 18568.

### Celastraceae (Staff-Tree Family)

*Euonymus atropurpureus* Jacq. var. *atropurpureus*; (Eastern) Wahoo; Old-field along S. Proctor Road; Rare; C = 5; BSUH 18720.

*EUONYMUS FORTUNEI* (Turcz.) Hand.-Maz. var. *RADICANS* (Siebold ex Miq.) Rehder; Winter-Creeper; Old-field along S. Proctor Road; Rare; C = 0; BSUH 18669.

### Chenopodiaceae (Goosefoot Family)

*CHENOPODIUM ALBUM* L. var. *ALBUM*; Lamb's-Quarters, Pigweed; Old-field along RR track; Infrequent; C = 0; BSUH 18783.

### Clusiaceae (Mangosteen Family)

*Hypericum prolificum* L.; SYN: *Hypericum spathulatum* (Spach) Steud.; Shrubby St.-John's-Wort;

Shrubby old-field; Infrequent, planted and naturalized; C = 4; BSUH 18625, 18641.

*Hypericum punctatum* Lam.; Spotted St. John's-Wort; Shrubby old-field, eastern-end; Infrequent; C = 3; BSUH 18740.

### Convolvulaceae (Morning-Glory Family)

*Calystegia sepium* (L.) R. Br.; Common Hedge-Bindweed, Hedge False Bindweed; Old-fields; Infrequent; C = 1; BSUH 18668.

*CONVOLVULUS ARVENSIS* L.; Field Bindweed; Old-field along SR 32; Rare but locally common; C = 0; BSUH 18836.

*Ipomoea pandurata* (L.) G. Mey.; Wild Potato, Man-of-the-Earth; Old-field along S. Proctor Road; Rare, one colony; C = 3; BSUH 18744.

### Cornaceae (Dogwood Family)

*Cornus drummondii* C.A. Mey.; Rough-Leaved Dogwood; Shrubby old-field; Abundant; C = 2; BSUH 18761, 18789, 18830.

### Cyperaceae (Sedge Family)

*Carex aggregata* Mack.; Smooth Clustered Sedge, Glomerate Sedge; Shrubby old-field; Common; C = 2; BSUH 18623.

*Carex blanda* Dewey; Common Wood Sedge, Eastern Woodland Sedge; Old-fields along S. Proctor Road and RR track; Abundant; C = 1; BSUH 18621.

*Carex cephalophora* Muhl. ex Willd.; Short-Headed Bracted Sedge, Oval-Leaf Sedge; Shrubby old-field; Common; C = 3; BSUH 18559.

*Carex conjuncta* Boott; Green-Headed Fox Sedge, Soft Fox Sedge; Shrubby old-field; Infrequent; C = 6; BSUH 18558.

*Carex davisii* Schwein. & Torr.; Awned Graceful Sedge, Davis' Sedge; Old-field along S. Proctor Road and shrubby old-field; Abundant; C = 3; BSUH 18620.

*Carex granularis* Muhl. ex Willd.; Pale Sedge, Limestone Meadow Sedge; Shrubby old-field; Common; C = 2; BSUH 18618.

*Carex grisea* Wahlenb.; Wood Gray Sedge, Inflated Narrow-Leaf Sedge; Old-fields along S. Proctor Road and RR track; Abundant; C = 3; BSUH 18619.

*Carex jamesii* Schwein. Grass Sedge, James' Sedge; Woodlands; Rare but locally abundant; C = 4; BSUH 18824.

*Carex leavenworthii* Dewey; Dwarf bracted sedge; Shrubby old-field; Abundant; C = 1; BSUH 18560, 18561, 18562.

*Carex molesta* Mack. ex Bright; Field Oval Sedge, Troublesome Sedge; Shrubby old-field; Infrequent; C = 2; BSUH 18615, 18616, 18617.

*Carex planispicata* Naczi; Flat-spiked sedge; Old-field along RR track; rare but locally common; C = 7; BSUH 18563.

*Carex radiata* (Wahlenb.) Small; Straight-Styled Wood Sedge, Eastern Star Sedge; Old-field along SR 32; Infrequent but locally common under oaks; C = 4; BSUH 18614.

*Carex shortiana* Dewey; Short's Sedge; Shrubby old-field; Rare; C = 3; BSUH 18613.

*Carex tribuloides* Wahlenb. var. *tribuloides*; Awl-Fruited Oval Sedge, Blunt Broom Sedge; Shrubby old-field; Infrequent; C = 5; BSUH 18847.

*Carex vulpinoidea* Michx. var. *vulpinoidea*; Brown Fox Sedge; Shrubby old-field; Infrequent; C = 2; BSUH 18611.

*Cyperus esculentus* L. var. *leptostachyus* Boeckeler; Yellow Nutsedge; Ditch of old-field along SR 32; Common; C = 0; BSUH 18639, 18742.

*Eleocharis obtusa* (Willd.) Schult.; Blunt Spike Rush; Ditch of old-field along SR 32; Common and locally abundant; C = 1; BSUH 18622.

### Dipsacaceae (Teasel Family)

*DIPSACUS FULLONUM* L.: SYN: *Dipsacus sylvestris* Huds., *Dipsacus fullonum* L. ssp. *sylvestris* (Huds.) Clapham; Fuller's or Common Teasel; Shrubby old-field; Common; C = 0; BSUH 18683.

### Elaeagnaceae (Oleaster Family)

*ELAEAGNUS UMBELLATA* Thunb. var. *PARVIFOLIA* (Wall. ex Royle) C.K. Schneid.; Autumn Olive; Shrubby old-field; Rare; C = 0; BSUH 18573.

### Euphorbiaceae (Spurge Family)

*Acalypha rhomboidea* Raf.: SYN: *Acalypha virginica* L. var. *rhomboidea* (Raf.) Cooperr.; Common Three-Seeded Mercury; Ditch in old-field along SR 32; Rare but locally abundant; C = 0; BSUH 18758.

*Chamaesyce maculata* (L.) Small; SYN: *Euphorbia maculata* L., *Euphorbia suprina* Raf.; Milk Purslane, Spotted or Creeping Spurge, Spotted Sandmat; Old-fields along S. Proctor Road and RR track; Common; C = 0; BSUH 18732.

*Chamaesyce nutans* (Lag.) Small; *Euphorbia nutans* Lag.; Nodding Spurge, Eyebane; Old-field along SR 32; Infrequent; C = 0; BSUH 18769.

### Fabaceae (Pea or Bean Family)

*Cercis canadensis* L. var. *canadensis*; Eastern Redbud; Woodland edge along RR track; rare; C = 3; BSUH 18700.

*Gleditsia triacanthos* L.; Honey Locust; Old-field along RR track and woodlands, locally abundant; C = 1; BSUH 18593.

*MEDICAGO LUPULINA* L.; Black Medic; Old-fields along S. Proctor Road and SR 32; Common; C = 0; BSUH 18823.

*MELILOTUS ALBUS* Medik.; SYN: *Melilotus officinalis* auct. non (L.) Lam.; White Sweet Clover; Old-fields along S. Proctor Road and RR track; Rare; C = 0; BSUH 18648.

*MELILOTUS OFFICINALIS* (L.) Lam.; Yellow Sweet Clover; Old-fields along S. Proctor Road and RR track; Infrequent; C = 0; BSUH 18822.

*SECURIGERA VARIA* (L.) Lassen; SYN: *Coronilla varia* L.; (Purple) Crown Vetch; Old-field along SR 32, eastern-end; Rare but locally abundant; C = 0; BSUH 18815.

*TRIFOLIUM PRATENSE* L.; Red Clover; Old-field along SR 32; Infrequent; C = 0; BSUH 18817.

### Fagaceae (Beech Family)

*Quercus alba* L.; White Oak; Shrubby old-field; Rare; C = 5; BSUH 18729.

*Quercus macrocarpa* Michx. var. *macrocarpa*; Bur Oak; Shrubby old-field; Rare; C = 5; BSUH 18570, 18656.

*Quercus muehlenbergii* Engelm.; Chinquapin (Chinkapin) or Yellow Oak; Shrubby old-field; Rare; C = 4; BSUH 18690.

*Quercus palustris* Münchh.; Pin Oak; Shrubby old-field and woodlands; Infrequent; C = 3; BSUH 18591.

*QUERCUS PHELLOS* L.; Willow Oak; Shrubby old-field in southwest corner, two trees, planted, not naturalized; C = 0; BSUH 18640, 18658.

*Quercus rubra* L.; Northern Red Oak; Shrubby old-field and woodlands; Infrequent; C = 4; BSUH 18671, 18696.

*Quercus shumardii* Buckley var. *shumardii*; Shumard Oak; Edge of planted woods; Rare, one tree; C = 7; BSUH 18759, 18760.

*Quercus velutina* Lam.; Black Oak; Shrubby old-field; Rare; C = 4; BSUH 18842.

### Geraniaceae (Geranium Family)

*GERANIUM DISSECTUM* L.; Wrinkle-Seeded Cranesbill, Cutleaf Geranium; Old-field along RR track, western-end; Infrequent but locally abundant; C = 0; BSUH 18579, 18606.

### Hamamelidaceae (Witch Hazel Family)

*Liquidambar styraciflua* L. Sweetgum, Red Gum; Planted woods; Rare but locally abundant, planted and naturalized; C = 4; BSUH 18569.

### Hydrangeaceae (Hydrangea Family)

*PHILADELPHUS INODORUS* L.; Scentless Mock-Orange, Edge of planted woods; Rare, one plant; C = 0; BSUH 18826.

### Iridaceae (Iris Family)

*Sisyrinchium angustifolium* Mill.; Stout or Narrowleaf Blue-Eyed-Grass; Shrubby old-field and old-field along SR 32; Infrequent; C = 3; BSUH 18809.

### Juglandaceae (Walnut Family)

*Juglans nigra* L.; Black Walnut; Shrubby old-field and woodland; Infrequent; C = 2; BSUH 18584.

### Juncaceae (Rush Family)

*Juncus tenuis* Willd.; Path Rush, Poverty Rush; Shrubby old-field; Abundant; C = 0; BSUH 18585, 18799.

### Lamiaceae (Mint Family)

*Agastache nepetoides* (L.) Kuntze; Catnip or Yellow Giant-Hyssop; Edge of planted woods; Rare; C = 4; BSUH 18754.

*GLECHOMA HEDERACEA* L.; Gill-Over-the-Ground, Ground Ivy, Creeping Charlie; Old-fields along RR track and in southeast corner; Abundant; C = 0; BSUH 18698.

*LAMIUM PURPUREUM* L. var. *PURPUREUM*; Purple Dead Nettle; Old-fields along S. Proctor Road and RR track; Abundant; C = 0; BSUH 18695.

*LEONURUS CARDIACA* L. ssp. *CARDIACA*; Common Motherwort; Old-field along RR track; Abundant; C = 0; BSUH 18818.

*Monarda fistulosa* L. ssp. *fistulosa* var. *mollis* (L.) Benth.; Wild Bergamot; Old-field along RR track; Rare; C = 3; BSUH 18737.

*NEPETA CATARIA* L.; Catnip; Old-field along RR track; Abundant; C = 0; BSUH 18643.

*PRUNELLA VULGARIS* L. ssp. *VULGARIS*; (Common) Selfheal, Heal-All; Old-fields; Infrequent; C = 0; BSUH 18743.

### Liliaceae (Lily Family)

*Allium canadense* L. var. *canadense*; Wild or Meadow Garlic; Planted woods and woodland; Abundant; C = 1; BSUH 18692.

*ALLIUM VINEALE* L. ssp. *VINEALE*; Field or Wild Garlic; Old-field along RR track; Abundant; C = 0; BSUH 18838.

*ASPARAGUS OFFICINALIS* L.; (Garden) Asparagus; Shrubby old-field; Rare; C = 0; BSUH 18652.

*HEMEROCALLIS FULVA* (L.) L.; Orange Day Lily; Old-field between planted woods and old-field along RR track; Rare, two colonies; C = 0; BSUH 18653, 18739.

*NARCISSUS PSEUDONARCISSUS* L.; Daffodil; Old-field between planted woods and old-field along RR track; Rare; C = 0; BSUH 18794.

*ORNITHOGALUM UMBELLATUM* L.; Common Star-of-Bethlehem, Sleepydick; Old-field between planted woods and old-field along RR track; Rare, one colony; C = 0; BSUH 18662.

*Polygonatum biflorum* (Walter) Elliott var. *biflorum*; Small or Smooth Solomon's Seal; Old-field along S. Proctor Road; Common; C = 4; BSUH 18667.

*Polygonatum biflorum* (Walter) Elliott var. *commutatum* (Schult. & Schult f.) Morong: SYN: *Polygonatum canaliculatum* auct. non (Muhl. ex Willd.) Pursh, *Polygonatum commutatum* (Schult. &

Schult. f.) A. Dietr.; (Giant) Smooth Solomon's-Seal; Old-field along S. Proctor Road; Infrequent; C = 4; BSUH 18600.

### Malvaceae (Mallow Family)

*MALVA NEGLECTA* Wallr.; Common Mallow, Cheeses; Old-field along RR track; Rare; C = 0; BSUH 18784.

### Menispermaceae (Moonseed Family)

*Menispermum canadense* L.; [Common] Moonseed; Old-field along S. Proctor Road and woodlands; Common; C = 3; BSUH 18601.

### Moraceae (Mulberry Family)

*MORUS ALBA* L.; SYN: *Morus tatarica* L.; White Mulberry; Shrubby old-field and woodlands; Common; C = 0; BSUH 18674, 18738.

### Nyctaginaceae (Four-O'clock Family)

*Mirabilis nyctaginea* (Michx.) MacMill.; Heart-Leaved Umbrella-Wort, Heartleaf Four-O'clock; Old-field along RR track; Rare; C = 0; BSUH 18821.

### Oleaceae (Olive Family)

*Fraxinus americana* L.; White or American Ash; Shrubby old-field and woodland; Infrequent; C = 4; BSUH 18582, 18800.

*Fraxinus pennsylvanica* Marsh.; SYN: *Fraxinus pennsylvanica* Marsh. var. *subintegerrima* (Vahl) Fernald, *F. pennsylvanica* Marsh. var. *lanceolata* (Borkh.) Sarg.; Green Ash; Shrubby old-field and woodland; Infrequent; C = 1; BSUH 18672.

*LIGUSTRUM OBTUSIFOLIUM* Siebold & Zucc.; Border Privet; Shrubby old-field; Infrequent; C = 0; BSUH 18833.

### Onagraceae (Evening Primrose Family)

*Circaea lutetiana* L. ssp. *canadensis* (L.) Asch. & Magnus; SYN: *Circaea latifolia* Hill; Common or Broadleaf Enchanter's-Nightshade; Shrubby old-field, planted woods, and woodland at eastern-end; Infrequent but locally common; C = 2; BSUH 18644, 18646.

*Epilobium coloratum* Biehler; Eastern, Cinnamon, or Purple-Leaf Willow-Herb; Shrubby old-field, eastern-end; Infrequent; C = 3; BSUH 18724.

*Gaura biennis* L.; Biennial Gaura, Biennial Bee-blossom; Old-field along S. Proctor Road, southern-end; Rare; C = 3; BSUH 18791.

*Oenothera biennis* L.; SYN: *Oenothera pycnocarpa* Atk. & Bartlett; Common Evening-Primrose; Old-field along RR track; Infrequent; C = 0; BSUH 18749.

### Oxalidaceae (Wood Sorrel Family)

*Oxalis dillenii* Jacq.; SYN: *Oxalis stricta* auct. non L.; Slender Yellow Wood Sorrel, Common Yellow Oxalis; Old-field along RR track; Abundant; C = 0; BSUH 18605, 18827.

### Phytolaccaceae (Pokeweed Family)

*Phytolacca americana* L. var. *americana*; American Pokeweed or Pokeberry; Old-field along RR track; Abundant; C = 0; BSUH 18835.

### Plantaginaceae (Plantain Family)

*PLANTAGO LANCEOLATA* L.; English or Narrow-Leaf Plantain, Buckhorn; Old-fields especially the one along S. Proctor Road; Common; C = 0; BSUH 18576.

*PLANTAGO MAJOR* L.; Common Plantain; Roadside along S. Proctor Road; Rare; C = 0; BSUH 18655.

*Plantago rugelii* Decne. var. *rugelii*; American, Red-Stemmed, or Blackseed Plantain; Old-fields especially the one along S. Proctor Road; Infrequent but locally common; C = 0; BSUH 18681.

### Platanaceae (Plane-Tree Family)

*Platanus occidentalis* L.; American Sycamore, Buttonwood; Shrubby old-field; Rare (planted); C = 3; BSUH 18798.

### Poaceae (Grass Family)

*AGROSTIS GIGANTEA* Roth; SYN: *Agrostis alba* auct. non L.; Redtop; Old-field along SR 32; Abundant; C = 0; BSUH 18691.

*Andropogon gerardii* Vitman; Big Bluestem; Roadside along S. Proctor Road; Rare, one large clump; C = 5; BSUH 18634.

*Andropogon virginicus* L. var. *virginicus*; Broom-Sedge, Virginia Bluestem; Old-field along S. Proctor Road; Rare; C = 1; BSUH 18774.

*BROMUS ARVENSIS* L.; SYN: *Bromus japonicus* Thunb. nom. illeg.; Japanese Chess, Field Brome; Old-field along S. Proctor Road; Rare; C = 0; BSUH 18849.

*BROMUS COMMUTATUS* Schrad.; SYN: *Bromus racemosum* auct. non L.; Hairy Chess, Hairy, Meadow, or Bald Brome; Old-field along RR track; Infrequent but locally common; C = 0; BSUH 18610.

*BROMUS INERMIS* Leyss. ssp. *INERMIS*; Smooth or Hungarian Brome; Old-fields along RR track and S. Proctor Road; Infrequent but locally common; C = 0; BSUH 18796.

*BROMUS TECTORUM* L.; Junegrass, Cheatgrass, Downy Chess or Brome; Old-field along S. Proctor Road; Rare; C = 0; BSUH 18604.

*CHLORIS VERTICILLATA* Nutt.; Windmill Finger-Grass, Tumble Windmill Grass; Roadside along S. Proctor Road; Abundant all along this road; C = 0; BSUH 18609.

*DACTYLIS GLOMERATA* L.; Orchard-Grass; Old-field along SR 32; Infrequent; C = 0; BSUH 18586.

*DIGITARIA SANGUINALIS* (L.) Scop.; Northern or Hairy Crab-Grass; Old-fields along the RR track and S. Proctor Road; Infrequent but locally common; C = 0; BSUH 18635, 18726.

*Echinochloa muricata* (P. Beauv.) Fernald var. *muricata*; Rough Barnyard-Grass; Old-field along the RR track; Infrequent; C = 1; BSUH 18607.

*ELYMUS REPENS* (L.) Gould; SYN: *Elytrigia repens* (L.) Desv. ex Nevski.; Quack Grass; Old-field along SR 32; Infrequent but locally common; C = 0; BSUH 18608.

*HORDEUM JUBATUM* L. ssp. *JUBATUM*; Foxtail Barley; Roadside and old-field along S. Proctor Road; Rare; C = 0; BSUH 18564.

*Glyceria striata* (Lam.) Hitchc.; Fowl-Manna-Grass; Open area in woodland near shrubby field; Rare but locally common; C = 4; BSUH 18747.

*Muhlenbergia schreberi* J.F. Gmel.; Nimblewill; Old-field along RR track; Common; C = 0; BSUH 18745.

*Panicum capillare* L.; Witch Grass; Old-field along RR track; Common; C = 0; BSUH 18632.

*Paspalum setaceum* Michx.; SYN: *Paspalum setaceum* Michx. var. *muehlenbergii* (Nash) D. Banks; Thin Paspalum, Hairy Lens Grass; Roadside along S. Proctor Road; Common; C = 3; BSUH 18636, 18730, 18785.

*Phalaris arundiacea* L.; Reed Canary Grass; Old-field along SR 32, southwest corner; Rare but locally abundant; C = 0; BSUH 18588, 18589.

*PHLEUM PRATENSE* L.; Timothy; Old-field along SR 32; Infrequent; C = 0; BSUH 18748.

*POA PRATENSIS* L. ssp. *PRATENSIS*; Kentucky Bluegrass; Old-fields; Abundant; C = 0: BSUH 18845.

*POA TRIVIALIS* L.; Rough Bluegrass; Woods and fields in southeast corner; Common; C = 0; BSUH 18825.

*SCHEDONORUS ARUNDINACEUS* (Schreb.) Dumort., nom. cons.; SYN: *Schedonorus phoenix* (Scop.) Holub, *Lolium arundinaceum* (Schreb.) S.J. Darbyshire, *Festuca arundinacea* Schreb., *Festuca elatior* L. var. *arundinacea* (Schreb.) Hook.; Tall Fescue; Old-fields; Common; C = 0; BSUH 18795.

*SETARIA FABERI* Herrm.; Nodding or Giant Foxtail-Grass, Japanese Bristlegrass; Old-field along RR track; Infrequent (abundant south of RR track); C = 0; BSUH 18633.

*SETARIA PUMILA* (Poir.) Roem. & Schult. ssp. *PUMILA*; SYN: *Setaria glauca* (L.) P. Beauv.; Yellow Foxtail-Grass; Old-field along RR track; Infrequent; C = 0; BSUH 18787.

*SETARIA VIRIDIS* (L.) P. Beauv. var. *VIRIDIS*; Green Foxtail, Green Bristle-Grass; Old-field along S. Proctor Road; Infrequent; C = 0; BSUH 18728.

*Sphenopholis intermedia* (Rydb.) Rydb.; SYN: *Sphenopholis obtusata* (Michx.) Scribn. var. *major* (Torr.) K.S. Erdman; Slender Wedge Grass, Slender Wedgescale; Shrubby old-field; Infrequent; C = 3; BSUH 18587.

*Tridens flavus* (L.) Hitchc. var. *flavus*; SYN: *Triodia flava* (L.) Smyth; Purpletop, Purpletop Tridens; Old-fields along SR 32 and S. Proctor Road; Common; C = 1; BSUH 18786.

### Polygonaceae (Smartweed Family)

*FALLOPIA CONVOLVULUS* (L.) Á. Löve; SYN: *Polygonum convolvulus* L.; Black Bindweed; Old-field along RR track; Rare but locally common; C = 0; BSUH 18781.

*FALLOPIA JAPONICA* (Houtt.) Ronse Decr.; SYN: *Polygonum cuspidatum* Siebold & Zucc.; Japanese Knotweed; Woodland especially the eastern half; Common and locally abundant; C = 0; BSUH 18721, 18736.

*Fallopia scandens* (L.) Holub; SYN: *Polygonum scandens* L. var. *scandens*; Climbing False Buckwheat; Old-fields especially the one along the RR track; Abundant; C = 0; BSUH 18723.

*PERSICARIA MACULOSA* Gray; SYN: *Polygonum persicaria* L., *Polygonum dubium* Stein, *Polygonum maculata* (Raf.) Gray, *Persicaria vulgaris* Webb & Moq.; Spotted Lady's-Thumb; Ditch in old-field along SR 32; Rare but locally common; C = 0; BSUH 18773.

*POLYGONUM AVICULARE* L.; SYN: *Polygonum monspeliense* Pers.; Doorweed, Common or Prostrate Knotweed; Old-fields; Common; C = 0; BSUH 18654.

*RUMEX CRISPUS* L. ssp. *CRISPUS*; Curly Dock, Sour Dock; Shrubby old-field; Infrequent; C = 0; BSUH 18571.

*RUMEX OBTUSIFOLIUS* L.; Bitter Dock, Blunt-Leaved Dock; Old-field along RR track and shrubby field; Infrequent; C = 0; BSUH 18840.

*Tovara virginiana* (L.) Raf.; SYN: *Polygonum virginianum* L., *Persicaria virginiana* (L.) Gaertn.; Jumpseed, Virginia Knotweed; Woodlands; Common and locally abundant; C = 3; BSUH 18757.

### Portulacaceae (Purslane Family)

*Claytonia virginica* L. var. *virginica*; Virginia Spring Beauty; Shrubby old-field; Infrequent; C = 2; BSUH 18699.

*PORTULACA OLERACEA* L.; Common Purslane, Little Hogweed; Ditch in old-field along SR 32; Infrequent but locally abundant; C = 0; BSUH 18741.

### Primulaceae (Primrose Family)

*Lysimachia ciliata* L.; Fringed Loosestrife; Shrubby old-field; Rare; C = 4; BSUH 18627.

### Rosaceae (Rose Family)

*Crataegus phaenopyrum* (L. f.) Medik.; Washington-Thorn (-Hawthorn); Shrubby old-field near planted woods; Rare, not naturalized; C = 0; BSUH 18831, 18832.

