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First Occurrence of the Bankclimber *Plectomerus dombeyanus* (Valenciennes, 1827) (Mollusca: Unionidae) in Illinois

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ABSTRACT

Fresh-dead specimens of the freshwater mussel Bankclimber *Plectomerus dombeyanus* (Valenciennes, 1827) were discovered in the Illinois portion of the Ohio River near America, Pulaski County, Illinois, at river mile 970 (37.12104N, 89.11468W) during the summer of 2012. The specimens were deposited in the Illinois Natural History Survey Mollusk Collection, Champaign (INHS 42354 and INHS 42977). While reported from elsewhere in the Ohio River basin, these specimens represent the first time the species has been recorded in Illinois.

The Bankclimber *Plectomerus dombeyanus* (Valenciennes, 1827) is a freshwater mussel (Mollusca: Unionidae) that typically has a thick, rhomboidal shaped, moderately inflated shell and obtains lengths up to 150-mm (Parmalee and Bogan, 1998; Williams et al., 2008). Its periostracum is greenish brown to brown and darkens to black with age, and its nacre is usually deep purple (Parmalee and Bogan, 1998; Williams et al., 2008). *Plectomerus dombeyanus* has been described as a "mud-loving" species that "delights in sluggish flowing water" (Call, 1895). The animal inhabits medium to large rivers, oxbow lakes, and lowland ditches, and is found in clay, mud, sand or rocky substrates (Oesch, 1984; Williams et al., 2008). It occurs along channel margins in sluggish to moderate current, but can be found buried in steep slopes a considerable distance from the main channel (Oesch, 1984; Williams et al., 2008).

Plectomerus dombeyanus is commonly found in Gulf drainage streams from the Alabama River west to eastern Texas, including the lower Mississippi River to its confluence with the Ohio River (Parmalee and Bogan, 1998; Williams et al., 2008). The species was first reported from the Ohio River basin in 1981, when two live individuals were discovered in Kentucky Lake, Trigg County, Kentucky (Pharris et al., 1984). Since then, *P. dombeyanus* has expanded its range throughout the lake (Parmalee and Bogan, 1998; Cicerello and Schuster, 2003), and has been found downstream of the Kentucky Dam in the Tennessee River (JES pers. obs). The Bankclimber also has been collected at three locations in the Kentucky portion of the Ohio River mainstem: 1) in 1982, a relict specimen at river mile 944, near Paducah, McCracken County (Ron Cicerello, Kentucky State Nature Preserves Commission, retired, pers. comm.); 2) in 1996, a fresh-dead specimen at river mile 784, which is at its confluence with the Green River, Henderson County (Watters and Myers Flaute, 2010; Ohio State University Division of Molluscs, Columbus, Bivalve Collection #58992), and 3) in 2012, two live individuals at river mile 935 (Heidi Dunn, Ecological Specialists, Inc., pers. comm.). However, the animal has not been listed as part of Illinois' native mollusk fauna (e.g., Cummings, 1991; Cummings and Mayer, 1992; Cummings and Mayer, 1997; Tiemann et al., 2007) until now. One fresh-dead 48-mm specimen was discovered in the Ohio River at river mile 970 (37.12104N, 89.11468W) near America, Pulaski County, Illinois, on 27 June 2012 by JES (Figure 1). Another fresh-dead specimen (44-mm) was recorded from the

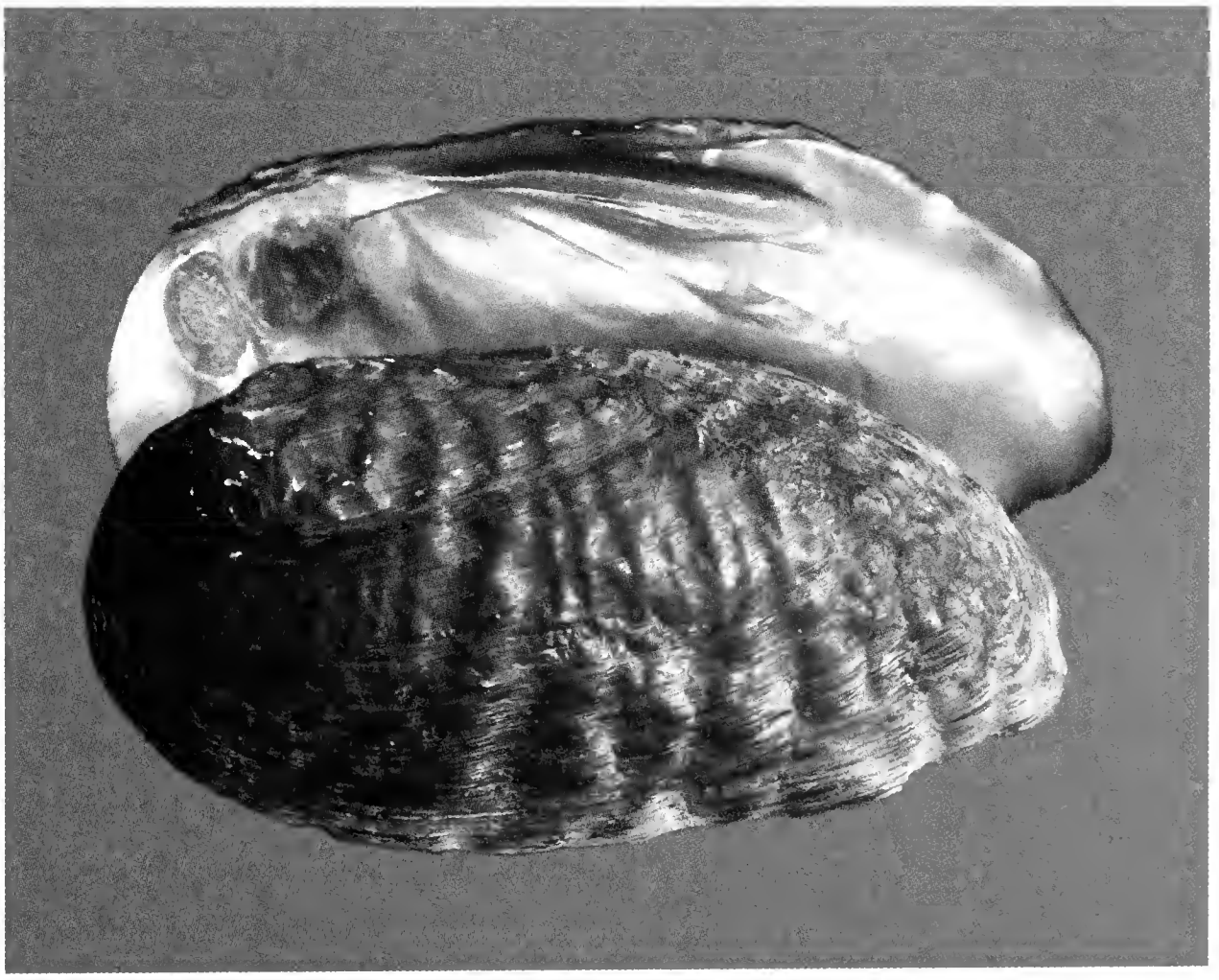

Figure 1. Bankclimber *Plectomerus dombeyanus* (INHS 42354) from the Ohio River at river mile 970 (37.12104N, 89.11468W) near America, Pulaski County, Illinois.

same site on 15 August 2012 by JST and KSC. These specimens represent the first time *P. dombeyanus* has been recorded in Illinois. The specimens were deposited in the Illinois Natural History Survey Mollusk Collection, Champaign (INHS 42354 and INHS 42977).