*Fragaria virginiana* Mill. ssp. *virginiana*; Thick-Leaved or Virginia Wild Strawberry; Shrubby old-field; Infrequent; C = 2; BSUH 18673.

*Geum canadense* Jacq. var. *canadense*; White Avens; Old-fields; Common; C = 1; BSUH 18647.

*Geum laciniatum* Murray var. *trichocarpum* Fernald; Rough Avens; Shrubby old-field and woods in southeast corner; Abundant; C = 3; BSUH 18828, 18829.

*Geum vernum* (Raf.) Torr. & A. Gray; Spring Avens; Woodland and shrubby old-field; Abundant; C = 1; BSUH 18844.

*MALUS PUMILA* Mill.; SYN: *Pyrus pumila* (Mill.) K. Koch, *Malus domestica* auct. non Borkh.; Domestic or Paradise Apple; Border of woodland and shrubby old-field, planted, not naturalized; Rare; C = 0; BSUH 18788.

*Potentilla norvegica* L. ssp. *monspeliensis* (L.) Asch. & Graebn.; Rough or Norwegian Cinquefoil; Shrubby old-field; Infrequent; C = 0; BSUH 18684.

*POTENTILLA RECTA* L.; Sulfur Cinquefoil; Old-field along RR track; Rare; C = 0; BSUH 18820.

*Prunus serotina* Ehrh. var. *serotina*; Wild Black Cherry; Woodland edge along RR track; Infrequent; C = 1; BSUH 18596.

*PYRUS CALLERYANA* Decne. ‘Bradford”; Bradford Pear; Shrubby old-field, naturalized; Common; C = 0; BSUH 18704.

*Pyrus* spp. (*Malus* spp.); Flowering Crabapple; Shrubby old-field, not naturalized; C = 0; BSUH 18705.

*ROSA MULTIFLORA* Thunb.; Multiflora or Japanese Rose; Old-field along S. Proctor Road; Common; C = 0; BSUH 18804.

*Rosa setigera* Michx. var. *setigera*; Climbing Prairie Rose, Illinois Rose; Old-field along S. Proctor Road and shrubby field; Common; C = 4; BSUH 18649.

*Rubus allegheniensis* Porter; Common or Allegheny Blackberry; Woods and field in southeastern corner; Common; C = 2; BSUH 18595.

*Rubus flagellaris* Willd.; Northern Dewberry; Old-field along RR track; Infrequent; C = 2; BSUH 18599.

*Rubus occidentalis* L.; Black Raspberry; Woods and field in southeastern corner; Common; C = 1; BSUH 18594.

### Rubiaceae (Madder Family)

*Galium aparine* L.; Cleavers, Annual Bedstraw, Stickywilly; Old-field along S. Proctor Road and shrubby old-field; Infrequent; C = 1; BSUH 18677.

### Salicaceae (Willow Family)

*Populus deltoides* W. Bartram ex Marshall ssp. *deltoides*; Eastern Cottonwood; Woodland and old-field along S. Proctor Road; Common; C = 1; BSUH 18676.

*Salix interior* Rowlee; SYN: *Salix exigua* Nutt. ssp. *interior* (Rowlee) Cronquist; Sandbar Willow; Shrubby old-field, eastern-end in a low area; Rare but locally abundant; C = 1; BSUH 18603.

### Scrophulariaceae (Figwort Family)

*VERBASCUM BLATTARIA* L.; Moth Mullein; Old-field along RR track; Rare; C = 0; BSUH 18839.

*VERBASCUM THAPSUS* L.; Common or Woolly Mullein; Old-field along RR track; Abundant; C = 0; BSUH 18837.

*VERONICA ARVENSIS* L.; Corn Speedwell; Old-fields along RR tract and S. Proctor Road; Abundant; C = 0; BSUH 18703.

*VERONICA SERPYLLIFOLIA* L. ssp. *SERPYLLIFOLIA*; Thyme-Leaved Speedwell; Shrubby old-field; Common; C = 0; BSUH 18572, 18675.

### Simaroubaceae (Quassia Family)

*AILANTHUS ALTISSIMA* (Mill.) Swingle; Tree of Heaven; Old-field along RR track; Abundant here; C = 0; BSUH 18666.

### Smilacaceae (Catbrier Family)

*Smilax tamnoides* L.; SYN: *Smilax hispida* Muhl. ex Torr., *Smilax tamnoides* L. var. *hispida* (Muhl. ex Torr.) Fernald; Bristly Greenbrier or Catbrier; Woodland and old-field along S. Proctor Road; Infrequent; C = 3; BSUH 18575, 18592.

### Solanaceae (Nightshade Family)

*Physalis heterophylla* Nees var. *heterophylla*; SYN: *Physalis nyctaginea* Dunal; Clammy Ground-Cherry; Old-field along RR track; Infrequent; C = 3; BSUH 18716, 18731.

*Solanum carolinense* L. var. *carolinense*; (Carolina) Horse-Nettle, Carolina Poppy; Old-field along RR track; Infrequent; C = 0; BSUH 18790.

*SOLANUM DULCAMARA* L. ssp. *DULCAMARA*; Bittersweet Nightshade, Climbing Nightshade; Old-field between planted woods and old-field along RR track; Rare; C = 0; BSUH 18841.

### Tiliaceae (Linden Family)

*TILIA CORDATA* Mill.; Small-Leaved European Linden, Little-Leaf Linden; Planted woods; Rare but locally abundant, planted and naturalized; C = 0; BSUH 18708, 18709, 18710.

### Ulmaceae (Elm Family)

*Celtis occidentalis* L., Northern or Common Hackberry; Woodland; Common; C = 3; BSUH 18597.

*Ulmus americana* L.; American or White Elm; Shrubby old-field and woodland; Common; C = 3; BSUH 18670.

*ULMUS PUMILA* L.; Siberian or Chinese Elm; Shrubby old-field and woodland, naturalized and spreading; Abundant; C = 0; BSUH 18689.

*Ulmus rubra* Muhl.; Red or Slippery Elm; Shrubby old-field, woodland and old field along S. Proctor Road; Infrequent; C = 3; BSUH 18659.

### Urticaceae (Nettle Family)

*Urtica dioica* L. ssp. *gracilis* (Aiton) Seland.; SYN: *Urtica dioica* L. var. *procera* (Muhl. ex Willd.) Weddell, *Urtica procera* Muhl. ex Willd.; Tall, California, or Stinging Nettle; Old-field along RR track, Infrequent but locally common; C = 1; BSUH 18753.

### Verbenaceae (Vervain Family)

*Verbena bracteata* Cav. ex Lag. & Rodr.; Long-Bracted or Big-Bract Vervain; Roadside along S. Proctor Road; Rare, one site; C = 0; BSUH 18629.

*Verbena urticifolia* L. var. *urticifolia*; White Vervain; Old-field along RR track; Infrequent; C = 3; BSUH 18687.

### Violaceae (Violet Family)

*Viola palmata* L.; SYN: *Viola triloba* Schwein.; Three-Lobe Violet; Shrubby old-field; Infrequent; C = 5; BSUH 18697.

*Viola sororia* Willd.; SYN: *Viola papilionacea* Pursh p.p.; Common Blue Violet, Dooryard Violet; Shrubby old-field and woodlands; Infrequent; C =1; BSUH 18661.

### Vitaceae (Grape Family)

*Parthenocissus quinquefolia* (L.) Planch.; Virginia Creeper, Woodbine; Most habitats; Common; C = 2; BSUH 18846.

*Parthenocissus vitacea* (Knerr) Hitchc.; SYN: *Parthenocissus inserta* (Kern.) Fritsch; Grape Woodbine, Woodbine; Shrubby old-field; Common; C = 2; BSUH 18715, 18812.

*Vitis riparia* Michx.; Riverbank Grape; Shrubby old-field and woodland; Common; C = 1; BSUH 18807.

*Vitis vulpina* L.; Frost, Fox, Winter, or Chicken Grape; Shrubby old-field and woodland; Common; C = 3; BSUH 18577, 18578, 18797.

## LITERATURE CITED

Bargeron, C.T., C.R. Minteer, C.W. Evans, D.J. Moorhead, G.K. Douce & R.C. Reardon. 2008. Invasive Plants of the United States: Identification, Biology and Control. At http://www.invasive.org/weedcd/ (Accessed 28 December 2014).

Collier, M.H., J.L. Vankat & M.R. Hughes. 2002. Diminished plant richness and abundance below *Lonicera maackii*, an invasive shrub. American Midland Naturalist 147:60–71.

Davis, M.A., L. Bier, E. Bushelle, C. Diegel, A. Johnson & B. Kujala. 2005. Non-indigenous grasses impede woody succession. Plant Ecology 178:249–264.

Deam, C. 1940 Flora of Indiana. Department of Conservation, Wm. B. Burford Printing Co., Indianapolis, Indiana. 1236 pp.

EPA (U.S. Environmental Protection Agency). 2009. Upper White Watershed. At http://cfpub.epa.gov/surf/huc.cfm?huc_code=05120201.

Gleason, H.A. & A. Cronquist. 1991. Manual of Vascular Plants of Northeastern United States and Adjacent Canada. New York Botanical Garden, Bronx, New York. 910 pp.

Hedge, R.L. 1997. Forested swell and swale: the Central Till Plain Natural Region. Pp. 195–199. *In* The Natural Heritage of Indiana (M.T. Jackson, ed.). Indiana University Press, Bloomington, Indiana.

Homoya, M.A., D.B. Abrell, J.R. Aldrich & T.W. Post. 1985. The Natural Regions of Indiana. Proceedings of the Indiana Academy of Science 94:245–268.

IDNR Nature Preserves. 2013. Endangered, Threatened, Rare and Extirpated Plants of Indiana. At: http://www.in.gov/dnr/naturepreserve/files/np-etr plants042513.pdf (Accessed 20 December 2014).

IHAPI (Indiana Geological Survey Maps). 2011. At: http://igs.indiana.edu/IHAPI/Map/ (Accessed on 27 December 2014).

IISC (Indiana Invasive Species Council). 2013. Official IISC Invasive Plant List. At http://www.entm.purdue.edu/IISC/invasiveplants.php (Accessed 28 December 2014).

IUPUI (Center for Earth and Environmental Science). 2013. Fluvial Erosion Hazards. At http://www.cees.iupui.edu/research/fluvial-erosion-hazards (Accessed 28 December 2014).

Keller, C., T. Crovello & K. Guild. 1984. Floristic database program (See C. Keller 1986. The computerization of regional floristic data. Proceedings of the Indiana Academy of Science 95:412).

Kimmins, J.P. 2004. Ecological Succession: processes of change in ecosystems. Pp. 463–515, *In* Forest Ecology: A Foundation for Sustainable Forest Management and Environmental Ethics in Forestry, 3rd edition. Prentice Hall, Upper Saddle River, New Jersey.

Monk, C.D. 1983. Relationship of life forms and diversity in old-field succession. Bulletin of the Torrey Botanical Club 110:449–453.

Overlease, W. & E. Overlease. 2007. 100 Years of Change in the Distribution of Common Indiana Weeds. Purdue University Press, West Lafayette, Indiana. 270 pp.

Prast, Z.B., D.G. Ruch, D. LeBlanc, M. Russell, K.S. Badger & P.E. Rothrock. 2014. The vascular flora and vegetational communities of Munsee Woods Nature Preserve, Delaware County, Indiana. Proceedings of the Indiana Academy of Science 122:93–117.

Quarterman E. 1957. Early plant succession on abandoned cropland in the central basin of Tennessee. Ecology 38:300–309.

Root, R.A. & R.E. Wilson. 1973. Changes in biomass of six dominant plant species during oldfield succession in southeastern Indiana. Ohio Journal of Science 73:370–375.

Rothrock, P.E. 1997. The vascular flora of Fogwell Forest Nature Preserve, Allen County, Indiana. Proceedings of the Indiana Academy of Science 106:267–290.

Rothrock, P.E. 2004. Floristic quality assessment in Indiana: The concept, use and development of coefficients of conservatism. Final Report for ARN A305 4 53, EPA Wetland Program Development Grant CD975586 01. 96p. At http://www.in.gov/idem/water/planbr/401/publications.html.

Rothrock, P.E. & M.A. Homoya. 2005. An evaluation of Indiana's Floristic Quality Assessment. Proceedings of the Indiana Academy of Science 114:9–18.

Rothrock, P.E., H. Starcs, R. Dunbar & R.L. Hedge. 1993. The vascular flora of Mounds State Park, Madison County, Indiana. Proceedings of the Indiana Academy of Science 102:161–199.

Ruch, D.G., A. Schoultz & K.S. Badger. 1998. The flora and vegetation of Ginn Woods, Ball State University, Delaware County, Indiana. Proceedings of the Indiana Academy of Science 107:17–60.

Ruch, D.G., B.G. Torke, C.R. Reidy, K.S. Badger & P.E. Rothrock. 2002. The flora and vegetational communities of Wilbur Wright Fish and Wildlife Area, Henry County, Indiana. Proceedings of the Indiana Academy of Science 111:147–176.

Ruch, D.G., C.R. Reidy, B.G. Torke, K.S. Badger & P.E. Rothrock. 2004. Additions to the flora of Ginn Woods, Delaware County, Indiana. Proceedings of the Indiana Academy of Science 113:1–6.

Ruch, D.G., B.G. Torke, C.R. Reidy, P.E. Rothrock, K.S. Badger, R. Waltz, E. Grossman-Urly, J.L. Chance & L. Click. 2007. The Vascular Flora and Vegetational Communities of Hayes Arboretum, Wayne County, Indiana. Proceedings of the Indiana Academy of Science 116:11–41.

Ruch, D.G., B.G. Torke, K.S. Badger, B.R. Hess, B.N. Christian & P.E. Rothrock. 2008a. The vascular flora and vegetational communities of Lick Creek Summit Nature Preserve in Wayne County, Indiana. Proceedings of the Indiana Academy of Science 117:29–54.

Ruch, D.G., B.G. Torke, B.R. Hess, K.S. Badger & P.E. Rothrock. 2008b. The vascular flora and vegetational communities of the wetland complex on the IMI Property in Henry County near Luray, Indiana. Proceedings of the Indiana Academy of Science 117:142–158.

Ruch, D.G., B.G. Torke, B.R. Hess, K.S. Badger & P.E. Rothrock. 2009. The vascular flora in three prairie cemeteries in Henry County, Indiana. Proceedings of the Indiana Academy of Science 119:35–51.

Ruch, D.G., B.G. Torke, K.S. Badger & P.E. Rothrock. 2010. The vascular flora and plant communities of the Bennett wetland complex in Henry County, Indiana. Proceedings of the Indiana Academy of Science 118:39–54.

Ruch, D.G., K.S. Badger, B.C. Daugherty, B.G. Torke & P.E. Rothrock. 2012. The vascular flora and vegetational communities of Mississinewa Woods in Randolph County, Indiana. Proceedings of the Indiana Academy of Science 121:23–44.

Stonehouse, A.L., K.S. Badger, D.G. Ruch & P.E. Rothrock. 2003. A floristic inventory and description of the structure and composition of the plant communities of Botany Glen, Grant County, Indiana. Proceedings of the Indiana Academy of Science 112:135–159.

Stover, M.E. & P.L. Marks. 1998. Successional vegetation on abandoned cultivated and pastured land in Tompkins County, New York. Journal of the Torrey Botanical Society 125:150–164.

Swink, F. & G. Wilhelm. 1994. Plants of the Chicago Region. 4th edition. Indiana Academy of Science, Indianapolis, Indiana. 921 pp.

Tungesvick, K., D.G. Ruch, B.G. Torke, K.S. Badger & P.E. Rothrock. 2011. Additions to the flora of Mounds State Park and Preserve, Madison County, Indiana. Proceedings of the Indiana Academy of Science 120:1–11.

USDA. 2013. Natural Resources Conservation Services Plants National Database. At http://plants.usda.gov/index.html.

WSS. 2013. Web Soil Survey, Natural Resource Conservation Service. At http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm (Accessed 2 February 2013).

Yatskievych, K. 2000. Field Guide to Indiana Wildflowers. Indiana University Press, Bloomington, Indiana. 357 pp.

*Manuscript received 20 December 2014, revised 28 May 2015.*

2014. Proceedings of the Indiana Academy of Science 123(2):179–195

# THE GREEN TREEFROG, *HYLA CINEREA* (SCHNEIDER), IN INDIANA

**Michael J. Lodato**[1]: 8438 Pelican Pointe Drive, Evansville, IN 47725 USA

**Nathan J. Engbrecht**[2]: Department of Anatomy and Cell Biology, Indiana University School of Medicine–Terre Haute, Indiana State University, Terre Haute, IN 47809 USA

**Sarabeth Klueh-Mundy**: Division of Fish and Wildlife, Indiana Department of Natural Resources, 5596 East State Road 46, Bloomington, IN 47401 USA

**Zachary Walker**: Wyoming Game and Fish Department, 260 Buena Vista, Lander, WY 82520 USA

**ABSTRACT.** The Green Treefrog, *Hyla cinerea*, is widely distributed in the southeastern quadrant of the United States. Although it did not occur historically in Indiana, it was recorded from Vanderburgh County in extreme southwestern Indiana in 2003. From 2003 to 2013 we documented this hylid's range expansion in Indiana as part of a rapid and recent range expansion in adjoining states in the middle Mississippi Valley. Likely dispersal mechanisms for its appearance and colonization in southwest Indiana are discussed. In addition to distributional records, its status, relative abundance, and potential for additional colonization within the state are reviewed. Our findings indicate that *H. cinerea* arrived in the state as part of a natural range expansion and that it appears to be permanently established as member of the state's herpetofauna.

**Keywords:** colonization, dispersal, distribution, *Hyla cinerea*, Indiana, treefrog, range expansion

## INTRODUCTION

The Green Treefrog, *Hyla cinerea* (Schneider), is a moderate sized elongate anuran, native to lowlands in the southeastern United States. It is a wide-ranging hylid, occurring historically on the Atlantic Coastal Plain from the Delmarva Peninsula and Chesapeake Bay region southward, throughout all of Florida and the Gulf Coastal Plain, westward through east Texas, and northward up the Mississippi Embayment to extreme southern Illinois and extreme western Kentucky (Conant & Collins 1998; Redmer & Brandon 2005). While the species is known from southern Illinois and western Kentucky, its historic occurrence there has been restricted to a few localities on the lower Mississippi and Ohio River floodplains. Published range maps reflect this limited distribution (Barbour 1956, 1971; Smith 1961). Prior to 2003, *H. cinerea* was not known from Indiana. It does not appear in any of the published accounts of the state's herpetofauna (Hay, 1886, 1892; Minton 1972, 2001; Minton et al. 1983).

In spite of the historical geographic hiatus between *H. cinerea* populations in the middle Mississippi Valley and Indiana, *H. cinerea* was discovered in the state in 2003 (Lodato 2003; Lodato et al. 2004). This discovery raised a number of questions about this species in Indiana: a) how did it come; b) its status, i.e., a native but previously overlooked species, a natural range expansion, or an introduction; c) its distribution; d) its ecological niche; e) its natural history and how it compares with its natural history elsewhere; and f) its future? Interest in addressing these questions led to collaboration between the senior author and personnel from the Indiana Department of Natural Resources Wildlife Diversity Program.

## METHODS

We reviewed the published literature, unpublished reports, and corresponded with regional herpetologists and naturalists knowledgeable about *H. cinerea*. In mapping the historical distribution, we relied on published

---

[1] *Corresponding author:* Michael J. Lodato, 812-477-3488 (phone), mikelodato@wowway.com.

[2] *Current address:* Cardno, 708 Roosevelt Road, Walkerton, IN 46574 USA

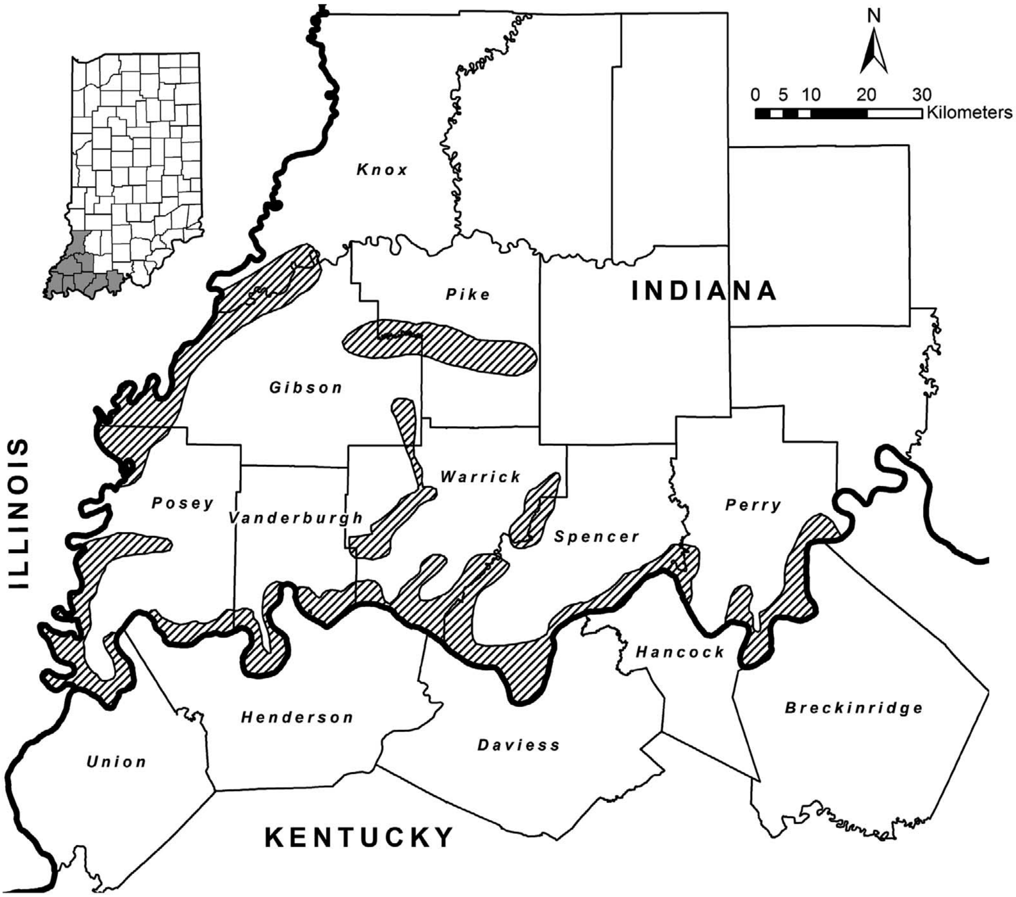


Figure 1.—Counties surveyed for *Hyla cinerea* in southwest Indiana, 2003-2013. Crosshatching depicts primary search areas along major rivers and tributaries in eight southwest Indiana counties.

and unpublished reports prior to 1985. We adopted this cut-off based on the analysis of Brainard Palmer-Ball, formerly of the Kentucky Nature Preserves Commission (Pers. Comm.), who used this date, and Redmer et al. (1999), who generally state that new and extra-limital Illinois populations were first noted in "the 1980s" and thereafter. Distribution records after that time were considered as current. Beginning in 2003, we surveyed for populations of *H. cinerea* by listening for breeding choruses and male advertisement calls during the active season, typically from the first week of May through the last week of July, with 4 May the earliest survey date and 1 August the latest. Surveys were conducted during evening and night, typically between 18:30 and 24:00 hours CDT. We conducted systematic field surveys annually from 2003 through 2013. Both known *H. cinerea* sites and potential sites were revisited each year in order to detect new populations and changes to known populations. Sites chosen for survey included known natural wetlands along stream corridors and river bottoms, and other wetland sites based on our experience with the species outside the state. More than 150 sites in eight counties in southwest Indiana (Gibson, Knox, Perry, Pike, Posey, Spencer, Vanderburgh, and Warrick) were surveyed (Fig.1). In addition to auditory surveys, we opportunistically examined vegetation adjacent to wetlands and surveyed roadways adjacent to potential sites. The geographic coordinates were recorded when *H. cinerea* was detected. When located in a new county, either a voucher specimen was collected or a photographic voucher was taken. Specimens were deposited at the University of

Michigan Museum of Zoology in Ann Arbor, Michigan, and photographic vouchers were deposited in the Illinois Natural History Survey in Champaign, Illinois. The natural features and vegetation at each site as well as relative abundance of the population were noted.