The means by which the animal is expanding its known range is unknown. Pharris et al. (1984) suggested that *P. dombeyanus* might be expanding its range by either artificial transportation (e.g., fish stockings) or as a result of habitat alterations from impoundment construction. The fish host for *P. dombeyanus* is unknown at this time. Pharris et al. (1984) also pointed out that their discovery of *P. dombeyanus* in the Tennessee River occurred before the Tennessee-Tombigbee connection occurred. Watters and Myers Flaute (2010) stated the Meyers Pool of the Ohio River probably represents the northernmost extent of the species. Given that the Ohio River is at the extreme northern limits of the species' range, and Williams et al. (1993) listed the species as currently stable throughout its range, we do not recommend *Plectomerus dombeyanus* for state-listing in Illinois.

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BOOK REVIEW - 2003 - #1

Book:
The Moon in the Nautilus Shell: Discordant Harmonies Reconsidered, From Climate Change to Species Extinction, How Life Persists in an Ever-Changing World by Dr. Daniel Botkin 449 pp. Oxford University Press, New York, NY, $22.12, ISBN 978-0-19-991391-6

Reviewer:
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REVIEW

Dan Botkin, the author of *The Moon and the Nautilus Shell*, is an ecologist whose iconoclastic ideas may make some environmentalists uncomfortable. Dr. Botkin has had a long career solving environmental problems. He helped to develop JABOWA, a very successful early computer-based forest growth simulation. He also has had close contact with the paleoecology community so he has a view of ecology on a geological time scale. He has written extensively on environmental topics working as a sort of "free-lance" environmental problem solver while based as a professor at UC Santa Barbara. *The Moon and the Nautilus Shell* is partly a memoir and partly a discussion of his ideas about nature and people's place in it.

Botkin's main argument is that the idea of "Balance of Nature" is not supported by science even though it is a commonly held paradigm among environmentalists. Some of the book is devoted to an academic discussion of the origins of the balance of nature paradigm and arguments against it. Botkin believes that equilibrium models of nature will ultimately fail because the earth is dynamic. Throughout geological history, life has responded to environmental change without any possibility of equilibrium. Botkin believes that there is no natural equilibrium but that life responds opportunistically to these changes. The logistic growth/carrying capacity model that we all learned in introductory ecology class is inadequate to describe nature. Even the landscape that the early American natural history explorers found was not in a natural equilibrium because it was managed by the people who were already living there. This realization presents a problem for ecological restoration. To what state should we restore a landscape if everything is always changing? Dr. Botkin argues for a paradigm shift from an equilibrium view of nature to a dynamic view.

A large portion of the book is devoted to a consideration of the impact of the dynamic view of nature on environmental management. The "Balance of Nature" model is deeply embedded in the environmental movement. Rachel Carson explicitly invoked the Balance of Nature in her two masterpieces, *The Sea Around Us* and *Silent Spring*. In *Silent Spring* she argues that the indiscriminant use of pesticides disturbs the balance of nature to the peril of humankind. Botkin believes that it is still important to protect the environment against human damage, but good data is important in environmental decision-making. Good data does not support a natural equilibrium. He has a great story of being called in to enhance salmon runs in Oregon and finding that no one had good counts of salmon in the important rivers. He cites numerous other examples where good data falsifies the application of equilibrium theory to environmental problems. He argues that the Balance of Nature is a soothing concept with no basis in fact and he provides many examples where equilibrium models failed to support good management decisions.

The controversial part of *The Moon and the Nautilus Shell* begins with Botkin's application of his theory to modern environmental problems. His consideration of global warming and its impacts will surprise many environmentalists. He believes that global warming is occurring, but is skeptical about whether it is human caused. As a computer modeler, he questions the projections of the global climatic models that are so important in predicting future climate change. He argues that a dynamic view of ecosystems suggests that living things have endured large climatic changes in the past without loss. The climatic warming at the Paleocene/Eocene Thermal Maximum (PETM) was as great as or greater than that predicted for our future. Also, at the end of the last glacial period, the Younger Dryas period was a 1,300 year long return to glacial climates. This period began and ended suddenly (probably in less than 100 years). However, both of these climatic changes occurred at times of large ecosystem change. The PETM resulted in increased speciation among mammals and caused extinctions of marine foraminifera. The close of the latest glacial age resulted in the extinction of many large mammals in North America. It is unclear whether this change resulted from human colonization of North America, from the climatic stress of the Younger Dryas or from both events acting together. This evidence from the paleoecological record would seem to suggest that Botkin is wrong about the impacts of global warming on living systems. However, his emphasis on the dynamism of earth's environment in contrast with a static equilibrium model is, I believe, correct.

Botkin argues that concern about mitigating global warming diverts our resources from more immediate problems. He explicitly mentions that he is not interested in overturning the advances of 50 years of environmentalism. He says that he does not mean to challenge Aldo Leopold's "Land Ethic." Environmentalism is still relevant. However Botkin says that we need to select among environmental issues and work on the ones that are solvable with current knowledge and methods. He also argues that, ultimately, solving the basic problems of the environment will allow us to meet the challenges of global warming. He lays out a series of problems that will resonate with environmentalists. He is most concerned about 1) sustaining the diversity of life on earth, 2) a sustained population of humans and 3) a continuation of human civilization. He provides a list of attainable goals which

include providing energy to society with the fewest negative effects, greatly reducing habitat destruction, and controlling invasive species. Dr. Botkin suggests that we can best solve these problems by abandoning an inappropriate faith in the balance of nature and equilibrium thinking and replacing it with a clear scientific understanding of the dynamism of nature.

In summary, *The Moon and the Nautilus Shell* is a thought provoking book that offers an alternative to the equilibrium thinking that dominates our ideas about nature. Dr. Botkin offers a rational alternative to the "Balance of Nature" that may be helpful in thinking about modern environmental problems. Some of his conclusions may disturb environmentalists but his theory is strongly supported by evidence. His ideas offer no less than a new direction for the environmental movement.

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Does Pollen Supply Limit Seed Set of *Baptisia bracteata*?

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ABSTRACT

Baptisia bracteata is a perennial legume native to tallgrass prairie that flowers early in the growth season and produces a relatively low seed set compared to a taller sympatric congener, *B. alba*. This study tested for evidence that *B. bracteata* is pollen limited. The study site was a reconstructed tallgrass prairie located in northeastern Illinois. Experimental treatments included a control, and two hand-pollination treatments, one where pollen transfer was limited to the same plant and the other where pollen was taken from other plants. Analysis of covariance (ANCOVA) was used to test the effect of treatment on two indicators of pollination success of a plant, i.e., arcsine √xi transformations of pods inflated/flower and seeds matured/flower. Log10(Flower count/plant +1) provided a covariate in both ANCOVAs, while likewise transformed counts of a seed predator, *Apion rostrum*, provided a second covariate to seeds matured/plant. Based on ANCOVA, pollination treatment did not affect the number of pods inflated/flower or seeds matured/flower. Flower count/plant showed a significant effect in both comparisons. *A. rostrum*, which synchronizes its life cycle to *B. alba*, did not affect seeds matured/flower of *B. bracteata*. Using Spearman Rank Correlation, flower count/plant was positively related to seeds matured/plant, indicating the importance of inflorescence size to seed set. Count of *A. rostrum*/plant was significantly correlated to pods inflated and seeds matured per plant. Factors not eliminated as affecting seed set of *B. bracteata* were resource limitations and pre-dispersal seed predation by *A. rostrum*.

INTRODUCTION

Environmental factors linked to low seed set include pollen limitation[pl], resource scarcities[rs], and pre-dispersal seed predation[sp] ([pl,sp]Cariveau et al., 2004; [pl]Coupland et al., 2005; [rs]Fulkerson et al., 2012; [pl,rs]Haig and Westoby, 1988; [pl, sp]Hainsworth et al., 1984; [sp]Langer and Rohde, 2005). Pollen supplies may be inadequate due to shortages or unreliability of pollinators particularly in extreme or highly disturbed environments like those in alpine, upper latitude (Fulkerson et al., 2012), fragmented (Holzschuh et al., 2012), or urban locations (Pellissier et al., 2012). Environmental factors causing low pollen supply may select for more apparent optical traits, such as a larger inflorescence, and more attractive floral scents. However, subsequent greater pollination success may result in seeds that a plant cannot support to maturity due to resource limits (Haig and Westoby, 1988) and the attraction of consumers (Adler and Theis, 2012; Ehrlen et al., 2012).

Baptisia bracteata Muhl. ex. Ell. (Cream Wild Indigo = *B. leucophaea*) is native to tallgrass prairie of the Midwest (Swink and Wilhelm 1994). The perennial legume produces a low seed set compared to its sympatric congener, *B. alba* (L.) Vent (White Wild Indigo = *B. leucantha*) (Haddock and Chaplin, 1982; Petersen and Wang, 2006). *B. bracteata* blooms during May, a month before *B. alba*, with little overlap in blooming period. Unlike the taller *B. alba* which can exceed 1m in height, *B. bracteata* rarely exceeds 0.3m. Each *B. bracteata* consists of subterranean rhizomes from which up to several dozen aerial shoots emerge to form a concentric cluster. Racemes bearing yellow flowers, arch outward from the cluster. Flowers last about 4 days, with 2 days spent in a staminate phase, followed by 2 days in a pistilate phase (Haddock and Chaplin, 1982). Self pollination can occur as pollinators, primarily *Bombus* spp., move down an indeterminate raceme. Pods inflate from pollinated flowers. Each pod bears an average of 18 to 19 ovules from which more than half can be expected to initiate seeds (Haddock and Chaplin, 1982; Petersen and Wang, 2006). Pod maturation is complete by August and seeds disperse as pods dehisce.

The cause of low seed output by *B. bracteata* compared to *B. alba* is unknown, but has been hypothesized to be explained by pollen scarcity (Haddock and Chaplin, 1982), limited resources, and avoidance of a seed predator (Haddock and Chaplin, 1982; Petersen and Wang, 2006). The objective of our study was to determine if *B. bracteata* is pollen limited by examining if hand-pollination could increase pollination success.

Complicating factors considered in the experiment were size of inflorescence and pre-dispersal seed predation. Plants with larger inflorescences are typically presumed to have the resources be able to produce a larger seed set, although this may not always be the case in light of pre-dispersal seed predators (Ohashi and Yahara, 2000). The major pre-dispersal seed predator in our study area located in northeastern Illinois, is *Apion rostrum* Say (Coleoptera: Apionidae). Overwintering weevils oviposit into pods as they inflate. The resulting larvae consume seeds as their only source of nutrition. The adult stage is reached by August, with the new generation of weevils dispersing as pods open.

METHODS

The study took place during 2012 in the 7.1 ha, reconstructed Russell Kirt Tallgrass Prairie located on the campus of College of DuPage, IL. The prairie plot, reconstructed beginning in 1984, is characterized by the grasses big bluestem (*Andropogon gerardii* Vitman), prairie dropseed (*Sporobolus heterolepis* Gray), and Indian grass (*Sorghastrum nutans* (L.) Nash), plus some 150 species of forbs to include *B. bracteata*. The prairie plot was burned during March of 2012 after a six-year period in which it was not burned.

A concentric cluster of *B. bracteata* was assumed to be one individual based on inspection of excavated *B. bracteata* not used in the experiment. Plants were selected randomly as they flowered during May. Flowers of plants in the control treatment

were not manipulated, while those of the other treatments were hand-pollinated using paint brushes. A "selfing" treatment involved introducing pollen to a stigma where pollen came from racemes of the same cluster, while in a "crossing" treatment, pollen was introduced from racemes of other clusters. These treatments did not limit pollen from contrary sources, but did permit examination of how supplemental pollination from a source could change pollination success. Hand pollination was repeated a week apart as to include flowers as they developed along indeterminate racemes. Due to the availability of individual *B. bracteata*, sample sizes were 18 for both a control and a selfing treatment, and 17 for a crossing treatment.

Counts taken were flowers/plant, pods inflated/plant, pods matured/plant, seeds matured/pod, and *A. rostrum*/pod. Counts of seeds matured/plant and *A. rostrum*/plant were pro-rated from the total number of ripe pods of a plant in the case when some ripe pods were damaged and contents could escape. Pollination success was quantified by pods inflated/flower and seeds matured/flower.