## GENERAL DESCRIPTION

*Hyla cinerea* is usually bright green with a rather streamlined, slender build (Fig. 2). The only other treefrogs in Indiana that may occasionally be confused with *H. cinerea* are the gray treefrogs of the *Hyla versicolor-chrysocelis* complex. Treefrogs of these sibling species, while usually gray, with a heavily mottled pattern on the dorsum, occasionally also display a bright green dorsal coloration. However, the body shape of gray treefrogs is stockier than *cinerea*, and the snout is blunt and rounded. Additionally, there is invariably a unique white blotch below the eye, and an orange or yellow wash is always present in the hidden area of the groin.

The advertisement call of males of *H. cinerea* is distinctive, easily detected, and is the best field indicator of its presence, particularly during the breeding season. Large choruses of singing males have considerable carrying power. Individual calls have a distinct metallic sound (Smith 1961), and several authors liken the call to the clanging of a bell, sometimes more specifically to a cowbell (Garman 1892; Wright & Wright 1949; Smith 1961). While the cowbell comparison may be dated, the metallic clanking sound is accurate. We describe the call as a monotonous and repetitive "wank, wank, wank..." and others describe it similarly (Wright & Wright 1949; Smith 1961). The call is repeated at a rate of between 0.27 and 1.1 calls per second (Oldham & Gerhardt 1975). An aggression call, described by Elliot et al. (2009) is said to be a harsh but quickly repeated "quarr-quarr-quarr."

## RANGE EXPANSION IN NEARBY STATES

A number of authors note a range expansion for this species (e.g., Dodd 2013, Green et al. 2014). The distribution maps for *H. cinerea* in this paper (Figs. 3 & 4) update recent maps in Dodd (2013) and Green et al. (2014). On a more local level, regional authorities, referenced below, provide a more detailed description of range expansion and the species' current distribution.

We estimate that this range expansion began about 15 years before *H. cinerea* appeared in Indiana, perhaps in the mid- to late-1980s. The expansion appears to have been pronounced at the northern periphery of the historical range for the species in the middle Mississippi Valley, and is well documented. In adjacent Illinois, Redmer et al. (1999) report an extraordinary range expansion beginning in the mid-1980s. In his monograph on Illinois amphibians and reptiles, Smith (1961) reports *H. cinerea* from just four localities in two counties in the extreme southwestern tip of the state, and he states, "I have been unable to find the species anywhere north of Union County" (p. 89). In contrast, Redmer et al. (1999) plots 127 localities including several new counties. A distribution map published that year for Illinois indicates that it was then present in nine counties in the southwestern corner of the state (Phillips et al. 1999). Subsequent to this, an undated online revision to the distribution map by the Illinois Natural History Survey (IHNS 2012) added Clinton and Monroe Counties. These records are based on collections in 2001 (Christopher Phillips, Pers. Comm.). Another major range expansion, to Jersey County (Tucker et al. 2008) brings to twelve the number of counties with populations of *H. cinerea* in Illinois. This range expansion, for the most part, occurred very rapidly, perhaps in little more than one or two decades. It is all the more remarkable when one considers that, as recently as the mid-1970s, *H. cinerea* was classified as a rare and/or endangered species in Illinois (Dyrkacz 1974; Ackerman 1975).

In adjoining Kentucky, John MacGregor of the Kentucky Department of Fish and Wildlife Resources, and Brainard Palmer-Ball of the Kentucky State Nature Preserves Commission (Pers. Comm. & unpublished distribution data) have data showing a rapid and continuing range expansion northward and eastward into the west Kentucky coal field and beyond, including Ohio River border counties adjacent to southwest Indiana. Historically *H. cinerea* was unknown outside the Jackson Purchase region of Kentucky, and even there it was restricted to the western edge of four counties bordering the Mississippi River (Dury & Gessing 1940; Barbour 1956, 1971). *Hyla*

Figure 2.—Photographs of *Hyla cinerea* from Indiana. Top: Specimen from Vanderburgh County, voucher for state of Indiana. Bottom: Photographic voucher of specimen from Warrick County.

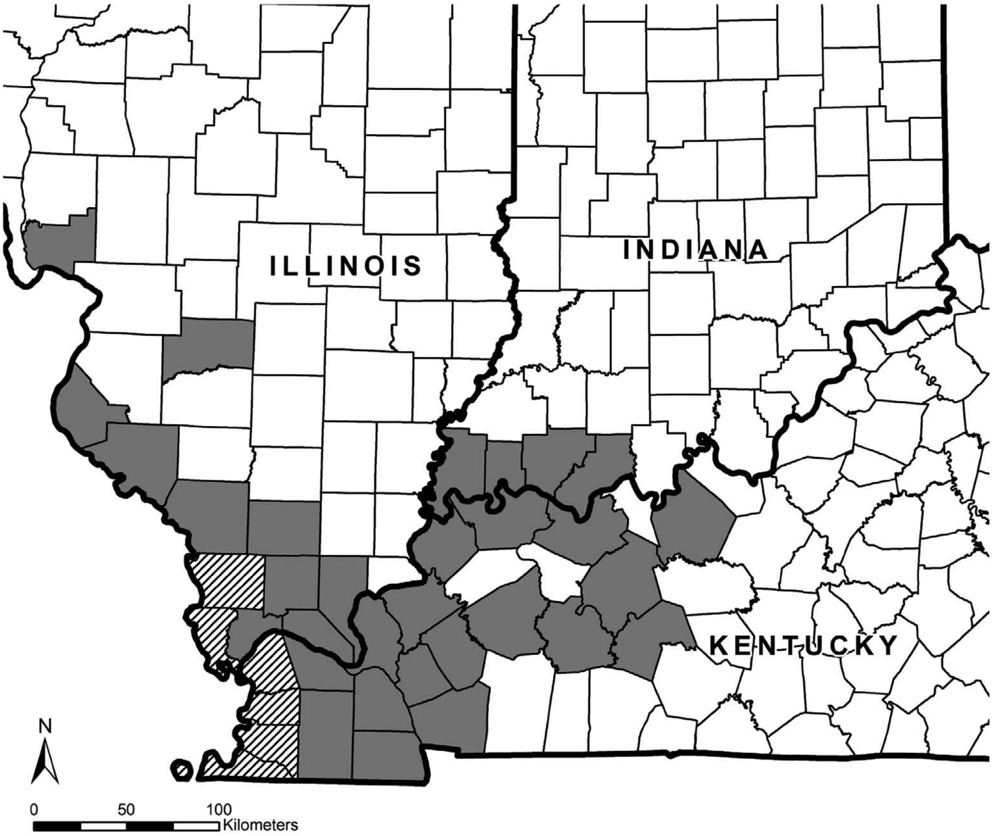


Figure 3.—Counties harboring populations of *Hyla cinerea* in Illinois, Indiana, and Kentucky. Slant lines depict counties with historical populations of *H. cinerea*; grayscale depicts range expansion for the species in the region since about 1985. Two counties in eastern Kentucky containing artificially introduced populations of *H. cinerea* are not included in this figure.

*cinerea* is currently known from at least 19 counties, 15 of which are east and north of the species' historical range, and four of these (Breckinridge, Daviess, Henderson, and Union) border Indiana (Kentucky Department of Fish & Wildlife Resources 2014; and John MacGregor, Pers. Comm.). Additionally, field work by MacGregor confirms the species in Hopkins County (Pers. Comm.). Independent field work by Noah Gordon and his students confirms the species in Caldwell County (Pers. Comm.). Twenty-one counties harbor *H. cinerea* in western Kentucky (Fig. 3).

In Missouri, Powell et al. (1995, 1996) document substantial range expansions from the historical range in the lowlands of the Missouri "bootheel." Jeff Briggler of the Missouri Department of Conservation reports new populations in central Missouri well outside the species' historical range (Pers. Comm.).

In Tennessee, *H. cinerea* "appears to be expanding its range upstream along the Cumberland River, as well as along the Tennessee River Valley west of Chattanooga...." (Reynolds 2013, p. 276).

The senior author has herpetological field experience dating from the 1960s in the middle Mississippi Valley region of southern Indiana and Illinois, western Kentucky and Tennessee, and southeastern Missouri, and field experience with *H. cinerea* in this region and throughout its range dating from the early 1970s. It is undeniable that *H. cinerea* has rapidly expanded its range from a few highly restricted localities at the northern edge of the Mississippi Embayment to a much larger landscape in suitable aquatic sites in multiple eco-regions and physiographic provinces, and now including some in extreme southwest Indiana. The rate of this range expansion,

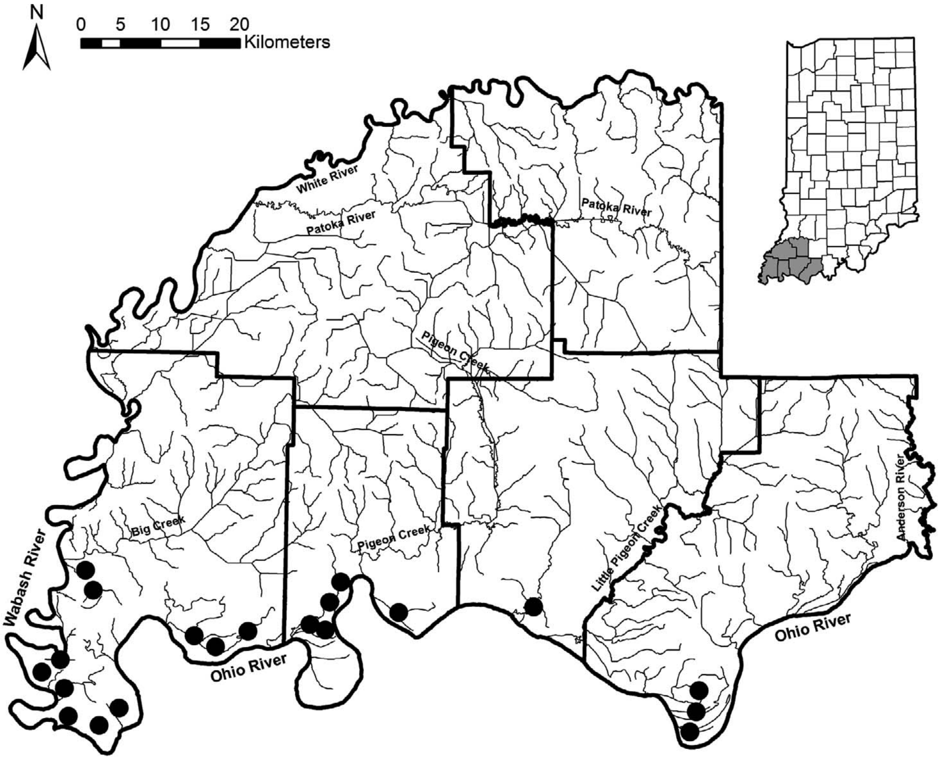


Figure 4.—Distribution of breeding colonies of *Hyla cinerea* in Indiana as of 2014.

observed firsthand, has been nothing short of remarkable.

The range expansion of *H. cinerea*, primarily northward and eastward in the middle Mississippi Valley, is not restricted to that region. Significant range expansions have been recently confirmed along the Atlantic Coastal Plain, northward into the Piedmont in South Carolina (Snyder & Platt 1997) and in both Georgia and South Carolina along the Savannah River drainage (Platt et al. 1999).

The impetus for this range expansion is unknown. In Illinois, it may be facilitated by climate change (Tucker et al. 2008) and possibly aided to by human activities (Phillips et al. 1999; Redmer et al. 1999); however, the consensus of these authors is that the range expansion is a natural phenomenon. Range expansion in Kentucky is likely similar in nature, although there are documented instances where the frogs have been inadvertently introduced with fish hatchery stock, probably as tadpoles, in at least two eastern Kentucky localities (John MacGregor, Pers. Comm.). In Indiana, there is no evidence of artificial introduction at any of our sites. Indeed, all known Indiana populations occur in natural lowland habitats or on adjacent terraces and nearly all of these sites are remote, seldom visited locations on the floodplains of the lower Wabash and Ohio Rivers (Fig. 4). Redmer & Brandon (2003) suggest that the species' ability to reproduce in wetlands and other aquatic situations with predatory fish has greatly aided its rapid colonization of new sites.

## APPEARANCE OF *HYLA CINEREA* IN INDIANA

*Hyla cinerea* was first confirmed in Indiana based on specimens collected on 14 June 2003 by Jim Horton of Indianapolis and Scott Kramer of Evansville, Indiana (Lodato 2003). These original specimens were retained by Mr. Horton in a private, living collection. The collection site was Howell Slough, an oxbow pond on the Ohio River floodplain and adjacent to Carpenter Creek. Howell Slough is located in Perry Township, Vanderburgh County, and at the southwestern limits of the city of Evansville. Subsequent to the first collection of specimens by Horton and Kramer, voucher specimens were collected for deposit in a museum collection (Lodato et al. 2004).

The appearance of *H. cinerea* in Indiana, while surprising, was not completely unexpected. In his revised monograph on Indiana amphibians and reptiles, Minton (2001) suggests that this species might be found in the state based on a recent record for *H. cinerea* from adjacent Henderson County, Kentucky (Lodato & Grannan 1990). Henderson County lies on the Ohio River and borders all of Vanderburgh County, Indiana, as well as portions of Warrick and Posey counties in Indiana. The original Henderson County collection site is a large cypress swamp on the Ohio River floodplain just west of the confluence with the Green River. The record is of interest because Ralph Gessing, a collector associated with the Cincinnati Museum of Natural History, states in correspondence with Philip Smith of the Illinois Natural History Survey that he and others collected *H. cinerea* in Henderson County in the 1940s (Smith 1966). This claim was dismissed at the time because the locality was so far out of range from known populations in southwest Illinois and western Kentucky (Smith 1966). The Cincinnati Museum of Natural History has no specimens of *H. cinerea* from Henderson County (Pers. Comm.).

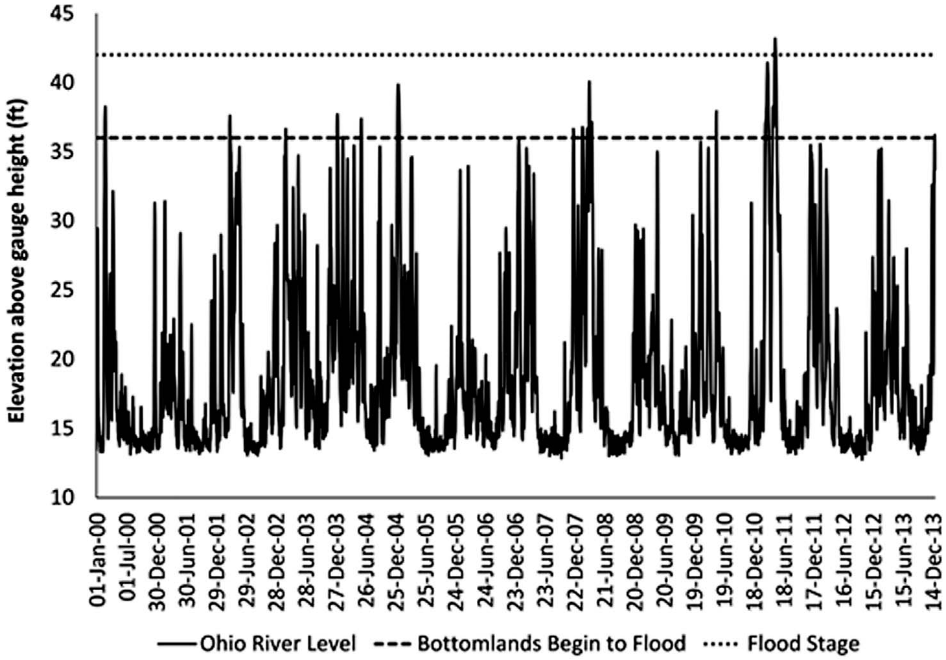
Subsequent to the 1989 discovery and verification of *H. cinerea* in Henderson County, the senior author surveyed for the species in suitable habitat in adjacent Indiana in Posey, Vanderburgh, and Warrick Counties. In 2000, Brodman (2003) conducted anuran call surveys in both Posey and Spencer Counties during times when *H. cinerea* is seasonally active. No green treefrogs were located in Indiana during any of these surveys. In 1998, *H. cinerea* appeared for the first time in the western portion of Henderson County in a bottomland wetland complex about 18 km west and downstream of the original collection site in Henderson County. This area, immediately north of Smith Mills, is known as "the sloughs." The senior author, in conjunction with Michael Kerr, had extensively surveyed the anurans of this area dating back to 1973, and no *H. cinerea* were present (Lodato & Kerr 1974). However, by 2000, we noted that *H. cinerea* was firmly established in these wetlands on and adjacent to the Ohio River floodplain in western Henderson County, and by 2002 it had begun to saturate available habitat. At that time one could drive from the town of Geneva westward along Kentucky State Route 268 on a warm evening in June and not be out of earshot of chorusing *H. cinerea*. Much of this area is immediately adjacent to the Ohio River, and the Indiana shore to the north is visible for much of the way. We believe that a larger range expansion of *H. cinerea* (described below) is underway in the middle Mississippi Valley and, more particularly, the rapid expansion of nearby populations in adjacent Henderson County and perhaps in more easterly, upstream locales in the state, was an important prelude to its eventual appearance in Indiana.

We surmise that Kentucky is the most likely source of the Indiana populations of *H. cinerea*. The circumstantial evidence for this conclusion is compelling, from both a spatial and temporal point of view. While the species was rapidly expanding its range in both Kentucky and Illinois, only in Kentucky did populations establish themselves at localities proximate to Indiana. In Illinois, this treefrog has expanded its range no further east than Pope County (Christopher Phillips, Pers. Comm.). Thus, there remains a considerable hiatus between the easternmost Illinois populations of *H. cinerea* in the Ohio Valley and the Indiana border. Further, the senior author has surveyed suitable habitat along the Illinois side of the lower Wabash River (bordering Posey County, Indiana) from White and Gallatin counties southward into Hardin County and has not located any *H. cinerea*. However, on these same surveys, *H. cinerea* was heard chorusing in adjacent Union County, Kentucky. Union County lies directly south of Posey County and both counties share an Ohio River border (Fig. 1).

From a temporal standpoint, it is clear that *H. cinerea* was first confirmed proximate to Indiana in 1989, in adjoining Henderson County, some 14 years before the first Indiana collections in 2003 (Lodato & Grannan 1990). Our field observations in the intervening years revealed a substantial expansion in both range and in population size in adjacent Henderson County wetlands prior to the first reports of the species in Indiana. In addition, by 2003 *H. cinerea* had been reported even further east along the Ohio River, in Breckinridge County, Kentucky (John MacGregor, Pers. Comm.). Each of these Kentucky localities is upstream from the earliest collection site of *H. cinerea* in Indiana.

The above timeline and account strongly suggests that *H. cinerea* successfully moved from adjacent Kentucky into southwest Indiana. A question arises as to how this occurred. As Sherman A. Minton, Jr., (1972) suggests, "[T]he Ohio River may be a formidable barrier to small amphibians...." We submit that, despite the river presenting such a barrier, these treefrogs did in fact cross the Ohio River to colonize Indiana and that the likely mechanism for doing so was rafting on drift and other flotsam during warm season flooding and during the time the treefrogs were active. The proposed evidence for this is as follows:

1) Population locations.—All of the known Indiana populations are on annual floodplains or on sites immediately adjacent to floodplains, either of the Ohio or Wabash rivers. These sites communicate with the Ohio River during flooding and indirectly connect Kentucky floodplain wetland habitats harboring *H. cinerea* and Indiana floodplain wetland habitats.
2) Chronology.—We have noted that discoveries of some new populations of *H. cinerea* in Indiana have occurred subsequent to high water events on the Ohio River. Pulses of high water occur primarily in spring, but may occur at any time of year (Fig. 5) (National Oceanic and Atmospheric Administration 2000–2013). These surges of water pick up and carry drift and flotsam and deposit such materials when waters recede. Such drift and flotsam may serve as a rafting medium for *H. cinerea* and facilitate colonization of new sites. Our field experience has shown that *H. cinerea* is locally active anytime between March and October, a period that includes frequent high water events on the Ohio River, as measured at the Evansville Gauge Station (Fig. 5). In particular, 2011 was a wet year with sustained spring high water at Evansville from the end of February until the end of May (Fig. 5) (National Oceanic and Atmospheric Administration 2000-2013). Several new colonies were discovered in Posey and Vanderburgh counties in 2011 after high water had receded. This sequence provides circumstantial evidence that spring high water and warm season flooding contribute to dispersal and colonization of new sites by *H. cinerea.*
3) Direct observation.—Eagle Slough, in southern Vanderburgh County, Indiana, had been surveyed annually for *H. cinerea* without success. However, in 2011, southwest Indiana experienced record-setting annual precipitation of more than 177.8 cm (National Weather Service Forecast Office 2011), and warm season flooding persisted until the end of June. During the peak of flooding, Eagle Slough was completely inundated by floodwater, and strong currents flowed over the site. On a visit to the slough on 9 July, after floodwaters had receded, we noted, for the first time, widely scattered calls of *H. cinerea* at the site. In this instance all were calling from isolated pools left by receding floodwater. Most of these temporary pools were situated under mature forest canopy. No *H. cinerea* were heard at the margins of an open cypress swamp at the northern end of this site. The following year (2012) we heard singing males in typical breeding choruses in the open buttonbush zones and vegetation at the margin of the open-canopied cypress swamp at this site. They appeared to have been deposited by the receding floodwaters. The following season they apparently migrated to the more open margins of the permanent cypress pond and began typical breeding activities (chorusing). The Eagle Slough site is both downstream and directly across the Ohio River from established Kentucky populations near the mouth of the Green River, as well as from other upstream Kentucky populations along the Ohio



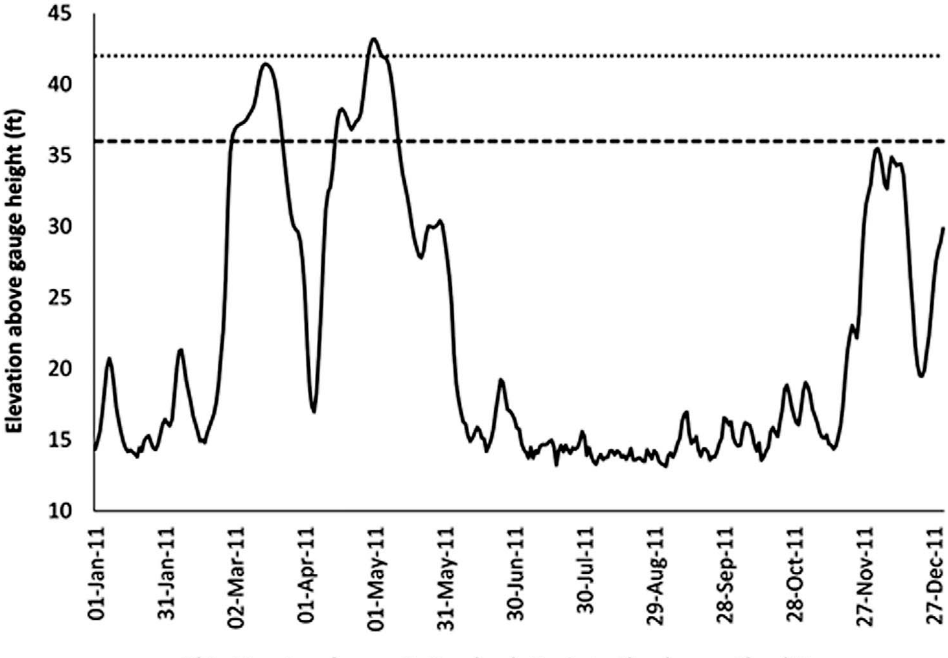


Figure 5.—Ohio River levels measured at the Evansville, Indiana gauge station. Top: Trimester Ohio River levels, 2000-2013. Bottom: Detail of periodic Ohio River stages for calendar year 2011. Pulses of high water occur at times when *Hyla cinerea* is active, March-October. Rafting under such conditions may facilitate dispersal and new colonization at floodplain sites.

River as far east as Breckinridge County (Fig. 3).

4) Rafting as potential dispersal mechanism for another Indiana species.—In the past decade, a reproducing colony of the common wall lizard, *Podarcis muralis*, a species of lizard native to Europe, was discovered in Clark County, Indiana, at Falls of the Ohio State Park (Walker & Deichsel 2005). These lizards were in rip-rap and drift along the river bank below the state park. Testing determined these lizards were genetically identical to a long established *P. muralis* colony upstream on the Ohio River riverfront at Cincinnati, Ohio (Walker & Deichsel 2005). While not completely excluding an introduction, rafting on river flotsam is believed to be the likely mechanism of dispersal. This theory is supported by a report documenting the dispersal of the lizard *Lacerta agilis* on river flotsam and new colonization during a substantial flood that occurred on the Elbe River near Meisen, Germany, in 2002 (Prokoph 2003).
5) Additional, parallel vertebrate range expansion.—It is also noteworthy that at least one other southern terrestrial vertebrate species, the nine-banded armadillo (*Dasypus novemcinctus*) invaded Indiana from the south and west at about the same time as *H. cinerea* appeared in Indiana (Whitaker 2010) and occupied virtually the same region as that now occupied by *H. cinerea* in southwest Indiana. Although Whitaker notes that the armadillo has expanded its range in the Southeast and appeared in Illinois and Kentucky prior to its arrival in Indiana, he does not speculate on its means of dispersal.

## INDIANA DISTRIBUTION RECORDS BY COUNTY

The following is an account of *H. cinerea* in each of the four counties where it has become established, in chronological order of discovery, based on field work during this study. During the course of the study, additional localities (other than the original site in each county) have been confirmed in three of the four Indiana counties harboring *H. cinerea* (Fig. 4). Although isolated treefrog vocalizations initially were recorded, we focused our attention on the location of breeding colonies, as determined by aggregations of chorusing males assembled in suitable aquatic habitats.

A report of a specimen of *H. cinerea* from Kirklin, Clinton County, was brought to our attention by former DNR employee Angie Garcia Miller. The specimen was found on 22 September 2009 and photographed by Wendell Zetterberg, Jr. The treefrog was perched on ornamental grasses in a garden setting near a residence. Given the latitude of the locality, its urban/residential setting, and the circumstance of discovery we consider this isolated record as a waif, likely escaped or released from captivity or accidentally transported by human agency.

**Vanderburgh County.**—The first records for Indiana were on 14 and 16 June 2003. Voucher specimens: University of Michigan Museum of Zoology (UMMZ 230109–230110) (Lodato et al. 2004).

Vanderburgh County was the site of the first collection of *H. cinerea* in Indiana. Since 2003 the species has colonized new sites in the county. At the present time, there are five breeding localities, all located on the Ohio River floodplain in Knight, Perry, and Union townships (Fig.4). Based on voice surveys, *H. cinerea* has sporadically occurred in wetlands on higher terraces adjacent to the floodplain, most notably in and around Burdette Park in Perry Township. Most of these are in artificial wetlands (e.g., farm ponds and impoundments), but none have persisted or established breeding colonies. The lack of well-developed vegetation about the margin of these sites may be the reason for this. The largest aggregations of *H. cinerea* in Vanderburgh County, and perhaps the most easily observed, are found along Bayou Creek, a shallow, sluggish backwater drain that forms the boundary between Perry and Union Townships. Here a paved road parallels the bayou for a portion of its course, with forest on one side of the road and cropland on the other. After dark, *H. cinerea* frequently move from the forested bayou margin to row crops across the road and vice versa, and the treefrogs can often be found on the road surface.

**Posey County.**—First recorded in the county on 10 June 2005. Photo vouchered: Illinois Natural History Survey (INHS 2005a) (Walker et al. 2006).

*Hyla cinerea* was first located in Posey County at the Gray's Woods-Goose Pond cypress slough and at Rail Marsh on the west side of Hovey Lake, both in Point Township. It is of interest that the senior author and Roger Hedge of the Indiana DNR Division of Nature Preserves checked these sites in early July 2003 and no *H. cinerea* was found. Additional populations were discovered in 2005, 2006, 2008, 2011, and 2012. There are now eleven known breeding sites in Posey County, and these occur on both the Ohio and Wabash River floodplains (Fig.4). The species began to ascend the Wabash River floodplain in 2008 following extensive June flooding (National Weather Service 2011). We surveyed for *H. cinerea* in July 2008 after the Wabash floodwaters had receded and noted widely scattered, individual calling males in the rural countryside well away from breeding sites. Some of these calling stations were from lawns of rural homesteads and nearby roadside ditches. During this survey we heard calling *H. cinerea* for the first time from the vicinity of Half Moon Pond. Based on this observation, it appeared that the warm season flooding had facilitated dispersal and colonization of new sites from established populations. Following additional June flooding in 2011 (National Weather Service 2011), *H. cinerea* appeared further north in an extensive buttonbush swamp east of Pitcher Lake in Black Township. Since that population was discovered, we have recently (in 2014) documented a range extension of about 1.5 km to the north where the treefrogs inhabit shrub swamp along a bayou northeast of Pitcher Lake. This site, northwest of Mt. Vernon and north of State Route 62, is currently the northernmost population along the Wabash River. The population of *H. cinerea* at the Gray's Woods/Cypress Slough Swamp near the confluence of the Ohio and Wabash Rivers in Point Township is perhaps the largest and most robust in the state.

**Warrick County.**—First noted on 15 July 2005. Photo vouchered: Illinois Natural History Survey (INHS 2012K) (Lodato 2013).

*Hyla cinerea* was discovered in Warrick County along an old meander of Cypress Creek in Anderson Township. While *H. cinerea* was first noted at the site in 2005, and has been monitored each year since, a voucher was not taken until 2012. It is noteworthy that the senior author repeatedly checked this site in 1989 and 1990 after *H. cinerea* was discovered in adjacent Henderson County, Kentucky, but the species was not found. Despite seemingly good habitat elsewhere along Cypress Creek and in shrub swamp along Pigeon Creek in the western portion of the county, this remains the only known site for *H. cinerea* in Warrick County. Mature forest surrounds this site, and the embankments adjacent to the watercourse are somewhat steep-sided. However, the aquatic environment itself provides favorable *H. cinerea* habitat, with bald cypress (*Taxodium distichum*), buttonbush (*Cephalanthus occidentalis*) and mats of spatterdock (*Nuphar advena*).

**Spencer County.**—First recorded on 11 June 2013 (voice record). Vouchered with photograph and with archived audio recording: Illinois Natural History Survey (INHS 2013b) (Lodato & Gordon 2013).

Spencer County has been surveyed annually for *H. cinerea* since 2003. Our searches have focused on bottomlands near the confluence of Little Pigeon Creek and the Ohio River (east of Yankeetown, Warrick County). Periodic surveys were also conducted in wetlands on the Ohio River floodplain in the southern lobe of the county (Luce and Ohio townships), but all of these surveys had been without success. However, in June 2013 *H. cinerea* was heard calling from an unnamed slough along Garrett Creek and from points immediately south of this site (Lodato & Gordon 2013). It is not known precisely when the treefrogs first colonized these sites because the specific area had not been surveyed since 2009 and *H. cinerea* was not present at that time. On 25 July 2013 two small groups of chorusing males were heard calling from artificial ponds on terraces immediately adjacent to the annual floodplain. These sites were in Luce Township, west of the 11 June 2013 vouchered locality. These treefrogs are of recent origin as these sites were checked in 2012 and no *H. cinerea* were detected.

The authors have made extensive surveys north and east of the four counties now known to harbor breeding populations of *H. cinerea*

(Fig. 3). Numerous visits to buttonbush swamps and other wetlands at the mouth of Poison Creek and Oil Creek in Perry County have been unsuccessful. However, a breeding colony is known from a buttonbush swamp just across the Ohio River in Breckinridge County (John MacGregor, Pers. Comm.). Likewise we have periodically surveyed seemingly good sites along the Wabash, White, and Patoka Rivers in Knox, Gibson, and Pike Counties without success. However, it is clear that populations of *H. cinerea* are dynamic and the history of colonization and range expansion noted in adjacent Kentucky and Illinois could be repeated in Indiana. For this reason, continued surveys and monitoring of known populations are warranted.

## OBSERVATIONS ON *HYLA CINEREA* IN INDIANA

**Phenology.**—The earliest date we observed *H. cinerea* was 14 March, and the latest date was 16 October. These observations were made at Eagle Slough in Vanderburgh County. The treefrogs were not calling at this time but were found perched on vegetation on sites elevated well above the breeding wetland. The March sighting was about 100 m from the breeding site while the October sighting was about 50 m distant.

**Breeding Dates.**—The earliest breeding chorus we have heard was 6 May, and the latest date was 28 July. This breeding period may be somewhat shorter than the "early May to early August" given for a population in southwestern Illinois (Garton & Brandon 1975) and is decidedly shorter than the March through September breeding period for a population in northwest Florida (Gunzburger 2006).

Indiana choruses begin to increase in intensity from early May and peak with the approach of the summer solstice. Choruses remain level for several days and then begin to decline until the end of July, when males cease calling. There is an order of magnitude increase in volume, frequency, and intensity between the first choruses in early to mid-May and the peak of such activity in mid- to late-June. Thus, mid-June through early July is the optimal time to survey for new populations. A number of authors report that *H. cinerea* has a rain call that portends inclement weather, particularly in the south (Wright & Wright 1949; Conant & Collins 1998; Elliott et al. 2009), but we have not noted any spontaneous calling in local populations in response to approaching rainstorms.

Amplexing pairs have been noted on various dates in Vanderburgh County, as early as 7 June and as late as 13 July. Recently metamorphosed juveniles have been found from mid- to late-September.

Multiple egg clutches per season have been shown for *H. cinerea* in Georgia (Perrill & Daniel 1983) but evidence for such in Indiana populations is lacking.

**Habitat.**—To date all of the breeding localities for *H. cinerea* occur within the Southern Bottomlands Natural Region of the state, a region of southwest Indiana along the floodplains of the major rivers and with natural communities of flora and fauna that have affinities with the lower Mississippi Valley and the Gulf Coastal Plain (Homoya et al. 1985). *Hyla cinerea* requires aquatic habitat in order to reproduce, and all of the Indiana populations are tied to particular wetland sites within this natural region. We have found the species in a variety of wetland habitats, including floodplain sloughs, swamps, oxbow ponds, bayous, and occasionally in flooded fields, ditches, and artificial ponds. However, based on our call surveys, preferred breeding habitat for the species here appears to be a natural, permanent or semi-permanent, shallow slough, pond, or swamp with an open, sunlit canopy with exposed shrub thickets and borders and with ample emergent and floating vegetation. We have observed that these aquatic sites often have scattered bald cypress, thickets of buttonbush, and mats of spatterdock (Fig. 6). An open canopy is essential as sites with mature swamp forest with a closed canopy are avoided. In Point Township, Posey County, *H. cinerea* is abundant in the open canopied Gray's Woods/Goose Pond Cypress Slough, but absent in the nearby heavily forested, closed canopied wetlands of the Twin Swamps Nature Preserve.

Our observations show that in Indiana, *H. cinerea* is essentially dependent on an open-canopied shrub swamp for its breeding sites. These observations are consistent with those of Redmer et al. (1999) in adjacent Illinois. It is noteworthy that when this treefrog colonized Indiana it found habitats not unlike those it occupies in its historical range in the southeastern United States. These open floodplain

Figure 6.—Breeding habitats for *Hyla cinerea* in Indiana. Top: Bayou Creek, Union Township, Vanderburgh County. Note bank-to-bank mat of spatterdock (*Nuphar advena*). Shrub borders are dominated by buttonbush (*Cephalanthus occidentalis*) and swamp rose mallow (*Hibiscus palustris*). Bottom: Unnamed cypress pond, Marrs Township, Posey County. Note bald cypress trees (*Taxodium distichum*) and widely spaced buttonbush shrubs. Water surface covered by duckweed (*Lemna spp.*) and mosquito fern (*Azolla caroliniana*).

wetlands favored by *H. cinerea* as breeding sites constitute an ecological niche scarcely used by any other Indiana hylid.

We have found *H. cinerea* perched on trees, including ash (*Fraxinus* spp.), bald cypress, pin oak (*Quercus palustris*), dogwood (*Cornus florida* and *C. drummondii*), silver maple (*Acer saccharinum*), boxelder (*A. negundo*), and willow (*Salix* spp.) and shrubs including buttonbush, swamp privet (*Foresteria acuminata*), swamp rose mallow (*Hibiscus palustris*), and elderberry (*Sambucus nigra*) in and adjacent to occupied wetland habitats. The most common aquatic plants in sites harboring *H. cinerea* are spatterdock and creeping yellow primrose (*Ludwigia* spp.). Commonly occurring floating and submerged plants have included duckweed (*Lemna* spp.) and hornwort (*Ceratophyllum demersum*). We have also found *H. cinerea* in cropland adjacent to breeding sites where they were perched on wheat (*Triticum* spp.) and soybeans (*Glycine max*) and in flooded fields perched on cocklebur (*Xanthium* spp.). Recently metamorphosed young-of-the-year were found in sedges (*Carex* spp.) and perched on shrub-sized roughleaf dogwood (*C. drummondii*) at the edge of a wetland in Vanderburgh County.

**Size/Color/Pattern.**—The size range given for adults of *H. cinerea* is from 32 to 57 mm, with a maximum of 64 mm (Conant & Collins 1998). Based upon snout-vent measurements (SVL) generously provided by Dale Edwards, Noah Gordon, and Anne Steele of the University of Evansville (Pers. Comm. 2013) and our own data, Indiana adult males averaged 46.2 mm SVL (N = 25). Adult females averaged 51.3 mm SVL (N = 3). Recently metamorphosed juveniles (young-of-the-year) measured 20.6 mm SVL (N = 6).

Indiana *H. cinerea* are apparently typical in color and pattern as well as size. All Indiana specimens we examined ranged from grass green to bright lime green, and all had a bright white to silver stripe from the upper lip extending down the side. Specimens lacking these light lateral stripes have been noted in some populations (Conant & Collins 1998; Elliot et al. 2009), but we have seen no patternless Indiana specimens. Many had small gold flecks on the dorsum that were either partially or completely circled in black. Recent studies indicate that the number and size of these dorsal spots vary over time on individual frogs (Beaudry & Höbel 2014).

**Stability of Populations.**—The *H. cinerea* colonies that have become established in the state appear to be stable and resilient. While there seems to be some variability in chorus intensity from year-to-year at certain locations, no breeding colonies have been lost during the course of this study. In 2010 and 2012, two drought years, one colony in Posey County and one in Vanderburgh County became dormant (all chorusing ceased) by the first week of July. At these locations surface water had largely evaporated. Chorusing resumed, however, at each of these sites in succeeding years.

## SUMMARY

The newly established Indiana populations of *H. cinerea* are at the northern periphery of the known range of this species. Based on the data collected in this study, and in the context of information reported from other states where the species occurs, we can now address some of the questions posed in the Introduction to this paper:

1) *Hyla cinerea* is thought to have arrived in Indiana as the result of a natural expansion of its range in the middle Mississippi Valley.
2) The most likely source of Indiana *H. cinerea* populations, based on temporal, spatial, and other factors, is adjacent Kentucky.
3) Rafting on drift during warm season flooding on the Ohio River is thought to be the likely mechanism for the arrival and establishment of initial populations in the state.
4) Subsequent warm season flooding seems to have facilitated colonization and saturation in suitable habitat along the lower Wabash and Ohio River floodplains in Indiana.
5) Upon its arrival in southwest Indiana, *H. cinerea* encountered and occupied austroriparian habitats not unlike those it occupies in its historical range in the southeastern United States. Its preference for open-canopied shrub swamp and other similar wetlands here is consistent with its habitat preference

in adjoining states. At its floodplain breeding sites, it fits into an ecological niche that is only marginally used for such purposes by any other local hylid.

6) Local populations have a somewhat shorter breeding period than that reported for more southern historic populations in the middle Mississippi Valley and the Gulf Coastal Plain.
7) In the decade since it was discovered in Indiana, this treefrog has survived northern winter temperatures; swift, roiling currents from flooding of breeding sites; and considerable drought. Under these conditions, it has continued to expand its range in the state.
8) This southern species now appears to be permanently established in the state and is poised for further expansion.

This documented recent range expansion of *H. cinerea* in the middle Mississippi Valley, including its recent colonization of southwestern Indiana, demonstrates the remarkable vagility of this species. It presents an intriguing biogeographic phenomenon and contrasts sharply with amphibian declines generally.

## ACKNOWLEDGMENTS

For field assistance, we thank Andrew Berger, Nick Burgmeier, Dale Edwards, Angie Garcia Miller, Noah Gordon, Roger Hedge, Mel Lodato, Dustin McBride, Jason Mirtl, Rebecca Schmidt, Anne Steele, and Greg Stephens. The following individuals provided information and data concerning populations of *H. cinerea* in their respective states: Jeff Briggler (Missouri), John MacGregor and Brainard Palmer-Ball (Kentucky), and Christopher Phillips (Illinois). For access and information concerning certain state-owned properties in southwest Indiana, we thank Brad Feaster and Mark Pochon of the Indiana Department of Natural Resources, Division of Fish & Wildlife. For research resources and related literature research, we thank Meg Atwater-Singer of the University of Evansville and Michael Lannoo of the Indiana University School of Medicine at Terre Haute. For assistance in manuscript preparation, we thank Mark Brown, Lee Casebere, Andrew Hoffman, Michael Homoya, Patricia Lodato, John MacGregor, and Jason Mirtl. We are particularly indebted to Tom Cervone and Rusty Yeager of the Lockmueller Group for their technical assistance in the preparation of the maps for this report. Catherine Gremillion-Smith of the Wildlife Diversity Program of the Indiana Department of Natural Resources, Division of Fish & Wildlife, provided verbal authorization to collect voucher specimens. Some early portions of fieldwork (pre-2007) were funded by the Indiana Department of Natural Resources Nongame Fund and a Federal State Wildlife grant (T-3-S).

## LITERATURE CITED

Ackerman, K. 1975. Rare and endangered vertebrates of Illinois. Bureau of Environmental Science, Illinois Department of Transportation, Springfield, Illinois. 50 pp.

Barbour, R.W. 1956. The Salientia of Kentucky, identification and distribution. Transactions of the Kentucky Academy of Science 17:81–87.

Barbour, R.W. 1971. Amphibians and Reptiles of Kentucky. University of Kentucky Press, Lexington, Kentucky. 334 pp.

Beaudry, P. & G. Höbel. 2014. *Hyla cinerea*: dorsal spots. Herpetological Review 45:111–112.

Brodman, R. 2003. Amphibians and reptiles from twenty-three counties of Indiana. Proceedings of the Indiana Academy of Science 112:43–54.

Conant, R. & J.T. Collins. 1998. A Field Guide to Reptiles and Amphibians of Eastern and Central North America. 3rd ed. expanded. Houghton Mifflin, Boston, Massachusetts. 616 pp.

Dodd, K.C., Jr. 2013. Frogs of the United States and Canada. Johns Hopkins University Press, Baltimore, Maryland. 982 pp.

Dury, R. & W. Gessing, Jr. 1940. Additions to the herpetofauna of Kentucky. Herpetologica 2: 31–32.

Dyrkacz, S. 1974. Rare and/or endangered species of Illinois: reptiles and amphibians. Bulletin of the Chicago Herpetological Society 9:15–16.

Elliot, L., C. Gerhardt & C. Davidson. 2009. The Frogs and Toads of North America: A Comprehensive Guide to Their Identification, Behavior, and Calls. Houghton Mifflin Harcourt, Boston, Massachusetts. 343 pp.

Garman, H. 1892. A synopsis of the reptiles and amphibians of Illinois. Illinois Laboratory of Natural History Bulletin 3(13):215–388.

Garton, J.S. & R.A. Brandon. 1975. Reproductive ecology of the green tree frog *Hyla cinerea* in southern Illinois (Anura: Hylidae). Herpetologica 31:150–161.

Green, D.M., L.A. Weir, G.S. Casper & M. Lannoo. 2014. North American Amphibians: Distribution and Diversity. University of California Press, Berkeley and Los Angeles, California. 340 pp.

Gunzburger, M.S. 2006. Reproductive ecology of the green tree frog *Hyla cinerea* in Northwestern Florida. American Midland Naturalist 155:321-328.

Hay, O.P. 1886. The amphibians and reptiles of Indiana. Thirty-sixth Annual Report of the State Board of Agriculture 28:201–227.

Hay, O.P. 1892. The batrachians and reptiles of the state of Indiana. Annual Report of the State Geologist 17:412–602.

Homoya, M.A., D.B. Abrell, J.R. Aldrich & T.W. Post. 1985. The Natural Regions of Indiana. Proceedings of the Indiana Academy of Science 94:245–268.

INHS (Illinois Natural History Survey-University of Illinois). 2012. Anura *Hyla cinerea*, Green Treefrog. At: http://www.inhs.uiuc.edu/animals_plants/herps/species/hy_cinerea.html (Accessed 1 August 2014).

Kentucky Department of Fish & Wildlife Resources. 2014. Species Information. County observation(s) for Amphibia. Green Treefrog (*Hyla cinerea*). At: http://app.fw.ky.gov/speciesinfo/speciesListCounty.asp?strScientificName=Hyla+cinerea&strGroup=5 (Accessed 1 August 2014).

Lodato, M.J. 2003. First records of the Green Treefrog, *Hyla cinerea*, from Indiana. Report to the DNR Non-Game Technical Advisory Committee for Amphibians and Reptiles. Indiana Department of Natural Resources Annual Meeting for the Technical Advisory Committee, November 1, 2003, Indianapolis, Indiana.

Lodato, M.J. 2013. Geographic distribution: USA, Indiana, Warrick County: *Hyla cinerea*. Herpetological Review 44:103.

Lodato, M.J. & N.M. Gordon. 2013. Geographic distribution: USA, Indiana, Spencer County: *Hyla cinerea*. Herpetological Review 44:620.

Lodato, M.J. & T.L. Grannan, Jr. 1990. Geographic distribution: USA, Kentucky, Henderson County: *Hyla cinerea*. Herpetological Review 21:37.

Lodato, M.J. & M.H. Kerr. 1974. The Western Bird voiced tree frog *Hyla a. avivoca* in Henderson County, Kentucky. Journal of Herpetology 8:259–260.

Lodato, M.J., S. Kramer & J. Horton. 2004. Geographic distribution: USA, Indiana, Vanderburgh County: *Hyla cinerea.* Herpetological Review 35:281.

Minton, S.A., Jr. 1972. Amphibians and Reptiles of Indiana. Indiana Academy of Science. Monograph 3, Indianapolis, Indiana. 346 pp.

Minton, S.A., Jr. 2001. Amphibians and Reptiles of Indiana. Revised 2nd ed. Indiana Academy of Science, Indianapolis, Indiana. 404 pp.

Minton, S.A., J.C. List & M.J. Lodato. 1983. Recent records and status of amphibians and reptiles in Indiana. Proceedings of the Indiana Academy of Science 92:489–498.

National Oceanic and Atmospheric Administration 2000-2013. At: http://water.weather.gov/ahps2/hydrograph.php?wfo=pah&gage=evvi3 (Accessed 3 March 2014).

National Weather Service. 2011. Advanced Hydrologic Prediction Service - Wabash River Crests - 6/10/08 and 5/3/11. At: http://water.weather.gov/ahps2/hydrograph.php?wfo=ind&gage=hazi3&view=1,1,1,1,1,1,1,1 (Accessed 12 July 2013).

National Weather Service Forecast Office - Paducah, KY. 2011. Annual Climate Report (CLA). Evansville, IN. December 31, 2011. At: http://www.nws.noaa.gov/climate/index.php?wfo=pah (Accessed 11 June 2014).

Oldham, R.S. & H.C. Gerhardt. 1975. Behavioral isolating mechanisms of the treefrogs *Hyla cinerea* and *H. gratiosa*. Copeia 1975:223–231.

Perrill, S.A. & R.E. Daniel. 1983. Multiple egg clutches in *Hyla regilla*, *H. cinerea*, and *H. gratiosa*. Copeia 1983:513–516.

Phillips, C.A., R.A. Brandon & E.O. Moll. 1999. Field Guide to the Amphibians and Reptiles of Illinois. Illinois Natural History Survey. Manual (8), Champaign, Illinois. 282 pp.

Platt, S.G., K.R. Russell, W.E. Snyder, L.W. Fontenot & S. Miller. 1999. Distribution and conservation status of selected amphibians and reptiles in the Piedmont of South Carolina. Journal of the Elisha Mitchell Scientific Society 115:8–19.

Powell, R., T.R. Johnson & D.D. Smith. 1995. New records of amphibians and reptiles in Missouri 1995. Missouri Herpetological Association Newsletter 8:9–12.

Powell, R., T.R. Johnson & D.D. Smith. 1996. New records of amphibians and reptiles in Missouri 1996. Missouri Herpetological Association Newsletter 9:9–14.

Prokoph, U. 2003. Feldherpetologische observations on the edge of the floods on the Elbe at Meissen in August 2002. The lizard. 14(2):61–63 [Corinthstraße33, D-01217, Dresden, Germany].

Redmer, M. & R.A. Brandon 2003. *Hyla cinerea* Schneider. Catalogue of American Amphibians and Reptiles 766.1–766.14.

Redmer, M. & R.A. Brandon. 2005. Green treefrog, *Hyla cinerea.* Pp. 452–454. *In* Amphibian Declines: The Conservation Status of United States Species. (M. Lannoo, Ed.). University of California Press, Berkeley, California.