All statistical summarization was done using Statistica (Statsoft, 2001). Analysis of covariance (ANCOVA) was performed on pods inflated/flower (IP/F), with flower count/plant entered as covariate, and also on seeds matured/flower (S/F), with counts of flowers/plant and *A. rostrum*/plant as covariates. In the ANCOVA involving weevils, plants were eliminated from analysis if all ripened pods had holes from which weevils could have escaped prior to sampling. Prior to analyses, pods inflated/flower (IP/F) and seeds matured/flower (S/F) of a plant were arcsine $\sqrt{xi}$ transformed, and counts of flowers/plant were log10(x + 1) transformed to meet assumptions of parametric analysis (Zar, 1984). Counts of *A. rostrum*/plant also were $\log_{10}(x + 1)$ transformed, but remained skewed (1.114 among all treatments). Hence, parametric analysis involving weevil counts is possibly spurious because of this violation. Preliminary analyses involving IP/F and S/F indicated that the "pollination treatment X flower" interaction was not significant ($P = 0.758$) and that the "pollination treatment X flower count/plant X A. rostrum count/plant" interaction was not significant ($P = 0.649$), respectively, satisfying homogeneity of slopes.

Due to failure in meeting assumptions of parametric testing with plant counts of weevils and seeds, Spearman Rank Correlation was used to test for relationships between plant counts of flowers and seeds matured, *A. rostrum* and pods inflated, and *A. rostrum* and seeds matured. The first contrast provided insight if a particular size of inflorescence could have advantage in seed set, and the last two how components of reproductive yield may attract the weevil to *B. bracteata* plus the potential effect of weevil abundance on seed yield.

RESULTS

Table 1 summarizes data from pollination treatments. Pollination treatment had no effect on pods inflated/flower, and also seeds matured/flower, although in both cases, flower count/plant did (Tables 2 and 3). With the absence of a treatment effect, group data were pooled to illustrate the relationship of flower count/plant to seeds matured/plant (Figure 1). Plants with a larger inflorescence showed a higher seed output (rs = 0.489; df = 51; P<0.05). *A. rostrum* count/plant was positively related to inflated pod count/plant (rs = 0.679; df = 41; P<0.05) and seeds matured/plant (rs =

Table 1. Summary (sample mean ± standard error) of select reproductive parameters and weevil infestation according to treatment. Sample size = 18 unless noted otherwise by subscript.

Treatment Variable	Control	Selfing	Crossing
Flower count/plant	105.1 ± 32.8	97.9 ± 25.1	$61.9 \pm 21.7_{17}$
Pods inflated/plant	36.2 ± 12.4	47.1 ± 16.4	$34.3 \pm 19.4_{17}$
Pods inflated/flower count	0.39 ± 0.086	0.38 ± 0.07	$0.45 \pm 0.07_{17}$
Seeds matured/plant	44.9 ± 21.4	62.2 ± 30.0	$65.2 \pm 27.8_{17}$
Apion rostrum count/plant	$15.3 \pm 8.0_{15}$	$21.0 \pm 10.9_{13}$	$17.8 \pm 11.7_{15}$

Table 2. Results of ANCOVA showing the effects of pollination treatment (control, selfing, crossing) and flower count/plant on pods inflated/flower. Symbol: F = flower count.

Effect	df	MS	F	*P*
Log_{10}(F/plant +1)	1	22.19	129.03	<0.001
Pollination treatment	2	0.215	1.25	0.296
Error	50	0.172		
Model vs. SS Residual r^2	0.72			

Note: Univariate Tests of Significance for arcsine$\sqrt{}$pods inflated/flower; Sigma-restricted parameterization; Type III decomposition.

Table 3. Results of ANCOVA showing the effects of pollination treatment (control, selfing, crossing), flower count/plant, and weevil count/plant on seeds matured/flower. Symbols: F = flower count, A = *Apion rostrum* count.

Effect	df	MS	F	*P*
Log_{10}(F/plant +1)	1	5.38	21.91	<0.001
Log_{10}(A/plant + 1)	1	0.27	1.08	0.307
Pollination treatment	2	0.43	1.75	0.192
Error	28	0.25		
Model vs. SS Residual r^2	0.63			

Note: Univariate Tests of Significance for arcsine$\sqrt{}$pods inflated/flower; Sigma-restricted parameterization; Type III decomposition.