Redmer, M., L.E. Brown & R.A. Brandon. 1999. Natural history of the bird-voiced tree frog *Hyla avivoca* and green tree frog *Hyla cinerea* in southern Illinois. Illinois Natural History Survey Bulletin 36:37–66.

Reynolds, R.G. 2013. Green treefrog, *Hyla cinerea.* Pp. 274–277. *In* The Amphibians of Tennessee.

(M.L. Neimiller, & R.G. Reynolds, Eds.). University of Tennessee Press, Knoxville, Tennessee.

Smith, P.W. 1961. The amphibians and reptiles of Illinois. Illinois Natural History Survey Bulletin 28:1–298.

Smith, P.W. 1966. *Hyla avivoca* Viosca. Catalogue of American Amphibians and Reptiles 28.1–28.2.

Snyder, W.E. & S.G. Platt. 1997. Anuran records from the Piedmont of South Carolina, USA. Herpetological Review 28:33.

Tucker, J.K., J.T. Lamer & C.R. Dolan. 2008. A northern range expansion for the green tree frog *Hyla cinerea* and trends in distributions of Illinois reptiles and amphibians. Transactions of the Illinois State Academy of Science 101:125–131.

Walker, Z. & G. Deichsel. 2005. Geographic distribution: USA, Indiana, Clark County: *Podarcis muralis*. Herpetological Review 36:202.

Walker, Z., N. Engbrecht & R. Schmidt. 2006. Geographic distribution: USA, Indiana, Posey County. *Hyla cinerea*. Herpetological Review 37:100.

Whitaker, J.O., Jr. 2010. Mammals of Indiana: A Field Guide. Indiana University Press, Bloomington, Indiana. 327 pp.

Wright, A.H. & A.A. Wright. 1949. Handbook of Frogs and Toads, 3rd ed. Comstock Publishing, Ithaca, New York. 640 pp.

*Manuscript received 17 September 2014, revised 11 February 2015.*

2014. Proceedings of the Indiana Academy of Science 123(2):196–203

# GROWTH, LENGTH-WEIGHT RELATIONSHIPS, AND CONDITION ASSOCIATED WITH GENDER AND SEXUAL STAGE IN THE INVASIVE NORTHERN CRAYFISH, *ORCONECTES VIRILIS* HAGEN, 1870 (DECAPODA, CAMBARIDAE)

**Thomas P. Simon**[1] and **Christopher R. Stewart**: School of Public and Environmental Affairs, 1315 E. Tenth Street, Indiana University, Bloomington, IN 47403 USA

**ABSTRACT.** The northern crayfish, *Orconectes virilis* Hagen 1870, is an invasive species in North America and Europe and is currently expanding its range and influence ecologically and globally. Growth patterns and relationships of body morphometrics were evaluated to understand basic life history relationships. Growth and size relationships are provided for gender, sexual phase distributions for adults and juveniles, and chelae length and width relationships to interpret information on sexual dimorphism. The length-weight relationship for the male form I ($y = 3.048x - 3.659$, $r^2 = 0.945$, $F = 839.2$, $p = <0.001$), and male form II ($y = 3.228x - 3.950$, $r^2 = 0.958$, $F = 1008.6$, $p = <0.001$) sexual reproductive phases; and female ($y = 3.071x - 3.734$, $r^2 = 0.948$, $F = 1848.8$, $p = <0.001$), showed positive Fulton Condition Index allometric rates of change with increasing length, while juveniles ($y = 1.137x - 1.544$, $r^2 = 0.784$, $F = 345.1$, $p = <0.001$) showed negative allometric change. Carapace width ($y = 0.4902x - 0.3973$, $r^2 = 0.971$, $F = 4.039$, $p = <0.001$), carapace depth ($y = 0.4767x - 0.1899$, $r^2 = 0.980$, $F = 4.311$, $p = <0.001$), abdomen width ($y = 0.4244x -0.4099$, $r^2 = 0.956$, $F = 5.308$, $p = <0.001$), chelae width ($y = 0.3011x - 1.0863$, $r^2 = 0.787$, $F = 8.675$, $p = <0.001$), and chelae length ($y = 0.705x - 2.1319$, $r^2 = 0.880$, $F = 1.770$, $p = <0.001$) all grew allometrically with respect to carapace length. Based on northern crayfish rapid growth and large size, a competitive advantage during invasion is attained by adults based on larger CL sizes and sexual dimorphism in male chelae size.

**Keywords:** morphometrics, Fulton Condition index, growth, length-weight relationships

## INTRODUCTION

The native distribution of the northern crayfish, *Orconectes virilis* Hagen, 1870, includes the northern USA and Canada (Hobbs 1989). It is native to the Great Lakes, the southern Arctic Ocean, and northern Mississippi drainages from northern Arkansas, Mississippi, and Tennessee to Alberta and southeastern Quebec, with populations extending west in the Mississippi drainage to Montana and Colorado (Hagen 1870; Faxon 1914; Holthuis 1962). It has been introduced to other regions in North America and into at least nine other states and the District of Columbia (Schwartz et al. 1963), including California (Riegel 1959), Utah (Johnson 1986), Washington (Larson et al. 2010), Arizona, Pennsylvania, New Jersey (Crocker 1979; Smith 1979), Maryland (Meredith & Schwartz 1960; Schwartz et al., 1963), Virginia, West Virginia (Loughman & Welsh 2010; Loughman & Simon 2011), and North Carolina (Bouchard 1976). It has also been introduced into New Brunswick, Canada (McAlpine et al. 2007), Chihuahua, Mexico (Campos & Contreras-Balderas 1985; Hamr 2002), North London, England (Ahern et al. 2008), and the Netherlands (Ahern et al. 2008).

In some parts of its introduced range, *O. virilis* has been reported to displace native crayfish species and disrupt reproductive success of native fish species (Dorn & Mittlebach 2004). The competitive advantage of *O. virilis* is speculated to be based on its large size compared to sympatric native species (Loughman & Simon 2011). This advantage may be based on size and weight differences caused by unequal growth of body parts (Lockwood et al. 2013). Change in growth of select structures, which might be sexually dependent, may be observed as either allometric or isometric rate change (Mazlum et al. 2007). The Fulton Condition Index (Nielson & Johnson 1983) is a measure of growth rate, such that it is a measure of the slope ($b$). Growth is isometric (equal) when

---

[1] *Corresponding author:* Thomas P. Simon, 812-332-4725 (phone), tsimon@indiana.edu.

$b = 3$, and when $b < 3$ or $b > 3$, growth is allometric. This suggests that positive allometric growth occurs when organism weight increases more than length ($b > 3$) and negative allometric growth occurs when length increases more than weight ($b < 3$). Allometry may change during growth and sexual stage. We propose that these growth rate changes can result in differential expression based on sex or sexual maturation phase, which may not provide a competitive advantage for females and juveniles.

Basic life history information is generally lacking for most crayfish species (Moore et al. 2013), while patterns in growth and length-weight relationships are limited (Stein 1976; Romaire et al. 1977; Rhodes & Holdich 1984; Garvey & Stein 1993), other than for commercial aquaculture species (Mazlum et al. 2007; Wang et al. 2011). The current study evaluates the relationships between growth, gender, and body morphology, which could enhance competitive advantage for the invasive northern crayfish. We investigate length and weight, carapace, chelae, and abdomen relationships among male form I and II, female, and juvenile individuals of *O. virilis*. This information will contribute to baseline information needs for evaluating invasive species life history attributes.

## METHODS

All specimens ($n = 298$) used for measurement of *O. virilis* morphometry were collected from ambient natural streams ($n = 183$), lakes ($n = 32$), and drowned river mouth coastal wetland ($n = 53$) environments associated with either the Laurentian Great Lakes ($n = 132$) or Ohio River ($n = 166$) basins, USA. Surveys were conducted in the Midwestern United States from Indiana, Michigan, Ohio, Wisconsin, and Minnesota from May 1999 until September 2005. Sampling was restricted to daylight hours and all available habitats within a reach (defined as a linear distance of 15 times the wetted stream width or minimum distance of 150 m of shoreline margin in lakes and wetlands). Crayfish were collected using standard operating procedures described in Simon (2004) based on a variety of gear types appropriate for each waterbody type. Collection methods included electrofishing (i.e., backpack, tow-barges, and boat-mounted), collection by hand by flipping rocks, and excavation methods. We have pooled data over the native range of this species in order to examine the relationships between growth, gender, sexual stage, and size.

A total of 104 females, 97 males ($n = 51$ form I and $n = 46$ form II), and 97 juveniles were measured using digital calipers to the nearest 0.1 mm. Individuals were segregated by gender and sexual stage groups. To avoid bias due to measuring procedures, the same individual completed all morphological measurements (CS). A second individual (TPS) measured 5% of the total individuals to ensure measurement precision and accuracy was within 5% using standard quality assurance procedures. All measured individuals had a full complement of chelae and walking legs and no visible body deformation. Damaged and regenerated chelae were not used. All individuals were measured for morphometric variables and for weight. Weight ($W_{WT}$) was measured by placing the individual on paper towel to remove excess water, and then weighed with a Mettler AT20 digital balance with an accuracy of 0.001 g. The following seven morphometric characteristics were measured for each specimen (Fig. 1) – carapace length (CL); postorbital carapace length (POCL) [from the anterior margin of postorbital spine to the posterior margin of the carapace]; carapace width (CW); carapace depth (CD) [distance from the sternum to the dorsal surface]; chelae length (ChL); chelae width (ChW); chelae depth (ChD) [vertical measure from the dorsal to ventral margins of the chelae at the thickest depth]; and abdomen width (ABW). Based on similar studies of other *Procambarus* crayfish species (Mazlum et al. 2007; Wang et al. 2011), these morphological characters are related to sexual dimorphism and are controlled by environmental and food resources.

Juvenile and adult specimens were distinguished using a size threshold of 25 mm CL, which corresponds to the smallest female with ripe gonads. This threshold was established for females by dissecting the oviduct aperture and evaluating ovarian development based on early maturing ova presence. We evaluated only females, but considered the size threshold for both sexes, since all individuals below this size belong to the first age group, and male gonopodia identification was not possible (Hobbs 1989). Any possible relationship between smaller (CL $<$ 25 mm) and larger (CL $>$ 25 mm) specimens were determined by

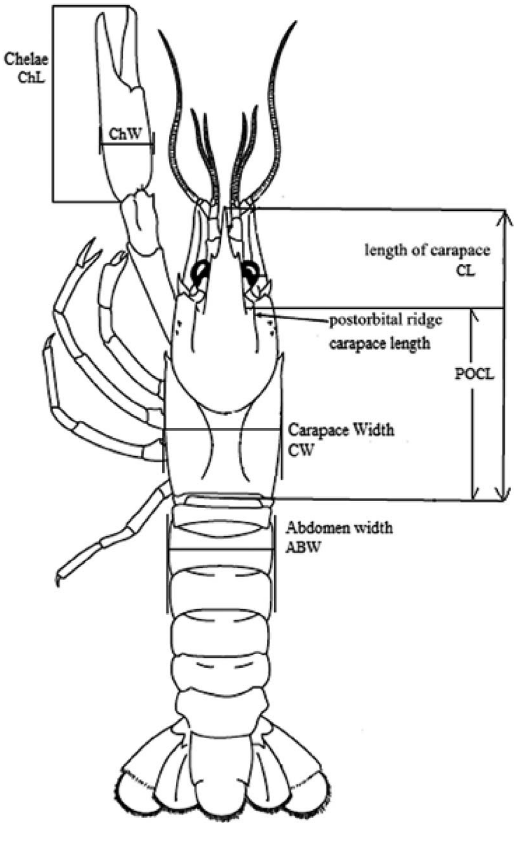


Figure 1.—Morphometric measurements taken for *Orconectes virilis* Hagen 1870 individuals ($n = 298$). CL = carapace length, POCL = Postorbital carapace length, CD = carapace depth, CW = carapace width, ChL = chelae length, ChW = chelae width, ABW = abdomen width. [Line art modified from Loughman & Simon (2011)].

comparing the ratios between the means of above measurements and mean carapace length (CL/ABW, CL/POCL, CL/CW, CL/CD, CL/ChL, CL/ChW) of all individuals in each group.

Carapace length was considered as the independent variable for all relationships performed as it appears to be minimally affected by growth variations and sexual maturation among decapod crustaceans (Lovett & Felder 1989). Regression analyses to determine the relationship between all measurements versus CL was investigated for each sex separately using the multiplicative model: $Y = aX^b$, where $Y$ and $X$ are the morphological dimensions and $a$ and $b$ are the regression constants. The relationships obtained were log transformed to the form $\log_{10} Y = \log_{10} a + b \log_{10} X$. The log transformation is preferred to better satisfy the assumptions of regression analysis (Sokal & Rohlf 1981) and allows the derivation of a single value from the analysis for the scaling relationship between the two-morphometric parameters. The allometry pattern for each parameter was established by testing the slope ($b$) of the regression equations against isometry ($H_o$: $b = 3$) applying the Student's t-test.

Fulton's condition factors for male (form I and form II), female, and the general population were calculated using the relationship between $W_{WT}$ and CL of each individual (Nielson & Johnson 1983). Weight was plotted by CL for all individuals within each sex or sexual phase and a trend line was applied to best fit each scatter plot graph, with the $b$ value of each line equation representing the Fulton's condition factor. The $b$ value represents the type of allometric growth (Nielson & Johnson 1983).

Analysis of Covariance (ANCOVA) was used to compare the slopes $b$ and carapace length between sexes, sizes, and sampling period (Zar 1984). The Kruskall–Wallis test (Zar 1984) was used to identify possible differences in time, area, and size, at the 95.0% confidence level with Mann–Whitney tests used to compare independent samples, at the 95.0% confidence level (Sokal & Rohlf 1981), while a simple regression analysis was used to examine the relationship between *O. virilis* morphological characters with sex as a covariate.

## RESULTS

Mean carapace length (CL ± SD), mean weight ($W_{WT}$ ± SD), and the range for the general population ($n = 298$) were 23.55 ± 12.78 mm (range = 2.61–54.13 mm), 6.21 ± 7.59 g (range = 0.05–35.28 g) (Table 1). Mean carapace length (CL ± SD), mean weight ($W_{WT}$ ± SD), and the range were calculated for male and female sex as: $CL_{male} = 31.28 \pm 8.49$ mm (range = 16.92–51.29 mm), $W_{WT} = 9.76 \pm 7.94$ g (range = 1.01–34.84 g), and $CL_{female} = 29.12 \pm 9.26$ (range = 13.0–54.13 mm), $W_{WT\ female} = 7.83 \pm 7.52$ g (range = 0.51–35.28 g), respectively. The normalized ($\log_{10}$) length-weight relationship for the general population was $y = 2.1285x - 5.4489$, $r^2 = 0.907$, $F = 2979$, $p = <0.001$ (Figure 2). The normalized $\log_{10}$ length-weight relationship for male and female was: $y_{male} = 3.169x - 3.851$,

Table 1.—Descriptive statistics, estimated parameters ($\log_{10}$), and growth type of length-weight relationships for 298 individual *Orconectes virilis*. SE = standard error of *b*; CL = confidence limits of *b*; n = number of crayfish; +A = positive allometric growth, -A = negative allometric growth.

| Sex and sexual form | n | Carapace length (mm) Mean (SD) | Min | Max | Wetted weight (g) Mean (SD) | Min | Max | Parameters of relationships *a* | *b* | SE | CL (*b*) | $r^2$ | Type of growth |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Male | 97 | 31.28 (8.49) | 16.92 | 51.29 | 9.76 (7.94) | 1.01 | 34.84 | 3.169 | 3.85 | 0.010 | 3.55-4.04 | 0.952 | +A |
| Male form I | 51 | 31.07 (7.05) | 17.22 | 51.29 | 9.28 (6.99) | 1.24 | 32.42 | 3.048 | 3.66 | 0.011 | 3.55-3.77 | 0.945 | +A |
| Male form II | 46 | 30.79 (9.75) | 16.92 | 49.60 | 9.69 (8.96) | 1.01 | 34.84 | 3.228 | 3.95 | 0.009 | 3.86-4.04 | 0.958 | +A |
| Female | 104 | 29.12 (9.26) | 13.00 | 54.13 | 7.83 (7.52) | 0.51 | 35.28 | 3.071 | 3.73 | 0.007 | 3.64-3.80 | 0.948 | +A |
| Juvenile | 97 | 8.73 (4.96) | 2.61 | 22.13 | 0.38 (0.35) | 0.05 | 2.13 | 1.137 | 1.54 | 0.037 | 1.50-1.58 | 0.815 | -A |
| Total | 298 | 23.55 (12.78) | 2.61 | 54.13 | 6.21 (7.59) | 0.05 | 35.28 | 2.129 | 5.44 | 0.008 | 3.12-4.00 | 0.910 | +A |

$r^2 = 0.952$, $F = 1894$, $p = <0.00$ and $y_{\text{female}} = 3.071x - 3.7342$, $r^2 = 0.9477$, $F = 1848$, $p = <0.001$, respectively.

Mean carapace length (CL ± SD), mean weight ($W_{WT}$ ± SD), and range were calculated for male form I and male form II sex phase: $CL_{\text{form I}} = 31.07 \pm 7.05$ mm (range = 17.22–51.29 mm), $W_{WT\ \text{form I}} = 9.28 \pm 6.99$ g (range = 1.24–32.42 g), $CL_{\text{form II}} = 30.79 \pm 9.75$ mm (range = 16.92–49.6 mm), $W_{WT\ \text{form II}} = 9.69 \pm 8.96$ g (range = 1.01–34.84 g), respectively (Figure 2). The normalized ($\log_{10}$) length-weight relationship for male form I was explained by the linear equation $y = 3.048x - 3.659$, $r^2 = 0.945$, $F = 839.2$, $p = <0.001$; male form II was explained by the linear equation $y = 3.228x - 3.950$, $r^2 = 0.958$, $F = 1008.6$, $p = <0.001$; female length and weight was explained by the linear equation $y = 3.071x - 3.734$, $r^2 = 0.948$, $F = 1848.8$, $p = <0.001$; and juveniles by the equation, $y = 1.137x - 1.544$, $r^2 = 0.815$, $F = 345.1$, $p = <0.001$) (Figure 2). All adult sexual phases showed positive allometric rates of weight change with increasing length, while juvenile growth was at a negative allometric rate.

Mean carapace width (CW ± SD), mean carapace depth (CD ± SD), and the range for male and female were $CW_{\text{males}} = 15.07 \pm 4.51$ mm (range = 6.89–24.83 mm), $CD_{\text{male}} = 14.51 \pm 4.40$ mm (range = 7.22–24.60 mm), and $CW_{\text{females}} = 14.08 \pm 4.79$ mm (range = 5.72–24.52 mm), $CD_{\text{female}} = 13.98 \pm 4.494$ mm (range = 5.72–26.97 mm), respectively. Abdomen width (ABW ± SD), and the range for form I male, form II male, and female were $ABW_{\text{form I}} = 12.54 \pm 2.69$ mm (range = 6.87–18.543 mm), $ABW_{\text{form II}} = 12.13 \pm 3.98$ mm (range = 5.65–20.19 mm), and $ABW_{\text{females}} = 12.76 \pm 4.69$ mm (range = 4.89–25.01 mm), respectively.

The relationship between carapace length with carapace width ($y = 0.4902x - 0.3973$, $r^2 = 0.971$, $F = 4.039$, $p = <0.001$), carapace depth ($y = 0.4767x - 0.1899$, $r^2 = 0.980$, $F = 4.311$, $p = <0.001$), abdomen width ($y = 0.4244x - 0.4099$, $r^2 = 0.956$, $F = 5.308$, $p = <0.001$), chelae width ($y = 0.3011x - 1.0863$, $r^2 = 0.787$, $F = 8.675$, $p = <0.001$), and chelae length ($y = 0.705x - 2.1319$, $r^2 = 0.880$, $F = 1.770$, $p = <0.001$) all grew at a positive allometric rate. Mean carapace width (CW ± SD), mean carapace depth (CD ± SD), and the range were calculated for form I male, form II male,

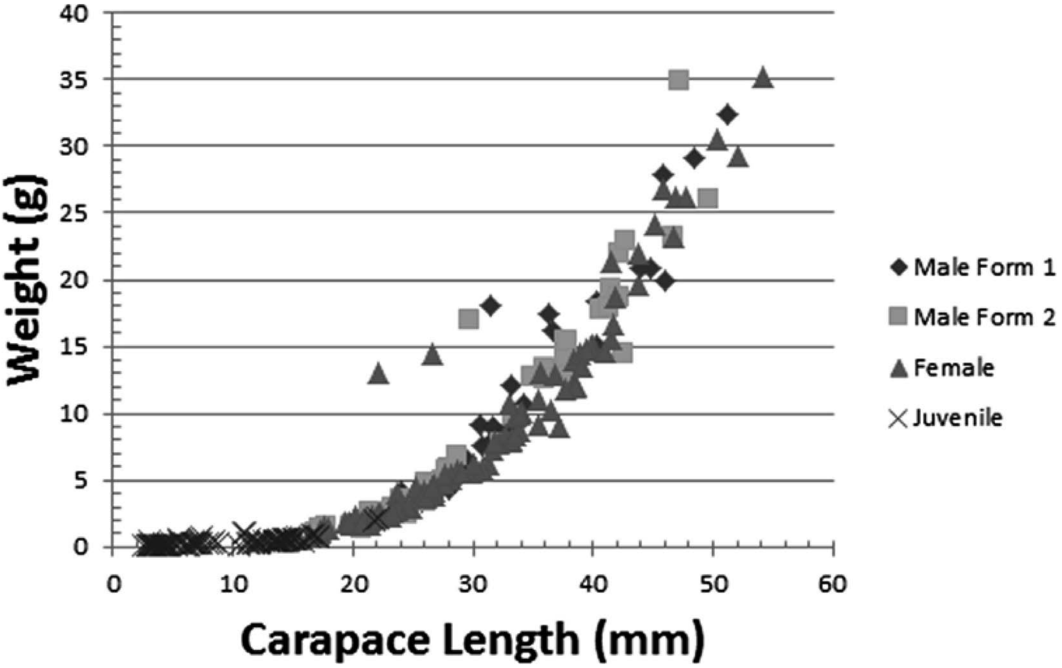


Figure 2.—Length-weight relationships for *Orconectes virilis* Hagen 1870 sexual phases. Diamonds (form I males), boxes (form II males), triangles (females), and x's (juveniles).

female, and juveniles respectively: $CW_{\text{form I}} = 15.27 \pm 3.74$ mm (range = 7.49–24.38 mm), $CD_{\text{form I}} = 14.44 \pm 3.89$ mm (range = 7.22–24.60 mm), $CW_{\text{form II}} = 14.85 \pm 5.27$ mm (range = 6.89–24.83 mm), $CD_{\text{form II}} = 14.59 \pm 4.95$ mm (range = 7.38–23.66 mm), $CW_{\text{female}} = 14.08 \pm 4.79$ mm (range = 5.72–26.97 mm), $CD_{\text{female}} = 13.98 \pm 4.94$ mm (range = 5.72–26.97 mm), and $CW_{\text{juv}} = 4.08 \pm 2.17$ mm (range = 1.23–9.91 mm), and $CW_{\text{juv}} = 4.41 \pm 2.41$ mm (range = 1.20–10.90 mm), respectively.

Carapace width (CW) growth rate increased at a negative allometric rate with weight for juveniles, while form I and form II male, female, and the general population grew with a positive allometric rate. ANCOVA tests showed that length-weight regression slopes and intercepts were significantly different among sexes and sexual stage ($p < 0.0001$). In addition, our results showed that form II male were 1.04 times heavier than form I male and 1.18 times heavier than females. Form I males were 1.95 mm larger than females and form II males were 1.67 mm larger than females. Mean total length and weight did not differ between males and females ($p > 0.060$); the only significant differences were detected among sexual stages ($p < 0.0001$).

Relationships among chelae length and width measurements for the population were evaluated for gender and sexual stage (Table 2). Mean chelae length (ChL ± SD), mean chelae width (ChW ± SD), and their range were calculated for form I, form II, and females, respectively, as $ChL_{\text{form I}} = 21.56 \pm 8.47$ mm (5.7-41.2 mm), $ChW_{\text{form I}} = 8.37 \pm 3.61$ mm (1.5-18.1 mm), $ChL_{\text{form II}} = 20.60 \pm 9.26$ mm (5.2-47.7 mm), $ChW_{\text{form II}} = 8.60 \pm 4.12$ mm (1.3-18.0 mm), and $ChL_{\text{female}} = 17.05 \pm 7.42$ mm (4.5-36.9 mm), $ChW_{\text{female}} = 7.31 \pm 4.21$ mm (1.1-30.5 mm).