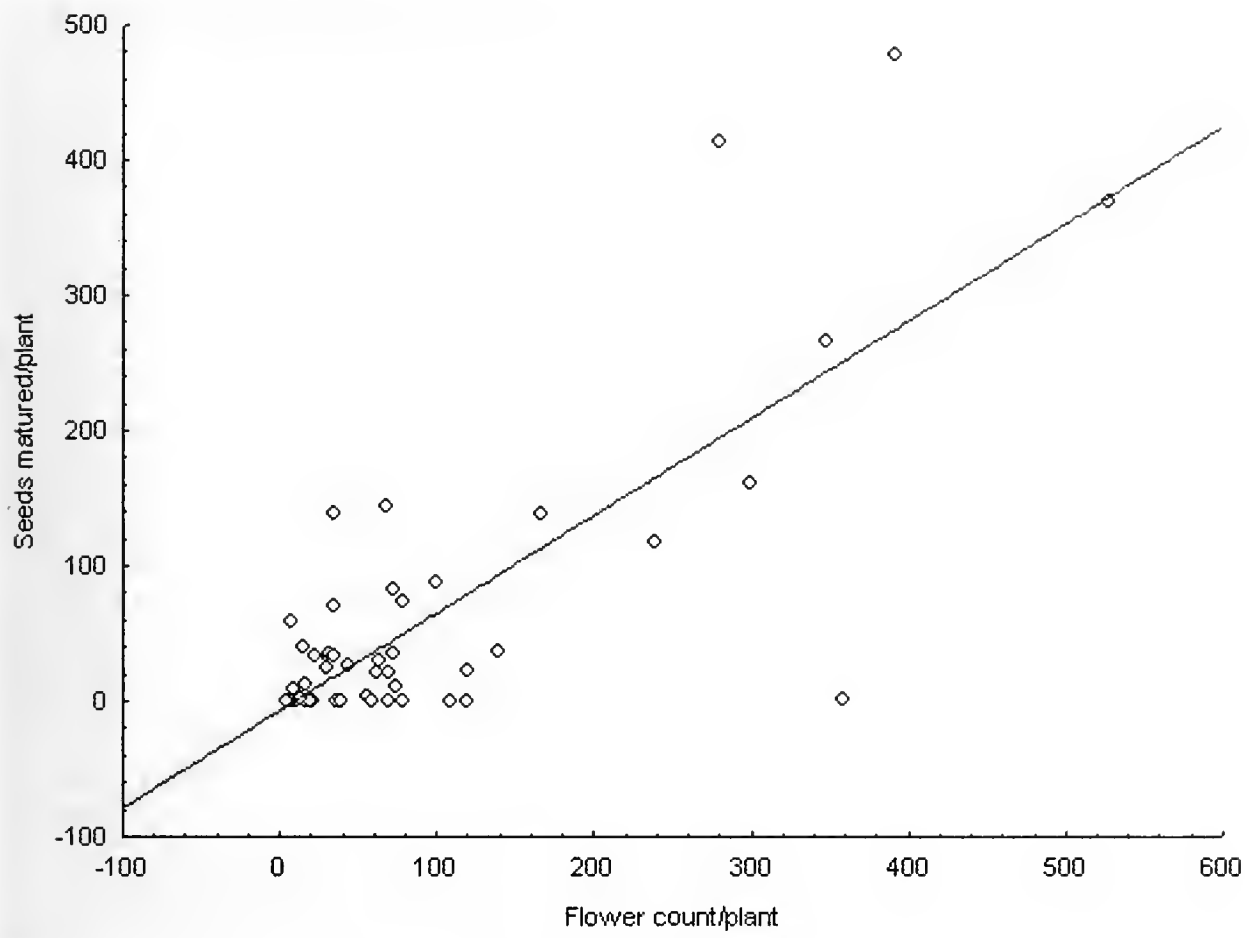

Figure 1. Scatter plot showing the relationship between counts of flowers/plant and seed matured/plant for *Baptisia bracteata*.

0.496; df = 41; P<0.05).

DISCUSSION

We did not find evidence that *B. bracteata* is pollen limited. Hand-pollination did not result in higher pod inflation/flower or seeds matured/flower. In view of the higher ovule to seed initiated ratio of *B. bracteata* found in an earlier study (Petersen and Wang, 2006), it is possible that seed set of the species is resource limited and cannot develop all pollinated ovules. Others have proposed that plants, in effect, bet hedge resource availability, where they produce more ovules during an average year than can be expected to develop into mature seeds (Burd et al., 2009; Fulkerson et al., 2012). Under occasional conditions of higher resource availability, these plants can mature more seeds. As our study only involved one season; any bet hedging could not be assessed.

Pre-dispersal seed predation has also been proposed to be a selective force that influences reproductive characteristics of plants including the timing of flowering (Elzinga et al., 2007; Kolb et al., 2007; Tsvuura et al., 2011). However, the earlier flowering time of *B. bracteata* compared to *B. alba*, unlikely would have deterred *A. rostrum* from synchronizing its lifecycle around the latter. The weevil appears quite adaptive to exploiting species of *Baptisia* around the Midwest and South (Evans et al., 1989; Horn and Hanula, 2004). The additive characteristic of lower seed set, whether explained genetically and/or by resource limitations, may enable *B. bracteata* to escape the brunt of seed predation. Hence, a divergent flowering period and initiating fewer seeds than *B. alba* may actually promote seed set of the cream wild indigo over time.

In our study, *A. rostrum* appeared attracted to *B. bracteata* based on the positive relationship of the weevil count/plant to inflated pod count/plant. More pods have the potential to produce more seeds, explaining the positive correlation of *A. rostrum* count to seeds matured/plant. However, the latter relationship was not negative as would be predicted if seed production was severe. Nonetheless, seed predation has been shown to be highly variable over time (Kolb et al., 2007), to include that by *A. rostrum* (Petersen et al., 2010), necessitating longer-termed study focusing on the relationship between *B. bracteata* and *B. alba*. High error values in the reproductive and weevil infestation measurements of *B. bracteata* (Table 1) may also reflect the small sample sizes available in our study. Future study should include larger populations of the *Baptisia* congeners to reduce errors that can affect statistical comparisons.

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The Effects of Tower Structure and Weather Conditions on Avian Mortality at Three Television Towers in Central Illinois

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ABSTRACT

Avian mortality has been documented at television towers and other constructed lighted structures for over 150 years, and it is estimated that 6.8 million birds are killed annually in the United States and Canada as a result of communication towers. Tower structure (lighting, height, and guy wires) and weather conditions (wind direction, cloud cover) play a large role in mortality rates. We examined the effects of tower structure and weather conditions on mortality at three television towers in central Illinois (WAND, WBUI, and WILL). Forty-three searches were conducted between August and November 2006-2009 with a total of 415 birds from 14 families found. Most birds found were of Family Parulidae (66%), Family Emberizidae (9%), and Family Turdidae (9%). The WILL tower accounted for 96% of the total birds killed. The high mortality observed at the WILL tower may be due to the tower's steady and flashing red lights as opposed to the flashing white lights on the WAND and WBUI towers. We found that more birds were killed following nights with winds from the north and ≥50% cloud cover. Most studies of tower collisions have focused on tower structure rather than weather conditions; however, the combination of tower lighting and weather may play a substantial role in avian mortality.

INTRODUCTION

Avian mortality associated with artificial lighting on human structures is thought to be a significant source of human-caused bird death (Evans 2007). The most recent mortality estimate at communication towers is 6.8 million birds per year in the United States and Canada; about 50% greater than the current estimate by the U.S. Fish and Wildlife Service (Longcore et al. 2012). Past studies have found that almost 95% of all birds that collide with lighted structures are neotropical migrants, particularly Family Parulidae (i.e. warblers; Longcore et al. 2013). The main factors associated with tower kills are tower structure (lighting, height, and guy wires) and weather conditions (Longcore et al. 2008; Gehring et al. 2009).

Artificial lighting affects the behavior of many plant and animal species, particularly at night (Rich and Longcore 2006). Species can be attracted to, or disoriented by, sources of artificial light through positive phototaxis (Verheijen 1985; Longcore and Rich 2004). This behavior in birds has been documented at communication towers for over 50 years as a result of the lighting systems required by the Federal Aviation Administration (FAA) (Gehring et al. 2009). Standard FAA lighting normally consists of a combination of steady and flashing red lights, although some towers use white lights instead. Previous studies have found that nocturnally migrating birds would fly around standard FAA lights of communication towers until the lights were turned off (Cochran and Graber 1958; Avery et al. 1977).

While the exact cause of this attraction is unknown, it is thought that migrating birds use both visual cues, such as stars, as well as an internal magnetic compass to navigate, and the artificial lighting somehow interferes with this (Gauthreaux and Belser 2006). For example, laboratory tests have suggested that the internal magnetic compass may be wavelength-dependent, with birds showing good orientation under white and green lights (Wiltschko and Wiltschko 1995) and disorientation under red light (Wiltschko et al. 1993).