No statistically significant difference was observed in mean ChL between form I and form II males (t-test, $p > 0.05$), but significant differences were detected in mean ChL form I male and females (t-test, $p < 0.05$) and form II male and females (t-test, $p < 0.05$). Form I male had longer ChL than either form II male or females. A similar trend was observed in mean ChW for form I and form II males, but a significant difference was observed between form II male and females ($p < 0.05$). Chela

Table 2.—*Orconectes virilis* mean and standard deviation (SD) for chelae length (ChL) and chelae width (ChW) characteristics and parameters of the relationship between ChL and ChW of each sex and sexual forms. SE = standard errors of *b*; CL = confidence limits of *b*; n = number of crayfish; $r^2$ = coefficient of determination.

| | | Chelae length | | | Chelae width | | | Parameters of relationships | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sex and sexual form | n | Mean (SD) | Min | Max | Mean (SD) | Min | Max | *a* | *b* | SE (*b*) | CL (*b*) | $r^2$ | *Type of growth* |
| Male form I | 51 | 21.56 (8.47) | 5.70 | 41.20 | 8.37 (3.61) | 1.50 | 18.10 | 1.902 | 0.538 | 0.043 | 0.50-0.58 | 0.946 | +A |
| Male form II | 46 | 20.60 (9.26) | 5.20 | 47.70 | 8.60 (4.12) | 1.30 | 18.00 | 1.109 | 0.528 | 0.052 | 0.48-0.58 | 0.950 | +A |
| Female | 104 | 17.05 (7.42) | 4.50 | 36.90 | 7.83 (7.52) | 0.51 | 35.28 | 1.202 | 0.631 | 0.078 | 0.55-0.71 | 0.903 | +A |
| Juveniles | 97 | 5.07 (2.76) | 1.34 | 12.64 | 2.14 (1.15) | 0.56 | 5.62 | 0.980 | 0.361 | 0.033 | 0.33-0.39 | 0.984 | -A |
| Total | 298 | 11.15 (6.36) | 1.23 | 24.97 | 11.04 (6.16) | 1.20 | 26.97 | 1.235 | 0.389 | 0.010 | 0.38-0.40 | 0.970 | +A |

lengths and width increased in a positive allometric rate with CL for both adult genders and sexual stages (Table 2). In addition, chelae length-weight relationships were positively correlated with gender and sexual states (Table 2). Although the slope and intercepts of regressions for ChL and ChW were similar for form I and form II males, the slope and intercepts of regression of females were not significantly different from form I male and form II male (ANCOVA, $P > 0.05$).

## DISCUSSION

The relative growth between the sexes differs only slightly as indicated by morphometric relationships. A positive allometry of all body relationships observed in both sexes and sexual phases reflects the decreasing growth rate of these morphological characters in relation to CL.

Studies focused on length-weight relationships in captive held individuals show that sexual dimorphism is common in freshwater crayfish species (Lindqvist & Lahti 1983; Holdich 2001; Mazlum et al. 2007; Wang et al. 2011). Differences in sexual dimorphism are a function of the rapid disproportionate growth of chelae in male compared to female genders. Differences in body size among sex and sexual stage was consistent with those reported in other studies (Stein 1976; Romaire et al. 1977; Rhodes & Holdich 1984; Garvey & Stein 1993; Mazlum et al. 2007; Wang et al. 2011). Juvenile crayfish grew at a negative allometric rate and rapidly attained adult sizes.

The relative growth rate of the abdomen in males form I and form II was not statistically significant; however, females were significantly different from males (ANCOVA $p > 0.001$). This is attributed to a sex-related variation (Wetzel 2002). Variation in abdomen width is commonly found in freshwater crayfish, but is always related to sex, sexual maturity, and size (Wetzel 2002). Widening of female abdomen width (ABW) reflects a sexually active female that is correlated with either swollen or white glair, dependent offspring, or remnants of egg stalks attached to pleopods (Wetzel 2002). Wetzel (2002) found that only form I females mated with form I males and reinforced the view that wide abdomens are a reflection of the act of mating and rearing offspring. Reasons for female variation may include presence of ovigerous stages of ova development, instar development during the prolonged period of recruitment, and larval growth (Wetzel 2002). Only a small portion of the *O. virilis* females are reproductively active and exhibit the widened ABW.

In this study, the length-weight relationships showed that the largest individual females were heavier than individual males of the same length (Figure 2). The largest male (51.29 mm CL) was shorter and lighter (34.84 g) than the longest female (54.13 mm) weighing 35.28 g. No statistical difference in mean weight was observed; however, this is attributed to the accelerated development of the chelae in sexually mature form I males, whereas chelae of females grow slowly throughout life. The relatively longer chelae of form I and form II males are due to sexually dimorphic change. In summary, *O. virilis* exhibits chelae dimorphism typical of many crayfish species with form I male attaining the largest size, but differs from other crayfish by attaining large body size and weight. With this baseline understanding, further comparative studies of native crayfish species that experience displacement by *O. virilis* may be undertaken and potential competitive advantages elucidated in native and introduced range.

## ACKNOWLEDGMENTS

The authors wish to express their appreciation to the staff and professionals associated with the Indiana Biological Survey, Aquatic Research Center, Bloomington, for field assistance and for professional courtesies. A list of materials used in this study is available from the corresponding author.

## LITERATURE CITED

Ahern, D., J. England & A. Ellis. 2008. The virile crayfish, *Orconectes virilis* (Hagen, 1870) (Crustacea: Decapoda: Cambaridae), identified in the UK. Aquatic Invasions 1:102–104.

Bouchard, R.W. 1976. Geography and Ecology of Crayfishes of the Cumberland Plateau and Cumberland Mountains, Kentucky, Virginia, Tennessee, Georgia and Alabama, Part I: The Genera *Procambarus* and *Orconectes*. Pp. 563–584. *In* Freshwater Crayfish. (J.W. Avaolt, Jr., Ed.) Louisiana State University Division of Continuing Education, Baton Rouge, Louisiana.

Compos, G.E. & S. Contreras-Balderas. 1985. First record of *Orconectes virilis* (Hagen) (Decapoda,-Cambaridae) from Mexico. Crustaceana 49: 218–219.

Crocker, D.W. 1979. The crayfishes of New England. Proceedings of the Biological Society of Washington 92:225–253.

Dorn, N.J. & G.G. Mittlebach. 2004. Effects of a native crayfish (*Orconectes virilis*) on the reproductive success and nesting behavior of sunfish (*Lepomis* spp.). Canadian Journal of Fisheries and Aquatic Sciences 61:2135–2143.

Faxon, W. 1914. Notes on the Crayfishes in the United States National Museum and the Museum of Comparative Zoology with descriptions of new species and subspecies to which is appended a catalogue of the known species and subspecies. Memoirs of the Museum of Comparative Zoology at Harvard College 40:351–427.

Garvey, J.E. & R.A. Stein. 1993. Evaluating how chela size influences the invasion potential of an introduced crayfish (*Orconectes rusticus*). American Midland Naturalist 129:172–181.

Hagen, H.A. 1870. Monograph of the North American Astacidae. Illustrated Catalogue of the Museum of Comparative Zoology at Harvard College 3:1–109.

Hamr, P. 2002. Orconectes. Pp.585–608. *In* Biology of Freshwater Crayfish. (D.M. Holdich, Ed.). Blackwell Science, Oxford, England.

Hobbs, H.H. & Jr. 1989. An illustrated checklist of the American Crayfishes (Decapoda: Astacidae, Cambaridae, and Parastacidae). Smithsonian Institution Press 480:1–236.

Holdich, D.M. 2001. Biology of Freshwater Crayfish. Wiley-Blackwell Publishing, Oxford, England. 512 pp.

Holthuis, L.B. 1962. The occurrence of the crayfish *Orconectes virilis* (Hagen, 1870) in Montana, USA (Decapoda, Macrura, Astacidae). Crustaceana 3: 246–247.

Johnson, J.E. 1986. Inventory of Utah crayfish with notes on current distribution. Great Basin Naturalist 46: 625–631.

Larsen, E.R., C.A. Busack, J.D. Anderson & J.D. Olden. 2010. Widespread distribution of the non-native northern crayfish (*Orconectes virilis*) in the Columbia River Basin. Northwest Science 84: 108–111.

Lindqvist, O.V. & E. Lahti. 1983. On the sexual dimorphism and condition index in the crayfish *Astacus astacus* L. in Finland. Freshwater Crayfish 5:3–11.

Lockwood, J.L., M.F. Hoopes & M.P. Marchetti. 2013. Invasion Ecology, 2nd ed. Wiley-Blackwell Publisher, Oxford, England. 466 pp.

Loughman, Z.J. & S.A. Welsh. 2010. Distribution and conservation standing of West Virginia crayfishes. Southeastern Naturalist 9 (Special Issue 3): 63–78

Loughman, Z.J. & T.P. Simon. 2011. Zoogeography, taxonomy, and conservation of West Virginia's

Ohio River floodplain crayfishes (Decapoda, Cambaridae). Zookeys 74:1–78.

Lovett, D.L. & D.L. Felder. 1989. Application of regression techniques to studies of relative growth in crustaceans. Journal of Crustacean Biology 9: 529–539.

McAlpine, D.F., A.H.E. McAlpine & A. Madden. 2007. Occurrence of the potentially invasive crayfish, *Orconectes virilis* (Decapoda, Cambaridae), in eastern New Brunswick, Canada. Crustaceana 80:509–511.

Mazlum, M., F. Can & A.G. Eversole. 2007. Morphometric relationship of length-weight and chelae length-width of eastern white river crayfish (*Procambarus acutus acutus*, Girard 1852), under culture conditions. Journal of Applied Ichthyology 23:616–620.

Meredith, W.G. & F.J. Schwartz. 1960. Maryland crayfishes. Maryland Department of Research and Education, Educational Series 46:1–32.

Moore, M.J., R. DiStefano & E.R. Larson. 2013. An assessment of life-history studies for USA and Canadian crayfishes: identifying biases and knowledge gaps to improve conservation and management. Freshwater Science 32:1276–1287.

Nielsen, L.A. & D.L. Johnson. 1983. Fisheries Techniques. American Fisheries Society, Bethesda, Maryland. 468 pp.

Riegel, J.A. 1959. The systematics and distribution of crayfishes in California. California Fish and Game 45:29–50.

Rhodes, C.P. & D.M. Holdich. 1984. Length-weight relationship, muscle production, and proximate composition of the freshwater crayfish *Austropotamobius pallipes* (Lereboullet). Aquaculture 37: 107–123.

Romaire, R.P., J.S. Forester & J.V. Avault. 1977. Length-weight relationships of two commercially important crayfishes of the genus *Procambarus*. Freshwater Crayfish 3:463–470.

Schwartz, F.J., R. Rubelmann & J. Allison. 1963. Ecological population expansion of the introduced crayfish, *Orconectes virilis*. Ohio Journal of Science 63:266–273.

Simon, T.P. 2004. Standard operating procedures for the collection and study of burrowing crayfish in Indiana. I. Methods for the collection of burrowing crayfish in streams and terrestrial habitats. Miscellaneous Papers of the Indiana Biological Survey Aquatic Research Center 2:1–18.

Smith, D.G. 1979. Variability of crayfish of the *Virilis* section (Cambaridae: *Orconectes*) introduced into New England and Eastern New York. American Midland Naturalist 102:338–391.

Sokal, R.R. & F.J. Rohlf. 1981. Biometrica. H. Blume Ediciones, Madrid, Spain. 832 pp.

Stein, R.A. 1976. Sexual dimorphism in crayfish chelae: functional significance linked to reproductive activities. Canadian Journal of Zoology 54: 220–227.

Wang, Q., J.X. Yang, G.Q. Zhou, Y.A. Zhu & H. Shan. 2011. Length-weight and chelae length-width relationships of the crayfish *Procambarus clarki* under culture conditions. Journal of Freshwater Ecology 26:287–294.

Wetzel, J.E. 2002. Form alternation of adult female crayfishes of the genus *Orconectes* (Decapoda: Cambaridae). American Midland Naturalist 147: 326–337.

Zar, J.H. 1984. Biostatistical Analysis, 2$^{nd}$ ed. Prentice Hall, Englewood Cliffs, California. 662 pp.

*Manuscript received 21 September 2014, revised 3 January 2015.*

2014. Proceedings of the Indiana Academy of Science 123(2):204–216

# 129TH ANNUAL ACADEMY MEETING[1]

## Presidential Address by Dale D. Edwards[2]

## "LET'S TALK SCIENCE—MITES OF FRESHWATER MOLLUSKS"

### ACADEMY MEETING WELCOME

Welcome to the 129th Annual Academy Meeting!

The Indiana Academy of Science has had the privilege of serving Indiana scientists from industry and academia, Indiana science educators, and Indiana graduate and undergraduate science students, as well as aspiring young future scientists and the Indiana general public since 1885. With the mission of promoting scientific research, diffusing scientific information, improving education in the sciences, and encouraging communication and cooperation between Indiana scientists, the Academy hosted its first Annual Academy Meeting in Indianapolis in 1885, at the Marion County Courthouse. From this historic, yet humble beginning a proud academy was built. There are many leading scientists in our membership, and many who have made the difference in science as we know it here in Indiana.

We have a wonderful Annual Meeting planned for you today, resulting in large part from the generosity of Eli Lilly and Company Foundation, the W.K. Kellogg Foundation, Subaru of America, and the White River State Park. Today, 160 of you, researchers from the State of Indiana, will be presenting science in both oral and poster presentations. Nationally recognized guest speakers Dr. James Bing, a Global Trait Introgression Leader at Dow AgroSciences, and Johannah Barry, President of the Galapagos Conservancy, will be adding to our science conversation. Hot topics will be delivered by those on the cutting edge of much of the conversation of those topics. Workshops will also be offered for your professional development, and for the first time this year, with the approval of the Department of Education, professional education credits will be granted for our Indiana science teachers participating in today's meeting. We are also very happy to have a handful of young high school science students with us today. I encourage you to take time to get to know these young people as they move about the meeting.

At our Luncheon today, in addition to hearing from our guest speaker Dr. Jim Bing, we will introduce our Academy leadership, welcome our new Academy Fellows, and applaud our 2014 Awardees. Immediately following lunch, our poster presenters will be standing aside their posters in Grand Ballroom 1-4 to talk with you about their research. Though their posters will be up for you to view all day, we will be dedicating our attention to their presentations from 2:00 to 3:10 p.m. We are also truly looking forward to hearing Johannah Barry's Plenary Address this afternoon, regarding the ongoing conservation efforts in the Galapagos Islands.

Following Ms. Barry's Plenary, we will hold a brief, but very important Academy Membership Meeting. At this meeting, we will hear from our Section leadership who will be meeting with you this morning (check for the room number of your section meeting in the program book). We will also take a few minutes to vote on recommended adjustments to our Bylaws, and welcome in the incoming Academy President, and the newly elected officers and committee members, who will officially take on their new responsibility June 1. Be sure to join us for desserts, soft drinks, coffee, tea, wine, and beer to wrap up our meeting this year.

Earlier this year, Delores Brown, Executive Director of the Academy, thought it would be a good idea to reinstate an old tradition at the annual meeting. One in which the Academy President opened the meeting by talking about science. In this case, she asked if I would be willing to talk about my research. I thought it was a great idea and was happy to oblige. So without further ado, let's talk science!

### MITES OF FRESHWATER MOLLUSKS

What I want to do this morning is give you an overview of some research that I have

---

[1] J.W. Marriott, Indianapolis, IN, 15 March 2014.

[2] University of Evansville, Department of Biology Evansville, IN 47722; 812-488-2645 (phone), de3@evansville.edu.

been doing for the past twenty years or so involving the ecology and evolution of water mites of the genus *Unionicola* that live in symbiotic association with freshwater mussels and snails.

The primary objectives of this talk are as follows: 1) to put the genus *Unionicola* into taxonomic perspective; 2) to provide you with a general life cycle of these water mites; 3) to characterize the precise nature of the symbiotic association between these mites and their molluscan hosts; 4) to discuss some of my behavioral research involving *Unionicola* mites and how these studies have changed our perception about what it means to be a species in the context of these mites; 5) to provide you with a framework regarding the phylogenetic systematics and biogeography of *Unionicola* mites; and 6) to leave you with insights regarding future directions of my research program involving these mites.

## PUTTING *UNIONICOLA* MITES INTO TAXONOMIC PERSPECTIVE

Mites, or taxonomically speaking the Acari, represent a diverse and variable group of arthropods. Three major lineages or superorders of mites are currently recognized: Opilioacariformes, Parasitiformes, and Acariformes. The Acariformes (the mite-like mites) contains over 300 families and over 30,000 described species. Two major lineages of Acariformes are recognized, the Sarcoptiformes (Oribatida and Astigmata) and Trombidiformes (Prostigmata). The Trombidiformes represents a diverse assemblage of mites. The largest and most spectacular lineage within Trombidiformes is Parasitengona, with over 7000 described species of terrestrial and aquatic mites. Mites belonging to several unrelated groups are commonly found in freshwater habitats. However, the true water mites (Acariformes: Trombiformes: Parasitengona) or Hydrachnida (= Hydrachnellae, Hydracarina, and Hydrachnidia) represent a series of extensive adaptive radiations occurring mostly in freshwater habitats. Well over 5000 species of water mites are recognized worldwide, representing more than 300 genera and subgenera in over 100 families and subfamilies.

Water mites of the genus *Unionicola* (Acari: Hydrachnida: Unionicolidae) represent a diverse collection of more than 250 species in some 57 subgenera (Edwards & Vidrine 2013) distributed in freshwater habitats around the world. More than half of the described species are symbionts of freshwater mussels and snails. Indeed, the Latin name *Unionicola* literally means 'living within mussels'—since 'cola' or 'icola' mean 'to live within' and 'unio' is a name for mussels.

## *UNIONICOLA* LIFE CYCLE

The life cycle of water mites is complex and includes the egg, larva, protonymph, deutonymph, tritonymph, and adult. Larvae, deutonymphs, and adults are motile, whereas protonymphs and tritonymphs are quiescent, transformational stages of the life cycle. The adults and deutonymphs of most water mite species are free-living predators. However, there are species from the Pionidae and Unionicolidae that are symbiotic with freshwater gastropods, mussels, and sponges (Mitchell 1955). Although some species of *Unionicola* are free-living predators as nymphs and adults and depend on hosts only for sites of oviposition and post-larval resting stages, most species are obligate symbionts of their hosts. Among those species living within mollusks, the females deposit eggs in specific tissues (gills or mantle or foot) of the hosts, with larvae emerging in late spring and summer. The larvae of most water mites parasitize aquatic insects and in so doing acquire nutrition for larval development and a primary mechanism for dispersal. Larval mites of the genus *Unionicola* utilize chironomids and generally locate these insect hosts during the pupal phase of development (Fig. 1), but the mechanisms of host location are not well understood. The larvae eventually reinvade a host mussel, embed in host tissue, and enter a transformational stage from which the sexually immature nymph emerges (Fig. 1). The nymph subsequently enters a transformational stage from which the sexually mature adult emerges.

## NATURE OF THE SYMBIOTIC ASSOCIATION BETWEEN *UNIONICOLA* MITES AND MOLLUSKS

Although *Unionicola* mollusk mites have been traditionally recognized as parasites, there is little known about the nutritional dependence of these mites on their hosts or the impact that unionicolids may have on the hosts with which they are associated. Baker (1976, 1977) provided evidence that *U. intermedia* from *Anodonta anatina* is capable of piercing

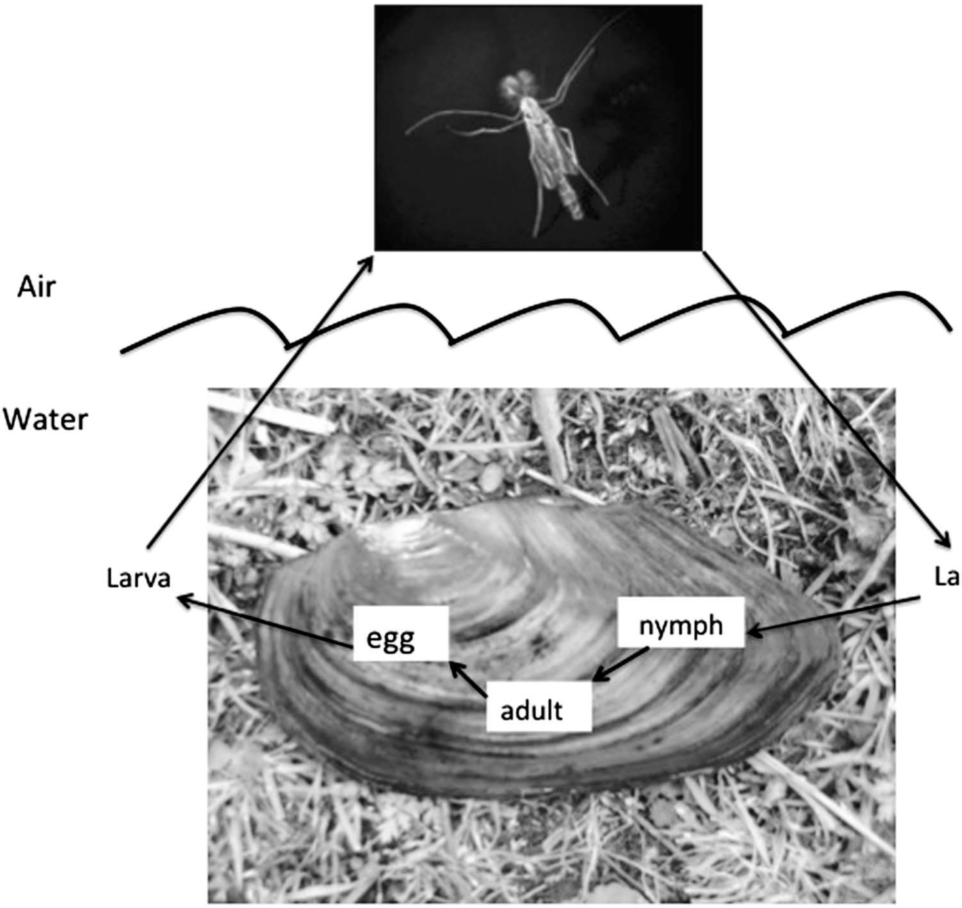


Figure 1.—Generalized life cycle of *Unionicola*.

the gills of host mussels with their pedipalps, allowing them to feed on hemolymph and mucus. Extensive infiltration of hemocytes into the damaged regions of the host's tissue may provide these mites with an additional nutritional source (Baker 1976). Observations by LaRochelle & Dimock (1981) of *U. foili* from *Utterbackia imbecillis* indicated that these mites would occasionally penetrate the gills of their host using their pedipalps. However, histological examination of the midgut of these animals could not definitely conclude that they were feeding on host tissues. More recently (Fisher et al. 2000) used both histochemical approaches and immunological assays to confirm that *U. formosa,* a sibling species of *U. foili,* does indeed ingest mucus and hemolymph from its mussel host, *Pyganodon cataracta*.

Although it is becoming increasingly apparent that *Unionicola* mollusk mites are utilizing host mucus, gill tissue, or hemolymph for at least part of their nutrition, the effects that these mites have on a host has not yet been examined in any detail. Laboratory experiments by MacArthur (1989) indicated that long-term exposure of *P. cataracta* to *U. formosa* did not significantly alter the host's shell morphology and composition, or soft-tissue mass and biochemical composition. In addition, there was no evidence that short-term exposure of *P. cataracta* to these mites significantly altered their ability to move water or filter particles.

## THE POPULATION BIOLOGY OF ADULT MITES

**A polygynous mating system.**—One of the main reasons I became interested in studying *Unionicola* mites was because of their peculiar population structure. While examining the population dynamics of *U. foili* (formerly identified as *U. formosa*) from the mussel *Utterbackia imbecilis*, my PhD advisor, Ron Dimock, discovered that the density (number of mites/mussel) of female mites was positively correlated with host size. Male *U. foili* were, on the other hand, under dispersed among their hosts, with most mussels harboring a single male. This drastic difference in the density of male and female mites was reported for every month of the year, with the mean sex ratio during a two-year study period being close to 30 females:1 male (Dimock 1985).