In the presence of lighted towers, birds generally follow a circular, curvilinear flight pattern, and will continually circle around them until they collide with some part of the tower or its guy wires, or succumb to exhaustion and can no longer fly (Gauthreaux and Belser 2006). In an examination of the role of tower height and guy wires on avian mortalities, Gehring et al. (2011) found that there are 54—86% fewer fatalities at medium height, guyed towers (116—146 m) than at tall height, guyed towers (>305 m) and that guyed towers account for 16 times more bird fatalities than towers of the same height without guy wires.

While birds can collide with towers on clear nights, previous studies have found that larger numbers of birds are killed on fall nights with heavy cloud cover, northerly winds, and a low cloud ceiling when they do not have the stars to navigate by (Avery et al. 1977; Seets and Bohlen 1977; Larkin and Frase 1988; Kruse 1996). These conditions force birds to fly at lower altitudes within the range of towers, exposing them to tower structure risks.

We examined how the number of birds killed at one class of communication tower, tall television towers, was influenced by tower structure as well as cloud cover and prevailing winds during fall migration. While there have been many studies on the effects of tower structure, fewer studies have examined the role of specific weather conditions on the number of bird collisions (although see Longcore et al. 2012). We predicted that birds would experience the greatest mortality during nights with ≥50% cloud cover and predominantly northerly winds. By understanding the effects of weather and tower structure on mortality, we can make recommendations on ways to reduce avian mortality at television towers.

METHODS

We conducted our study at three television

towers in central Illinois between August and November 2006—2009. The location of the towers were as follows: 1) WAND-TV tower, Macon Co.: Whitmore Twp. (T17N, R3E, S11), ca 2¼ mi. NE Oreana; 2) WBUI-TV tower, Macon Co.: Whitmore Twp. (T17N, R3E, S11), ca 2 mi. NE Oreana; and 3) WILL-TV tower, Piatt Co.: Willow Branch Twp. (T18N, R5E, S67/8), ca 5½ mi. W Monticello.

The towers were searched for carcasses on mornings following nights with four weather conditions: 1) ≥50% cloud cover and northerly winds, 2) ≥50% cloud cover and non-northerly winds, 3) <50% cloud cover and northerly winds, and 4) <50% cloud cover and non-northerly winds. Nights were classified using hourly weather observations from http://www.wunderground.com. To determine which morning to look for birds, we *a priori* selected days to search at the beginning of the fall season. To balance the number of searches by weather condition category, we did additional searches specific to those categories by monitoring conditions the previous evening and searching for birds that morning. Searches began at dawn to reduce carcass loss to scavengers (Crawford 1971).

At each of the three television towers, we first searched the paved and grassy areas just outside the tower facility. We then entered the facility and searched around the tower, including the roof. The areas under the guy wires were searched after harvest by walking straight paths from the tower base to the base of the three sets of guy wires and back, encompassing approximately 5 m to each side of the guy wires. Not searched was the extensive area between the guy wires. The area searched was similar between towers. However, because of differences in when crops were harvested, some towers may have been searched more extensively than others on certain visits. Nevertheless, the similarity in height and guy wire lengths among the towers should not result in significant bias in the number of dead birds found at each tower (Table 1). Carcasses that were not decomposed, based on the recession of the eyeballs, were transported to Millikin University for identification and further processing. For each bird collected, the date; tower; species; colors of the iris, maxilla, mandible, tarsi, and toes; and any other general remarks were recorded. Birds collected were deposited at the J.W. Powell-D. Birkenholz Natural History Collection at Illinois State University.

Table 1. Characteristics of three television towers and the landscape that surrounded each in central Illinois.

Chacteristic	WILL	WAND	WBUI
Tower Variables			
Tower Height	282 m[a]	379 m	390 m
Number of Wires	27	24	24
Guy-Wire Length	6202 m	Not determined[b]	5538 m
Number of Flashing Lights	3	13	13
Number of Steady Lights	12	0	0
Light-Pulse Frequency	30/min	40/min	40/min
Light Color	Red	White	White
Construction Color	Red/White	Steel	Steel
Landscape Variables			
Ground Elevation	210 m	209 m	208 m
Distance to Water Source	5.7 km	4.1 km	4.1 km
Distance to City	9.7 km	8.9 km	8.9 km

[a] Tower height and ground elevation were obtained from http://www.fccinfo.com.
[b] The exact guy-wire length could not be determined; however, the tower construction of WBUI and WAND is nearly identical. Therefore, we expect the guy-wire length to be similar.

We collected characteristics of each tower that could influence collision frequency. These included tower height, number of wires, guy-wire length, number of lights, light-pulse frequency, light color, tower color, ground elevation, and distance to nearest water source and city. Distance characteristics of each tower were measured using an Opti-Logic Laser Rangefinder.

We determined whether the number of dead birds collected per night was equivalent among our four weather categories using a chi-square test. A *P*-value of <0.05 was considered statistically significant.

RESULTS

Tower characteristics varied among our three towers (Table 1). In particular, tower height and lighting differed between WILL, WAND, and WBUI.

Forty-three searches were made between August and November 2006—2009. We found 415 birds from 14 families at the three towers, with the most birds from Family Parulidae (Table 2, n=272). The WILL tower had the most kills (n=397), followed by WAND (n=14), and WBUI (n=4). We recorded two kills with greater than 50 birds, the first on 4 October 2006 with 275 birds found, and the second on 28 October 2009 with 60 birds found.

We found that the number of birds killed was not equivalent in each of our four weather categories (Fig. 1, X^2=33.3, P<0.05). The majority of our birds were found fol-

Table 2. The number of birds found from each of 14 familes at 3 television towers in central Illinois from 2006-2009.

Family	Number of Fatalities
Parulidae	272
Turdidae	38
Emberizidae	38
Vireonidae	23
Regulidae	13
Troglodytidae	6
Cardinalidae	5
Icteridae	5
Mimidae	5
Certhiidae	2
Picidae	2
Tyrannidae	2
Unidentified	2
Cuculidae	1
Sturnidae	1

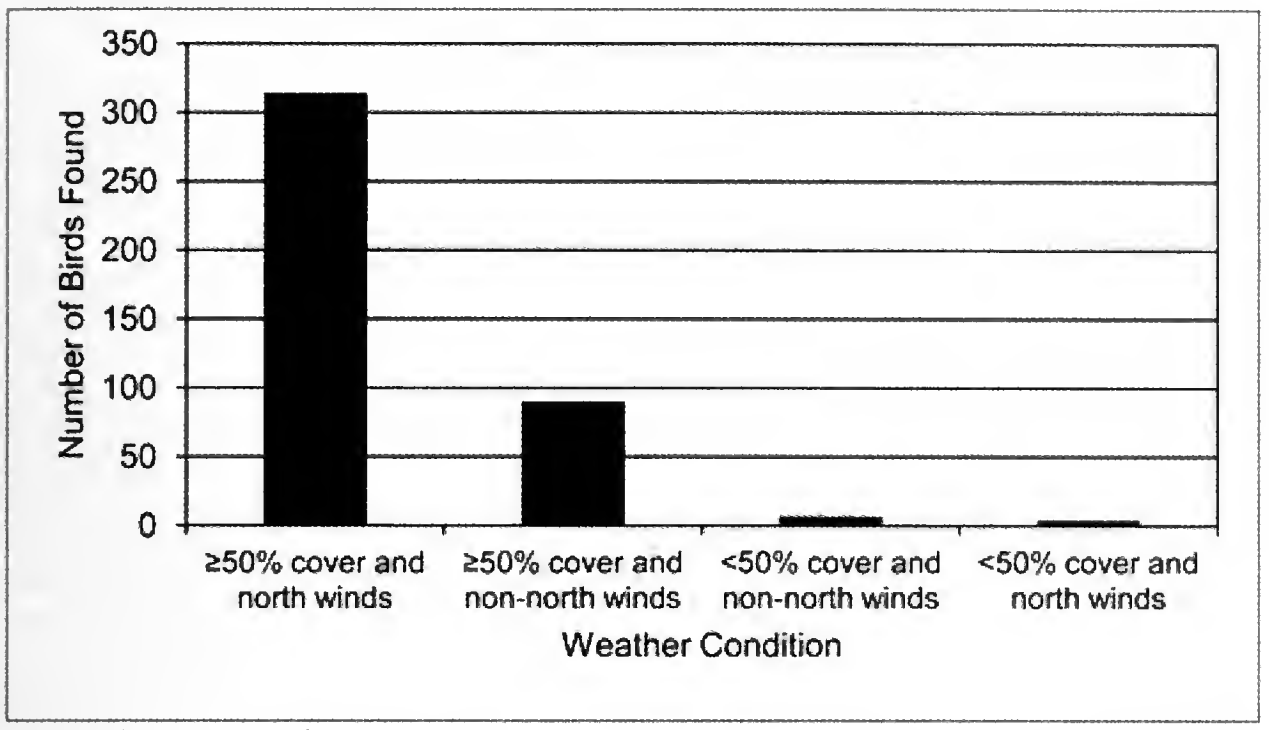

Fig. 1. The number of fatalities differed among weather conditions. More birds were found following nights with ≥50% cloud cover and northerly winds compared to other conditions (X^2 =33.3, P<0.05).

lowing nights with ≥50% cloud cover and northerly winds, with 304 individuals collected (73%). The nights that accounted for the second highest number of birds collected were nights with ≥50% cloud cover and non-northerly winds, with 98 individuals collected (24%).

DISCUSSION

Sixty-six percent of the birds found were members of Family Parulidae (i.e., warblers). Longcore et al. (2013) combined mortality data from previous studies to estimate mortality by species, and estimated that of the over 5,200,000 birds recorded, Family Parulidae accounted for 3,075,659 (58.4%). While a smaller percentage than ours, warblers had the highest mortality of any family-specific category.

Both of our large kills occurred at the WILL tower, which has steady and flashing red lighting. Gauthreaux and Belser (2006) compared bird flight patterns near towers with steady and flashing red lights, towers with only white strobes, and a control tower, which was unlit. They found that birds flew in straight paths over the control area, while birds flew in curvilinear paths and congregated near lighted towers. Between the two lighting categories used, they found that birds congregated in much higher numbers at towers lit with steady and flashing red lights than towers lit with white strobes, although the white strobes did have an effect on flight patterns.

Gehring et al. (2009) examined mortality rates between towers similar in construction, with different lighting systems. They attempted to determine whether mortality rates differed among towers equipped with flashing lights of various types and colors only versus towers equipped with the FAA standard combination of steady and flashing red lights. They found that more birds were killed at towers with steady and flashing red lights compared to towers with only white, flashing strobes; red, strobe-like lights; and red, flashing, incandescent lights (Gehring et al. 2009). Thus, the steady and flashing red lights on the WILL tower may explain why we observed 96% of our total kills at that location.

A correlation has been documented between tower height and mortality rates for towers with the same lighting scheme (Longcore et al. 2008; Gehring et al. 2011; Longcore et al. 2012). Our shorter tower experienced greater mortality than the two taller towers combined, but it had a different lighting scheme and more guy wires. The WILL tower has more guy wires per group and a combination of steady and flashing red lights, while the WBUI and WAND towers have fewer guy wires per group and flashing white lights. Studies have found that avian mortality increases with the number of guy wires present, but guy wires correlate with height (Longcore et al. 2008; Gehring et al. 2011). While our shorter tower (by 93 m) had more guy wires, it was only one more guy wire per group than each of the other two towers. Given the dramatic effect recorded for solid versus flashing lights (Gehring et al. 2009) and small difference in guy wire number, it is most likely that the lighting system of the WILL tower had a larger effect on mortality rates.

We found that more birds were killed following nights with ≥50% cloud cover and northerly winds, with our two largest kills occurring under these conditions at WILL. Longcore et al. (2008), through a meta-analysis of over 20 towers, found that the largest kills occurred on nights with heavy cloud cover in the presence of a combination of steady and flashing red lights. This suggests that while both weather and lighting play a large role separately, it is the combination of the two that may be most important.

While previous studies have reported higher kills following nights with heavy cloud cover (Avery et al. 1977; Crawford 1981; Larkin and Frase 1988), examinations of the combination of cloud cover and wind direction could be tested more rigorously. Most of our birds (73%) were found following nights with ≥50% cloud cover with the presence of northerly winds. This suggests that northerly winds in addition to heavy cloud cover create the most deadly conditions. However, in our study an additional 24% of birds were killed on nights with heavy cloud cover and non-northerly winds. Previous studies have concluded that while more birds are killed following nights with northerly winds than nights with non-northerly winds, overcast nights consistently experience mortality events regardless of wind direction (Avery et al. 1977; Crawford 1981; Larkin and Frase 1988).

Our estimates of mortality should be considered minimum values, as there were some possible sources of error in our study. We began our searches at dawn to lower the impact of scavengers, which can greatly reduce the number of carcasses (Crawford 1971). However, it is possible some carcasses were taken before we were able to collect them. We did not search the area be-

tween the guy wires, and thus, some birds will have been missed. In addition, we did not determine searcher efficiency. Finally, differences in harvest times between both tower sites and seasons meant that some towers were searched more extensively than others on some visits.