The persistent female-biased sex ratio reported by my advisor, fit together with other work (Dimock 1983, Edwards & Dimock 1991) indicating that male mites are territorial and aggressive to other males. The behavior by males was characterized as being consistent with those of a female-defense polygynous mating system. Although a female-biased sex ratio appears to be typical for many species of *Unionicola* (Mitchell 1965; Davids 1973; Baker 1987), there is little known about the impact of this population structure on the reproductive biology of *Unionicola* mollusk mites. Because fertilization among these mites most likely occurs within the confines of a host mussel (Hevers 1978), then establishing and maintaining this territory would dramatically increase a male's reproductive success. Unfortunately, we know next to nothing regarding the structure (e.g., can resident males successfully inseminate all females residing inside the mantle cavity of a host mussel?) and dynamics (e.g., how often are males displaced by other males during the mating season?) of the mating system for *Unionicola* mollusk mites, making further comments about male mating success speculative at best (Edwards et al. 2004).

**Behavioral specificity.**—Symbiotic relationships between *Unionicola* mites and their molluscan hosts are characterized by a diversity of host-influenced behaviors by the mites (Dimock 1988). The first experiments to examine and document these behaviors in some detail were performed by Welsh (1930, 1931). Welsh's (1930) paper reported that the mite *U. ypsilophora* (probably *U. formosa*) was positively phototactic in the absence of any chemical influence of its host mussel, *Anodonta* (now *Pyganodon*) *cataracta,* but exhibited negative phototaxis when tested in water containing extract of host gill tissue or in water from the mantle cavity of the host. Since the pioneering work of Welsh (1930, 1931), other studies have found that the response to light by several additional species of unionicolid mites is influenced by the chemistry of the water in which they were examined (e.g., mites are positively phototactic when tested in water that is free of any chemical influence from a host, but in the presence of extracts from its host, the sign of their response reverses to negative; Roberts et al. 1978).

Host-specific behavior by *Unionicola* mussel mites is also evident from studies examining the recolonization of mussel hosts. For example, when either *U. formosa* (from the mussel *Pyganodon cataracta*) or its sibling species *U. foili* (from the mussel *Utterbackia imbecillis*) are removed from a mussel and presented with a choice between *P. cataracta* and *U. imbecillis,* I found that adult mites would preferentially reenter the host species from which they had initially been collected (Edwards 1988). The mechanisms by which *Unionicola* mussel mites discriminate among host mussels are not known. The behavioral studies of LaRochelle & Dimock (1981) and Werner (1983) emphasize the role of contact chemoreceptors in mediating host recognition. However, the findings of LaRochelle & Dimock (1981) and the fact that the induction of mite negative phototaxis can occur in water modified by mussels clearly suggest that it can be mediated by distance chemoreception as well.

Although most studies regarding the specificity of the host recognition behavior of *Unionicola* mussel mites have involved adults, there have been few attempts to characterize the behavioral specificity during other stages (nymphal and larval) of the life cycle. Because it is the larvae that initiate an association with a host mussel (Fig. 1), characterizing the behavior of this stage of the life cycle was critical in documenting the nature of host specificity of these mites. When I examined the behavior of larval *U. foili* from *Utterbackia imbecillis* and *U. formosa* from *Pyganodon cataracta,* (what was then thought to be one species of mite from two different species of host mussels), I found that they preferentially responded to chemical signals from their respective host mussels, but the pattern of their responses changed during larval ontogeny (Edwards & Dimock 1995). For example, larvae emerging from *U. imbecillis* that had completed their parasitic phase with chironomids (what I referred to as post-chironomid larvae) exhibited negative phototaxis only in the presence of water that had been modified by *U. imbecillis.* The host-influenced behavior exhibited by these larvae was absent among mite larvae prior to parasitizing chironomids (what I referred to as pre-chironomid larvae). The changes in the behavior of pre-chironomid and post-chironomid larvae probably reflected major differences in the life history strategies of these developmental stages. For example, post-chironomid larvae represent the invasive stage of the mussel-mite symbiosis. A preferential response to a host chemical factor would, therefore, be expected, especially if it increased the likelihood of locating a host.

**Cryptic species of molluscan symbionts.**—I was intrigued by the specificity of host discrimination behavior by larval mites between the host mussels *U. imbecillis* and *P. cataracta,* because these findings, coupled to the fact that fertilization among these mussel-mites occurs only within the confines of a host mussel (Hevers 1978), suggested that specific behavioral responses to mussels could maintain reproductive isolation between mites occurring with different host species. An examination of the genetic structure of populations of mites from *U. imbecillis* and *P. cataracta* using allozyme electrophoresis (Edwards & Dimock 1997) revealed a high degree of genetic differentiation between these host-associated populations, including mites from the two species of hosts being fixed for different alleles at three loci. Edwards & Dimock (1997) concluded that mites from these two species of mussels were reproductively isolated and thus constituted good biological species. Mites from *P. cataracta* were recognized as *U. formosa* sensu stricto, whereas mites from *U. imbecillis* were identified as a new sibling species, *U. foili.* Since this work was published, genetic studies in my lab, including allozyme analysis (Edwards et al. 1998, Edwards & Labhart 2000) and DNA sequence comparisons (Ernsting et al. 2006, Ernsting et al. 2008), have been helpful in delineating additional species of *Unionicola* that were, on the basis of traditional anatomical criteria, morphologically indistinguishable.

Interestingly, North American *Unionicola* mussels-mites are known to exhibit highly variable patterns of host specificity, with some species occurring in association with a long list of host species and others utilizing one or at most a few species of hosts (Edwards & Vidrine 2006). An examination of both interspecific and intraspecific genetic diversity among host-associated populations of these mites undoubtedly will play a valuable role in testing hypotheses about current species designations and potentially uncover sibling species of *Unionicola* mussel-mites. Results of some recent molecular genetic work in my laboratory are beginning to bear witness to the predication. A comparison of partial COI sequences between host-associated populations of *U. hoesei*, a mite that is known to occur in association with many species of host mussels throughout North America, has revealed a high degree of genetic differentiation. Moreover, these differences are within range of the genetic differentiation that has been observed among previously recognized sibling species of *Unionicola*, including those in which morphological differences among species are relatively minor (Ernsting et al. 2008) and those that appear to be morphologically indistinguishable (Ernsting et al. 2006). The discovery of cryptic species of *Unionicola* mites based on molecular sequence data has obvious implications regarding estimates of biodiversity within this taxon. A failure to recognize cryptic species among unionicolid mites would also have important implications for anyone trying to unravel the nature of co-evolutionary relationships among *Unionicola* mites and their hosts.

## A PHYLOGENETIC BLANK SLATE

Our understanding of the evolutionary relationships among *Unionicola* water mites is limited and has largely been derived from morphology-based classifications among members that comprise the group. For example, Vidrine (1996) and Wu et al. (2009) suggested that sponge-associated mites of the subgenus *Hexatax* (formerly *Unionicola*) represent the least-derived taxon within the genus. Morphologically, these mites closely resemble species of free-swimming mites from the genus *Neumania* (Unionicolidae: Piontacinae). Vidrine (1996) subsequently identified 20 groupings of *Unionicola* subgenera based on sets of shared morphological and life-history characters. Despite these rather broad assessments of unionicolid systematics, the evolutionary history of the genus has not been adequately tested using phylogenetic approaches.

A number of recent studies have attempted to reconstruct evolutionary relationships among a limited number of mussel-mite taxa based on morphological characteristics (Edwards & Vidrine 2006, Wu et al. 2009) and molecular data sets (Edwards et al. 2010, Wu et al. 2012). The topologies of trees generated by these analyses are congruent in that they suggest that mites that live in the gills of host mussels (= gill mites) are monophyletic. This hypothesis is consistent with that of Vidrine et al. (2007) who suggested a shared evolutionary history among the gill mites based upon a number of anatomical similarities. These studies, however, have revealed conflicting hypotheses regarding relationships among *Unionicola* mites that live in the mantle and foot area of host mussels (= mantle mites). While morphologically-based trees recognize mantle mites as a distinct monophyletic grouping (Edwards & Vidrine 2006), molecular phylogenies suggest that these mites are part of a paraphyletic grade that includes gill mite taxa (Edwards et al. 2010). Thus, although the gill mites represent a monophyletic clade (Edwards & Vidrine 2006, Vidrine et al. 2007, Wu et al. 2009, Edwards et al. 2010), the relationship between gill mites and other species of *Unionicola* remains unclear. The mantle mites appear to be a conglomerate of diverse taxa at the subgeneric level, with some subgenera having morphological affiliations with sponge mites, and others sharing morphological similarities with gill mites (Vidrine 1996, Edwards et al. 2010).

One major caveat of this previous work is that both the morphological and molecular phylogenetic studies were limited in their geographical scope (e.g., limited to one continent) and in their sampling of taxa. Furthermore, the trees generated by these studies were based on a relatively small number of characters. For example, the morphologically-based phylogeny of Edwards & Vidrine (2006) was constructed using 32 characters. The gene tree generated by my colleagues and I (Edwards et al., 2010) was based on 664 bp from the cytochrome oxidase subunit I gene. Clearly, a more robust phylogenetic hypothesis of the genus *Unionicola* would require broader taxon sampling (both in terms of geographic distribution and sample size) and the incorporation of a substantially larger number of characters into the analysis.

A phylogenetic analysis of *Unionicola* mites based on molecular sequence data would undoubtedly be the best approach to resolving evolutionary relationships among taxa that comprise the genus. There are, however, at least two compelling reasons why generating a molecular phylogeny for the group could be problematic and thus warrant reconstructing the evolution history among these mites based on morphological data. First, many of the mollusk mites that have been identified and described were collected long ago and would be difficult to relocate primarily due to host extinction and habitat destruction. Second, holotypes and representative paratypes of described species have been preserved in solutions that have invariably damaged the quality and integrity of their DNA. In short, a phylogenetic analysis of *Unionicola* mites based on non-molecular data would presumably allow for greater taxon sampling.

Addressing evolutionary relationships among *Unionicola* mites based on morphological criteria is not without its challenges, given that so few characters historically have been used to diagnose the genus and its subgenera (Cook 1974). Moreover, a cursory glance at the taxonomic studies involving *Unionicola* mites suggests that a limited number of characters are available for phylogenetic inference. Despite the apparent pitfalls of using morphological data to reconstruct the phylogeny of unionicolid mites, Malcolm Vidrine, a colleague of mine from Louisiana, and I revisited the taxonomic literature for the group and generated 158 characters that could be used to estimate evolutionary relationships among most of the currently named subgenera that comprise the genus, including relationships between free-swimming taxa and those that have adopted symbiotic lifestyles (Edwards & Vidrine 2013). We subsequently identified 139 characters that could be used to reassess and potentially resolve conflicting hypotheses regarding the phylogeny of *Unionicola* mites that occur in association with mollusks (molluscan gill mites and mantle mites).

A tree based on the Bayesian inference of morphological data for *Unionicola* mites (e.g., representative species from 53 subgenera that comprise the genus) is presented in Fig. 2. The Bayesian tree suggests that most of the free-swimming *Unionicola* subgenera are a distinct radiation (see node labeled A). Although the tree recognizes multiple clades of free-

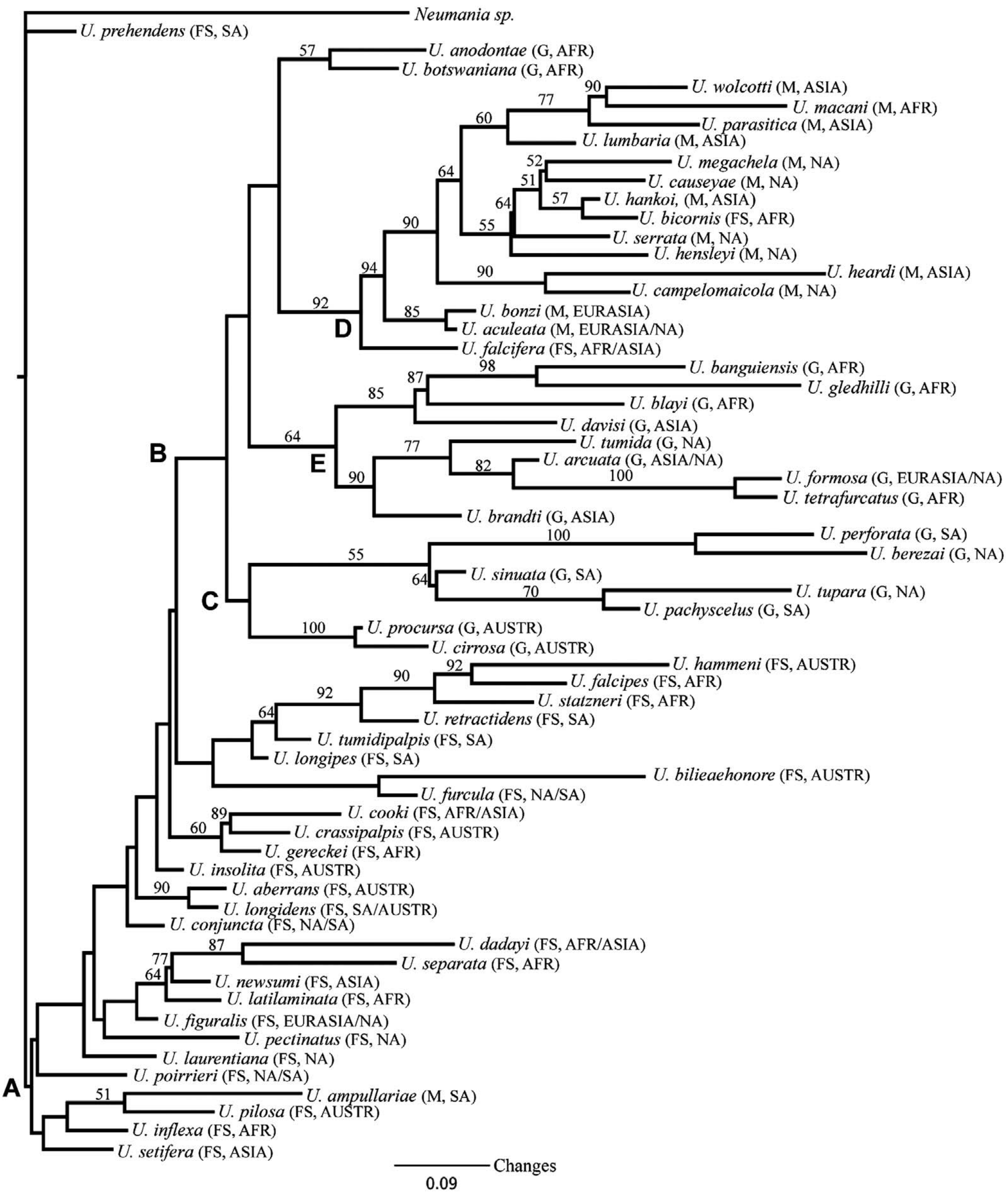


Figure 2.—Bayesian tree based on 158 morphological characters for representative species from 53 subgenera of *Unionicola* mites. Numbers above branches represent posterior probability values. Letters indicate notable clades: A=free-swimming mites; B=Mollusk mites; C=Australian, South American, and North American gill mites; D=mantle mites; E=African, Eurasian, and North American gill mites. Abbreviations in parentheses: FS=free-swimming mites; G=gill mites; M=mantle mites; NA=North America; SA=South America; AFR=Africa; AUSTR=Australia.

swimming mites, there appears to be no distinct relationship between the taxa that comprise these clades and their geographic distributions. The tree also shows several lineages of free-swimming mites forming a basal grade with molluscan mites. Mollusk mites appear to represent a monophyletic grouping (see node labeled B) and are divided into two major clades, with Australian gill mite subgenera along with gill mites from South America and

North America forming one clade (see node labeled C) and *Unionicola* mantle mites (see node labeled D) and gill mites from Africa, Eurasia, and North America forming the other (see node labeled E). Two species of gill mites (*U. anodontae* and *U. botswaniana*) from the subgenus *Iridinicola* appear to be sister taxa to the mantle mites. This latter group of mites appears to represent a more derived lineage within the genus.

The tree that resulted from the Bayesian phylogenetic analysis of the morphological data for *Unionicola* mollusk mites (e.g., representative species from 30 subgenera) is presented in Fig. 3. Based on the typology of this tree, the Australian gill mites are a separate clade (see node labeled A) from a large monophyletic grouping that includes the world's remaining gill mites along with all of the mantle mites (see node labeled B). Within this larger clade, there is a branch that includes gill mites from North and South America (see node labeled C). Another well-supported monophyletic grouping within the larger mollusk mite branch is one that is formed by African and Laurasian gill mites along with the mantle mites (see node labeled D). This mollusk mite tree, like the tree generated for *Unionicola* subgenera, supports a sister group relationship between mantle mites (see node labeled E) and African and Laurasian gill mites (see node labeled F). The mollusk mite tree has been reproduced with the subgeneric designations of the species used to generate the tree being shown in parentheses (Edwards & Vidrine 2013). With few exceptions, species that have been taxonomically assigned to the same subgenus form distinct clades.

There are some consistencies in the general patterns depicted by both the *Unionicola* and mollusk mite trees. For example, the typologies of these trees suggest that the mollusk mites represent a monophyletic clade. In addition, they suggest that the mantle mites are a sister taxon to the African and Eurasian gill mites. A close affinity between mantle mites and gill mites was also indicated by Edwards et al. (2010) in their paper assessing evolutionary relationships among molluscan-mite subgenera of North America. Furthermore, the phylogenetic hypothesis for the *Unionicola* mollusk mites, especially the gill mites, appears to dovetail our present understanding of the diversification of these mites. The Australian mites are thought to represent the least derived group of gill mites and these mites are the first clade to branch in the proposed tree for mollusk mite taxa. In the mollusk mite tree the South American and North American gill mites form a distinct clade from a monophyletic grouping that includes African gill mites and mantle mites. These groupings are consistent with the hypothesis that mites on the South American and African continents represent early radiations of *Unionicola* from an ancestral stock occurring in Australia that occurred in Pangaea prior to its break-up. Mites from the subgenus *Unionicolides* occur in both the South American and North American continents and their occurrence in North America appears to represent a secondary radiation that coincides with the diverse radiation of their host mussels on this continent. Mites from the subgenus *Prasadatax* from India appear to have characteristics that are shared by African gill mites and many of the mite subgenera from Eurasia. These African and Eurasian mites occur largely as a distinct clade in the mollusk mite tree. Not surprisingly, three subgenera (*Dimockatax, Unionicola,* and *Wolcottatax*) that occur both in Eurasia and North America form a monophyletic grouping. Vidrine (1986) has previously argued that mites from these North American subgenera represent descendant lineages from the Eurasian continent.

It is important to note that the morphological trees generated for the *Unionicola* subgenera and the mollusk mites should be viewed as working hypotheses. We are now in a position to collect sequence data for a broad array of taxa from specific regions of these trees to test the validity of the proposed relationships. To this end, an initial first step might be to sample and examine relationships among the globally distributed, highly speciose, monophyletic clade of mollusk mites. Future studies could expand on these research findings through a comprehensive assessment of the evolutionary history among the closely related *Unionicola* free-swimming mites.

## RESOLVING *UNIONICOLA* PHYLOGENY USING GENOME-LEVEL CHARACTERS

In an approach that is complementary to morphological and sequence-based molecular phylogeny, my lab has begun to sequence the mitochondrial genomes of *Unionicola* mites in an effort to assess the potential contributions of genome-level rearrangements and other unique events toward phylogenetic reconstruction

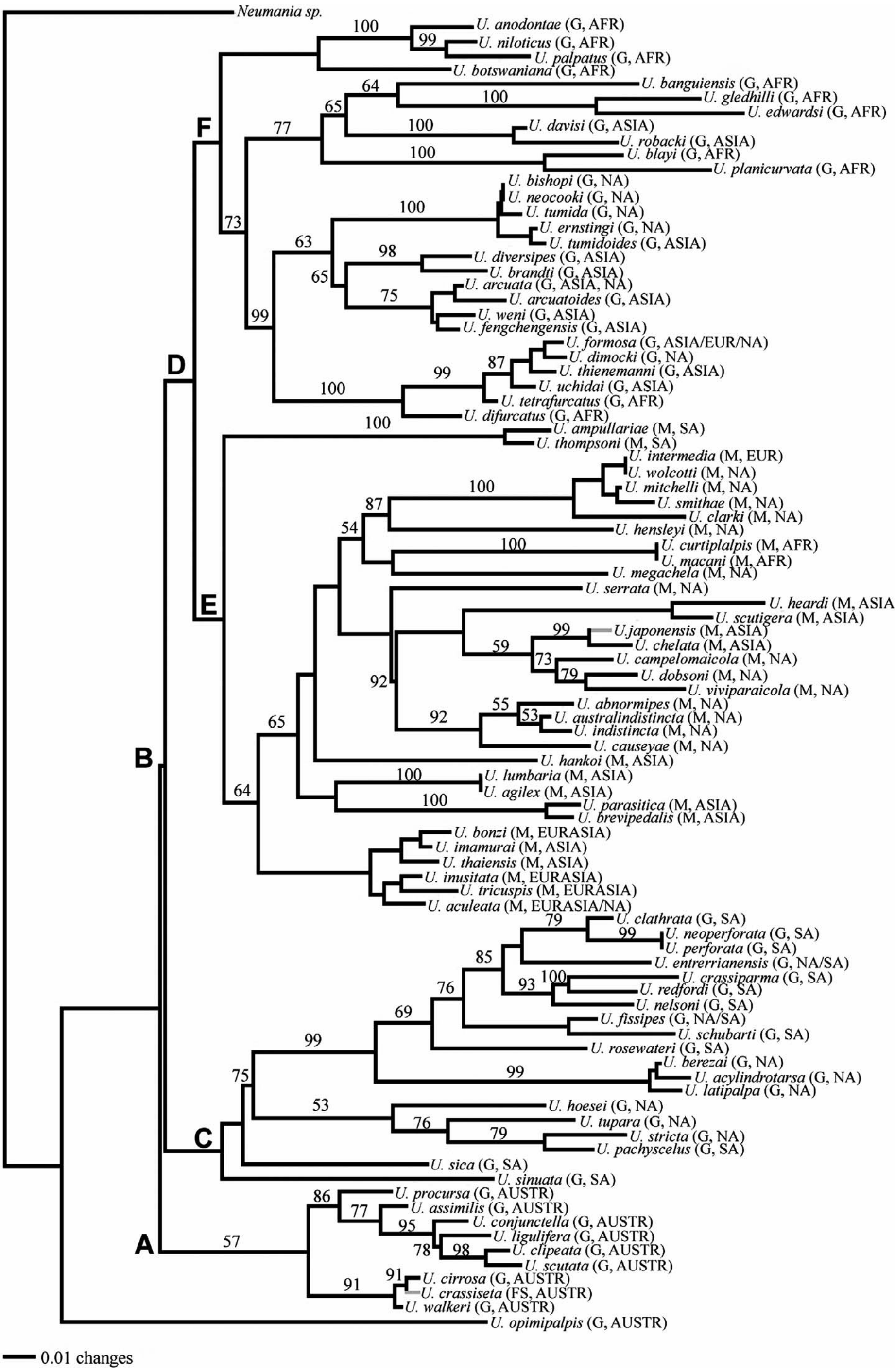


Figure 3.—Bayesian tree based on 139 morphological characters for representative species from 30 subgenera of *Unionicola* mollusk mites. Numbers above branches represent posterior probability values. Letters indicate notable clades: A=Australian gill mites; B=gill mites, excluding those from Australia and mantle mites; C=gill mites from North and South America; D=African and Laurasian gill mites along with the mantle mites; E=mantle mites; F=African and Laurasian gill mites. Abbreviations in parentheses: G=gill mites; M=mantle mites; FS=free-swimming mites; AFR=Africa; AUSTR=Australia; EUR= Europe; NA=North America; SA=South America.

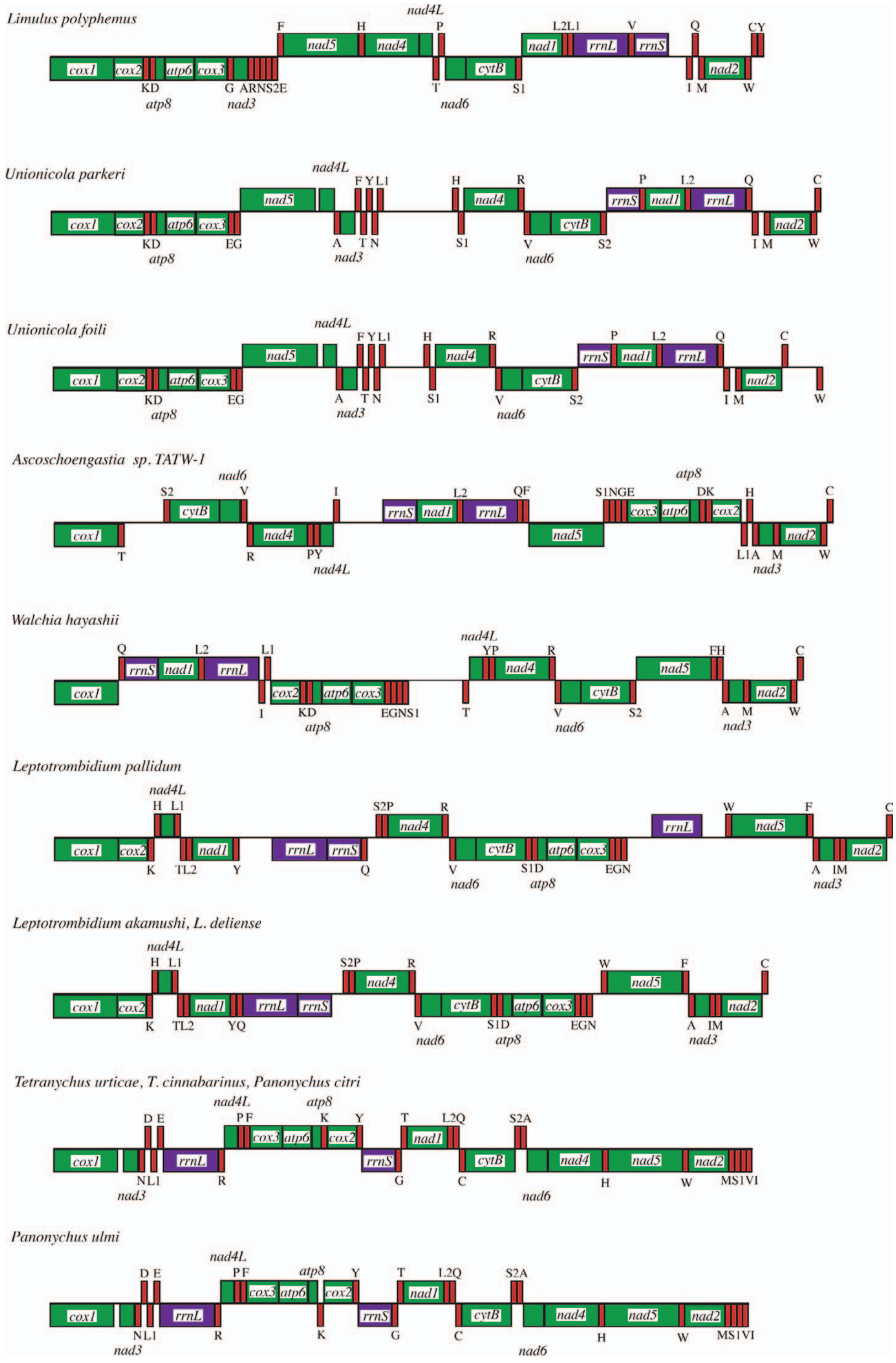


Figure 4.—Comparison of the mitochondrial genome structures of Trombidiformes mites and the horseshoe crab *Limulus polyphemus*. Green: protein-coding genes, red: tRNA genes, purple: rRNA genes. Circular genome sequences were linearized at the 5' end of the cox1 gene. Genes transcribed in the same direction as cox1 (left to right) are shown below the line, and genes transcribed in the opposite direction are shown above the line. For protein-coding and rRNA genes, the gene names are shown either in the rectangle or above or below the line. For tRNA genes, gene names are abbreviated with the single-letter abbreviation for the amino acid specified. (Modified from Edwards et al. 2011.)

among *Unionicola* mites. As a first step to this approach, the complete mitochondrial genomes of two species of *Unionicola* gill mites, *Unionicola foili* (subgenus *Unionicola*; Ernsting et al. 2009) and *U. parkeri* (subgenus *Unionicolides*; Edwards et al. 2011), have been sequenced. The annotation of these mitochondrial genomes indicated unique gene orders, highly rearranged in comparison to other Trombidiformes mites (Fig. 4). Moreover, a comparison of the mitochondrial genome sequence between *U. foili* and *U. parkeri* revealed genome-level synapomorphies, including tRNA rearrangements, a significantly longer long noncoding region between tRNAs for *U. parkeri,* and differences in reading frames between species mitochondrial genes (Edwards et al. 2011). Overall, the differences in genome structure between relatively closely-related *Unionicola* underscore the potential for molecular synapomorphies to be phylogenetically informative within the genus.

## FUTURE DIRECTIONS

Resolving the evolutionary history of *Unionicola* mollusk mites will provide us with countless avenues for future research. For example, a robust phylogeny of *Unionicola* mollusk mites could be examined in the context of the phylogenetic history of their host mussels. A comparison of the evolutionary relationships between mollusk mites and their host mussels would present an ideal opportunity to address not only the degree to which their phylogenies are congruent, but to understand the mechanisms responsible for mediating those patterns, including the effects of dispersal capacity by mites (Downes 1989), competitive exclusion (Davids et al. 1988), and behavioral specificity (Edwards & Dimock 1995). Also, once general patterns of host utilization by symbiotic species have been elucidated, and the relationship of these mites to free-swimming species has been reconstructed, we can begin to address the ecological and evolutionary processes responsible for patterns of host association, at both the regional scale (emphasizing the importance of contemporary ecological factors) and over broad geographical areas (emphasizing the importance of historical biogeography).

## ACKNOWLEDGMENTS

There are many people that I would like to thank with regards to my research program involving *Unionicola* mites over the past twenty years. I am grateful to Malcolm Vidrine, Professor of Biology, Louisiana State University at Eunice, for his taxonomic expertise regarding these mites. As the ancient Chinese proverb tells us, "The beginning of wisdom is to call things by their right names." I also want to thank Brian Ernsting, Professor of Biology, University of Evansville, for his assistance with molecular protocols and the analysis of molecular sequence data. Finally, I am deeply indebted to countless scores of students who dedicated significant portions of their undergraduate lives to work on this obscure group of mites. Much of the research reported in this talk was supported by grants from the Indiana Academy of Sciences and UExplore, an undergraduate research program at the University of Evansville.

## LITERATURE CITED

Baker, R.A. 1976. Tissue damage and leukocytic infiltration following attachment of the mite *Unionicola intermedia* to the gills of the bivalve mollusc *Anodonta anatina*. Journal of Invertebrate Pathology 27:371–376.

Baker, R.A. 1977. Nutrition of the mite *Unionicola intermedia* Koenike and its relationship to the inflammatory response induced in its molluscan host *Anodonta anatina*. Parasitology 75:301–308.

Baker, R.A. 1987. Aspects of the life history of *Unionicola ypsilophora* (Bonz 1783). Naturalist 112:53–58.

Cook, D.R. 1974. Water Mite Genera and Subgenera. Memoirs of the American Entomological Institute 211–860, Ann Arbor, Michigan.

Davids, C. 1973. The relations between mites of the genus *Unionicola* and the mussels *Anodonta* and *Unio*. Hydrobiologia 41:37–44.

Davids, C., J. Holtslag & R.V. Dimock, Jr. 1988. Competitive exclusion, harem behaviour and host specificity of the water mite *Unionicola ypsilophora* (Hydrachnellae, Acari) inhabiting *Anodonta cygnea* (Unionidae). Internationale Revue der gesamten Hydrobiologie 73:651–657.

Dimock, Jr., R.V. 1983. In defense of the harem: intraspecific aggression by male water mites (Acari: Unionicolidae). Annals of the Entomological Society of America 76: 463–465.

Dimock, Jr., R.V. 1985. Population dynamics of *Unionicola formosa* (Acari: Unionicolidae), a water mite with a harem. American Midland Naturalist 114:168–179.

Dimock, Jr., R.V. 1988. Photobiology and behavior of the water mite genus *Unionicola*: a minireview. Comparative Biochemistry and Physiology 91:193–197.

Downes, B.J. 1989. Host specificity, host location and dispersal: experimental conclusions from freshwater mites (*Unionicola* spp.) parasitizing unionid mussels. Parasitology 98:189–196.

Edwards, D.D. 1988. The population biology of *Unionicola formosa* from two anodontine mussels in a North Carolina farm pond. M. S. Thesis. Wake Forest University, Winston-Salem, North Carolina. 72 pp.

Edwards, D.D. & R.V. Dimock, Jr. 1991. The relative importance of size versus territorial residency in intraspecific aggression by symbiotic male water mites (Acari: Unionicolidae). Experimental and Applied Acarology 12:61–65.

Edwards, D.D. & R.V. Dimock, Jr. 1995. Specificity of the host recognition behavior of larval *Unionicola* (Acari: Unionicolidae): the effects of larval ontogeny and early larval experience. Animal Behavior 50:343–352.

Edwards, D.D. & R.V. Dimock, Jr. 1997. Genetic differentiation between *Unionicola formosa* and *U. foili* (Acari: Unionicolidae): cryptic species of molluscan symbionts. Invertebrate Biology 116:124–133.

Edwards, D.D. & M. Labhart. 2000. Genetic differences among host-associated populations of water mites (Acari: Unionicolidae: *Unionicola*): allozyme variation supports morphological differentiation. Journal of Parasitology 86:1008–1011.

Edwards, D.D. & M.F. Vidrine. 2006. Host specificity among *Unionicola* spp. (Acari: Unionicolidae) parasitizing freshwater mussels. Journal of Parasitology 92:977–983.

Edwards, D.D. & M.F. Vidrine. 2013. Mites of Freshwater Mollusks. Malcolm F. Vidrine, Eunice, Louisiana. 336 pp.

Edwards, D.D., R. Bogardus & N. Wilhite. 1998. Geographic Differences in Host Specialization between the Symbiotic Water Mites *Unionicola formosa* and *U. foili* (Acari: Unionicolidae). Pp. 195–206. *In* Ecology and Evolution of the Acari. (J. Briun, L. van der Geest and M.W. Sabelis, Eds.), Kluwer Academic Publishers, Dordrecht, The Netherlands.

Edwards, D.D., D.E. Deatherage & B.R. Ernsting. 2004. Random amplified polymorphic DNA analysis of kinship within host-associated populations of the symbiotic water mite *Unionicola foili* (Acari: Unionicolidae). Experimental and Applied Acarology 34:67–77.

Edwards, D.D., M.F. Vidrine & B.R. Ernsting. 2010. Phylogenetic relationships among *Unionicola* (Acari: Unionicolidae) mussel-mites of North America based on mitochondrial cytochrome oxidase I sequences. Zootaxa 2537:47–57.

Edwards, D.D., L.E. Jackson, A.J. Johnson & B.R. Ernsting. 2011. Mitochondrial genome sequence of *Unionicola parkeri* (Acari: Trombidiformes: Unionicolidae): molecular synapomorphies between closely-related *Unionicola* gill mites. Experimental and Applied Acarology 54:105–117.

Ernsting, B.R., D.D. Edwards, M.F. Vidrine, K.S. Myers & C.M. Harmon. 2006. Phylogenetic Relationships among species of the subgenus *Parasitatax* (Acari: Unionicolidae: *Unionicola*) based on DNA sequence of the mitochondrial cytochrome oxidase I gene. International Journal of Acarology 32:195–202.

Ernsting, B.R., D.D. Edwards, M.F. Vidrine & H. Cun. 2008. Genetic differences among sibling species of the subgenus *Dimockatax* (Acari: Unionicolidae: *Unionicola*): heterogeneity in DNA sequence data supports morphological differentiation. International Journal of Acarology 34:403–407.

Ernsting, B.R., D.D. Edwards, K.J. Aldred, J.S. Fites & C.R. Neff. 2009. Mitochondrial genome sequence of *Unionicola foili* (Acari: Unionicolidae): a unique gene order with implications for phylogenetic inference. Experimental and Applied Acarology 49:305–316.

Fisher, G.R., R.V. Dimock, Jr. & R.E. Kuhn. 2000. The symbiotic water mite *Unionicola formosa* (Acari: Unionicolidae) ingests mucus and tissue of its molluscan host. Journal of Parasitology 86:1254–1258.

Hevers, J. 1978. Interspezifische Beziehungen zwischen *Unionicola*-Larven (Hydrachnellae, Acari) und Chironomidae (Diptera, Insecta). Verhandlungen Gesellschraft für Oekologie 7:211–217.

LaRochelle, P. & R.V. Dimock, Jr. 1981. Behavioral aspects of host recognition by the symbiotic water mite *Unionicola formosa* (Acarina, Unionicolidae). Oecologia 48:257–259.

MacArthur, R.D., Jr. 1989. Morphometric and physiological assessment of the effects of the symbiont, *Unionicola formosa,* on its molluscan host, *Andonta cataracta*. M. S. Thesis. Wake Forest University, Winston-Salem, North Carolina. 72 pp.

Mitchell, R. 1955. Anatomy, life history, and evolution of the mites parasites fresh-water mussels. Miscellaneous Publications Museum of Zoology, University of Michigan No. 89:1–28.

Mitchell, R. 1965. Population regulation of a water mite parasitic on unionid mussels Journal of Parasitology 51:990–996.

Roberts, E., R. Dimock, Jr. & R. Forward, Jr. 1978. Positive and host-induced phototaxis of the symbiotic water mite *Unionicola formosa*. Biological Bulletin 155:599–607.

Vidrine, M.F. 1986. Five new species in the subgenus *Parasitatax* (Acari: Unionicolidae: *Unionicola*) from North America and Asia, with a re-evaluation of related species. International Journal of Acarology 12:141–153.

Vidrine, M.F. 1996. North American *Najadicola* and *Unionicola*: Systematics and Coevolution. Gail Q. Vidrine Collectables, Eunice, Louisiana. 146 pp.

Vidrine, M.F., A.E. Bogan & S.R. Hazelton-Robichaux. 2007. Re-evaluation of Australian and South American *Unionicola* Haldeman (Acari: Unionicolidae). International Journal of Acarology 33:49–52.

Welsh, J. 1930. Reversal of phototrophism in a parasitic water mite. Biological Bulletin 59:165–169.

Welsh, J. 1931. Specific influence of the host on the light responses of parasitic water mites. Biological Bulletin 61:497–499.

Werner, W.E. 1983. Discrimination of potential molluscan hosts by the symbiotic water mite *Unionicola formosa*. M.A. Thesis, Wake Forest University, Winston-Salem, North Carolina. 43 pp.

Wu, H., B. Hu, Z. Zhu & C. Wen. 2009. Cladistic analysis on the genus *Unionicola* (Acari: Unionicolidae) from China. Entomotaxonomia 31: 152–160.

Wu, H., C. Wen & W. Guo. 2012. Sequence variation of the mitochondrial 12S rRNA gene among *Unionicola (Wolcottatax) arcuata* (Acari: Unionicolidae) from freshwater mussels in China. International Journal of Acarology 38:394–401.

Dale D. Edwards, PhD, 2013-2014 Indiana Academy of Science President. Dale D. Edwards is a professor of biology at the University of Evansville. He earned his B.S. in zoology at Brandon University in Canada, and later completed his M.S. and Ph.D. degrees in biology at Wake Forest University. He is broadly interested in ecology and evolution of organisms with symbiotic lifestyles, and has spent that past 27 years studying the evolutionary ecology of Unionicola mites that live in association with freshwater mussels. His research involving these mites has addressed issues regarding patterns of host specificity, the genetic structure among host-associated populations, patterns of species richness, and the effects that the ectoparasitic larval stages have on their insect hosts, including their potential role in influencing host survival and reproduction. He has also had a keen interest in Unionicola systematics, and has worked in collaboration with Brian Ernsting (University of Evansville) and Malcolm Vidrine (Louisiana State University at Eunice) to address phylogenetic relationships among unionicolid mussel-mites, using both morphological and molecular approaches. He is the author of 25 peer-reviewed scientific publications, and one book titled “Mites of Freshwater Mollusks.”

2014. Proceedings of the Indiana Academy of Science 123(2):217–218

# MINUTES OF THE BUSINESS MEETING
# SATURDAY, MARCH 15, 2014
# JW MARRIOTT, INDIANAPOLIS

The meeting was called to order at 5:11 pm

President **Dale Edwards** called for Section Reports

Anthropology: **(Charity Upson-Taboas)**
Good turnout. Problem with website information regarding presentations, especially times. A vice chair may be needed.

Botany: **(Darrin Rubino)**
Darrin had to leave prior to the Business meeting and asked Mike Foos to report that Darrin would be the chair of the Botany Section next year. We had a good meeting and expressed no concerns.

Cell Biology: **(Sarah Mordan McCombs)**
Considering a joint meeting with Micro and Molecular Biology. Good turnout. Sarah will be chair next year.

Chemistry: **(Jessica Thomas)**
Will use a flyer to reach out to non-members. Want to coordinate with the Cell Biology and the Micro and Molecular Biology Sections.

Earth Science: **(Darrell Schulze)**
Darrell will be chair next year. Gerry Guentie will be vice chair. OK with name change of Environmental Quality to Environmental Science. Suggested non-members should be able to present without joining.

Ecology: **(Robert Chapman)**
Good turnout. No input about awards. No issues with change for Environmental Quality to Environmental Science. Get bulletin out sooner. Next year Sammy Davis will be chair.

Engineering: **(Terry West)**
No report

Environmental Quality: **(Michael Guebert)**
No report

Micro and Molecular Biology: **(Elizabeth Rueschhoff)**
Perhaps plan new awards for undergrad and grad presentation. Could not find pages with section information. Add Section pages to web. David Trevis will be vice chair.

Physics and Astronomy: **(Horia Petrache)**
New chair; 30 attendees. Low attendance for Section meeting; perhaps have hot topic in Section.

Plant Systematics and Biodiversity: **(Nick Harby)**
Great meeting. Marcia Moore will chair next year, Scott Namestnik will be vice chair. Web had details on BioBlitz.

Science Education: **(Steve Kristoff)**
Small but friendly meeting. Looking for papers on “what works.” Scott Rahschulte will be chair next year.

Zoology and Entomology: **(Brad Poteat)**
Andy Ammons will chair next year. Good posters. Schedules should be available earlier.

Expand areas where meetings can be held. Academy would be more appealing if DNR or others were to participate.

Bylaws changes approved by Council and brought to the membership for a vote are listed below. Additions are in bold; deletions struck through. A vote was taken and the bylaw changes passed as a group by voice vote.

1. Current with proposed changes:

Article VIII, § 4, No. 8. The **Science and Society Committee** shall be composed of ~~three~~ **a maximum of four** members: the Executive Director, who shall serve as chair, and ~~two~~ **a maximum of three** members appointed by the President.….

New bylaw:

Article VIII, § 4, No. 8. The **Science and Society Committee** shall be composed of a maximum of four members: the Executive Director, who shall serve as chair, and a maximum of three members appointed by the President.….

2. Current with proposed changes:

Article VIII, § 4, No. 4. The **Finance Committee** shall be composed of three members **and the Treasurer as *ex officio* without vote** who shall audit The Academy's financial records annually.

New bylaw:

Article VIII, § 4, No. 4. The **Finance Committee** shall be composed of three members and the Treasurer as *ex officio* without vote who shall audit The Academy's financial records annually.

3. Current with proposed changes:

Article VIII, § 3, No. 2. The **Research Grants Committee** shall consist of six members, elected for three-year rotating terms, and may stand for reelection. The Secretary shall serve as an *ex-officio* member, but without vote. **The past chair shall serve in a non-reading, non-voting, *ex-officio* status for one year after termination of the elected term, if the term ends while member is chair.**

New bylaw:

Article VIII, § 3, No. 2. The **Research Grants Committee** shall consist of six members, elected for three-year rotating terms, and may stand for reelection. The Secretary shall serve as an *ex-officio* member, but without vote. The past chair shall serve in a non-reading, non-voting, *ex-officio* status for one year after termination of the elected term, if the term ends while member is chair.

4. Current with proposed changes:

Article III, § 2, No. 5. **Emeritus Member** - A member, who is 65 years of age or over, is retired, and has been **an active** member of The Academy for ~~25~~ **15** years or more.

New bylaw:

Article III, § 2, No. 5. **Emeritus Member** - A member, who is 65 years of age or over, is retired, and has been an active member of The Academy for 15 years or more.

5. Current with proposed changes:

Article III, § 2, No. 9. **Fellow** - A member for at least five years with recognized standing as a scientist, who has contributed to the objectives of The Academy, ~~been recommended by a majority of the Council, and been approved by a majority of the members voting at the annual meeting~~.

New bylaw:

Article III, § 2, No. 9. **Fellow** - A member for at least five years with recognized standing as a scientist, who has contributed to the objectives of The Academy.

The following individuals were recognized and presented with the following awards at the luncheon session during the March 15, 2014 Academy meeting.

Fellows: **Alice Heikens, Luke Jacobus, Rex Strange**

Distinguished Scholar Award: **Paul Rothrock**

Distinguished Service Award: **Uwe Hansen**

**Dale Edwards** declared election of officers:

President-elect (2014-2015) - **Michael Homoya**

Treasurer (2014-2017) - **Edward Frazier**

Council Member at Large (2014-2016) - **Alice Long Heikens**; Academy Foundation Committee (2014-2017) - **Clare Chatot**; Academy Foundation Committee (2014-2016) - **Wendell McBurney**; Research Grants Committee (2014-2017) - **Daniel Bauer**; Research

Grants Committee (2014-2017) - **Robert Sammelson**

President Edwards suggested that members sign up for Scientist Expert and that people go to BioBlitz.

Dale introduced **Arden Bement** as the incoming president.

Arden's comments:
Thanked Dale. Thanked Delores, especially for a particularly good meeting. Thanked the membership for the vote of confidence in the election. Having reviewed the history of the Academy, Arden was impressed with the organization. He has accepted the position with two charges in mind: to build membership and to assure a bright financial future. He will establish working teams to develop action plans in these two areas.

Meeting adjourned at 5:41 pm.

Respectfully submitted by **Michael Foos,** IAS Secretary

# INDIANA ACADEMY OF SCIENCE
## 2014 Year End Financial Report

| | Balance 1-Jan-2014 | Revenues | Expenses | Balance 31-Dec-2014 |
|---|---|---|---|---|
| OPERATING FUND | | | | |
| Dues | | 24,010.00 | | |
| Interest | | 91.16 | | |
| Misc. Income | | 1,007.94 | | |
| Contributions | | 1,300.00 | | |
| Annual Meeting | | 41,810.00 | | |
| Foundation Support | | 153,212.49 | | |
| Officer's Expenses | | | 132,897.30 | |
| Operating Expenses | | | 22,987.46 | |
| Financial Expenses | | | 3,033.60 | |
| Newsletter Expenses | | | 2,000.00 | |
| Annual Meeting | | | 58,719.09 | |
| Academy Store | | | 299.00 | |
| Web Site | | | 11,606.31 | |
| Operating Fund Total | 118,624.59 | 221,431.59 | 231,542.76 | 108,513.42 |
| RESTRICTED FUNDS | | | | |
| Proceedings | 14,465.06 | 12,730.68 | 12,703.68 | 14,492.06 |
| Publications | (41,747.20) | 8,964.34 | 16,509.38 | (49,292.24) |
| * Research Grants | 4,594.35 | 95,611.67 | 89,694.71 | 10,511.31 |
| Lilly Library | 6,756.47 | 0.00 | 0.00 | 6,756.47 |
| Welch Fund | 6,608.56 | 0.00 | 500.00 | 6,108.56 |
| Life Members Fund | 14,343.61 | 0.00 | 0.00 | 14,343.61 |
| Past Presidents Fund | 8,599.17 | 0.00 | 0.00 | 8,599.17 |
| Special Projects | 3,186.20 | 26,975.00 | 29,120.65 | 1,040.55 |
| Total Restricted Funds | 16,806.22 | 144,281.69 | 148,528.42 | 12,559.49 |
| **TOTAL FUNDS** | **135,430.81** | **365,713.28** | **380,071.18** | **121,072.91** |
| FUNDS ON DEPOSIT | | | | |
| Checking Account | 67,045.07 | 452,120.37 | 461,569.43 | 57,596.01 |
| Money Market Savings | 55,105.48 | 75,047.90 | 80,000.00 | 50,153.38 |
| Cert. of Deposit | 13,280.26 | 43.26 | 0.00 | 13,323.52 |
| **TOTAL FUNDS DEPOSITED** | **135,430.81** | **527,211.53** | **541,569.43** | **121,072.91** |

* Provided 27 senior member grants and 25 high school grants.

| | | | | |
|---|---|---|---|---|
| ACADEMY FOUNDATION FUNDS | | | | |
| **TOTAL FOUNDATION FUNDS** | **8,552,291.63** | | | **8,906,910.88** |

**Foundation Funded Used For:**

| | |
|---|---|
| Operating Fund | 153,212.49 |
| Proceedings | 12,703.68 |
| Grants | 89,611.17 |
| Special Projects | 26,975.00 |
| **Total** | **282,502.34** |

Edward L. Frazier
Treasurer