There are three main solutions to reduce avian mortality at television towers. The first would be to reduce tower height, as mortality risk increases exponentially with height (Longcore et al. 2012). The second solution is to reduce or eliminate the number of guy wires. Since guy wires account for the majority of bird kills due to the circling behavior of birds in the presence of tower lights, removing them could reduce collision rates (Brewer and Ellis 1958; Kruse 1996), but it is not possible for towers > 300 m (Longcore et al. 2012). Thus, while these two solutions will lower mortality rates, they are unlikely to happen, especially for towers that are already constructed.

The third solution is a change in tower lighting systems. Gehring et al. (2009) mainly suggested the removal of non-flashing red lights leaving only the flashing red strobe, but recommended a color change to white strobes as well. Taylor (1981) recorded a drastic reduction in fatalities at a Florida tower when the lighting system was changed from steady and flashing red lights to white strobe lights.

Arnold and Zink (2011) suggest that while millions of birds are killed by collisions, not only with communication towers but with other constructed structures, it may not have a significant effect on population trends. However, mortality rates are not the same for all species (Longcore et al. 2013). Longcore et al. (2013) found that some species, including U.S. Fish and Wildlife Service Birds of Conservation Concern, are suffering losses of several percent of their estimated population size. Because of the differences in mortality rates between species, Longcore et al. (2013) suggest per species estimates are undertaken for all human-caused sources of avian mortality.

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Examining the Causes of Rarity for the Odonata of Illinois

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ABSTRACT

Odonata (dragonflies and damselflies) play an important role in habitat management and conservation, but our understanding of the causes of commonness versus rarity in this group is limited. In this study we examined the causes of rarity for the Odonata of Illinois. Using S-ratings for conservation status and published habitat classifications for Illinois odonates, we investigated whether habitat type (lotic versus lentic) or habitat specificity (whether they were limited to a specific type of aquatic habitat) was related to commonness. We found that lotic species and habitat specialists were more likely to be rare than lentic and generalist species. More information, however, is needed on the distributions and natural histories of Illinois odonates if we are to more fully understand the causes of rarity in this important group.

INTRODUCTION

Odonata are considered 'flagships' for the conservation of insects (Corbet, 1999). Of the 5,680 extant species of Odonata (Kalkman et al., 2007), the International Union for Conservation of Nature states that one in ten species are threatened, while 35% are defined as data deficient (Clausnitzer et al., 2009). The status of Odonata may be tightly linked to their habitats; because their larvae are aquatic, the degradation of many aquatic habitats can decrease the number of successful individuals (Olsvik and Dolmen, 1992; Bossart and Carlton, 2002; Korkeamaki and Suhonen, 2002; Clausnitzer et al., 2009). Consequently, odonate species may be good indicator species for the quality of aquatic habitats (e.g. Briers and Biggs 2003).

The purpose of this current study is to identify the habitat factors that may be correlated with species commonness for Odonata in the state of Illinois. As with studies on other taxa (Goerck, 1995; Bevill and Louda, 1997; Yu and Dobson, 2000; Manne and Pimm, 2001) or on Odonata in other regions or at other spatial scales (Korkeamaki and Suhonen, 2002; Kalkman et al., 2007; Clausnitzer et al., 2009), we address this goal by comparing the likelihood that rare and common species fall into different categories. Specifically, we compare the likelihood of Odonata in Illinois to be lentic versus lotic or generalists versus specialists.

MATERIALS AND METHODS

The list of Odonata for Illinois, as well as their state conservation status ("S-Ratings"), was obtained from the Illinois State Museum (www.museum.state.il.us). The taxonomy we used was the most current available according to the North American Odonata list maintained at the Pugent Sound Museum (www.pugetsound.edu). The state status ratings ranged from S1 to S5, with S1= critically imperiled with five or fewer occurrences, S2= imperiled in state with 6 to 20 occurrences, S3= rare or uncommon with 21 to 100 occurrences, S4= secure in state, and S5= demonstrably secure in state (www.natureserve.org). In order to obtain an adequate sample size for analyses, we created two categories, with S1, S2 and S3 representing the rare/uncommon species and S4 and S5 representing common species. For our analyses, we only wanted to include the species with breeding populations within the state. Accordingly, vagrant species, which are given an S-rating of SRF, SR, and SR/WL, were omitted from all analyses.

We classified habitat in two ways. First, the individuals were classified as lotic or lentic. Second, we classified them as specialist or generalist. We defined specialist as a species described as only in either the lotic or lentic habitat, or required certain vegetation (e.g. spatterdock for *Rhionaeshna mutata*). Generalist was defined as a species that could be found in both lentic and lotic with no specific vegetation requirements. Our classifications were determined using recent field guides for Odonata including Curry (2001), Lam (2004), Abbott (2005), Beaton (2007), and Paulson (2011). In the case of discrepancy among our sources (which occurred for only 3 species out of 136), we used Paulson (2011) or Lam (2004) because their field guides encompassed the majority of the Eastern United States.

The frequencies of uncommon/rare versus established species of Odonata were compared between suborders (Anisoptera – dragonflies and Zygoptera – damselflies), habitat specificity, and primary habitat using chi-square analyses. In order to take phylogeny into account, we conducted an additional set of analyses in which the average S-Ratings were compared between habitat type and specificity (using a Wilcoxon test) for those genera in which some members fell in both categories. For example, we would compare average S-ratings between *Aeshna* species which occupied lotic versus lentic habitats or were generalists versus specialists. All analyses were performed using StatView version 5.0, Abacus System. Nonparametric statistics took ties into account when appropriate.

RESULTS

We first compared the proportion of species in the uncommon/rare category to the proportion of common species between the suborders Anisoptera and Zygoptera (Table 1). Although a trend existed for Anisoptera to have a higher proportion of species in the uncommon/rare category than Zygoptera, the trend was not statistically significant (χ^2= 1.2, df=1, P= 0.26). However, because of this trend, in the remaining analyses we conduct analyses with suborders both combined and separate in order.

There were significantly more uncommon/rare odonate species that primarily inhabited lotic habitats than lentic habitats (χ^2= 7.8, df=1, P= 0.0053). Conducting the analyses within suborders, Anisoptera had a significantly higher proportion of uncommon/rare species that primarily inhabited lotic habits (χ^2= 11.0, df =1, P= 0.0009),

whereas Zygoptera did not (χ^2= 0.22, df = 1, P= 0.66).

For habitat specificity, we found no significant difference between the proportion of habitat generalists and specialists between uncommon/rare and common taxa for all Odonata (χ^2= 6.6, df=1, P= 0.10). However, when assessing suborders, specialist Anisoptera were significantly more likely to be uncommon/rare than generalist Anisoptera (χ^2= 8.0, df=1, P= 0.005). No significant pattern for habitat specificity was found for Zygoptera (χ^2= 0.22, df=1, P= 0.66).

Analyzing patterns within genera, we found a borderline-significant trend for generalist species to have a higher average S-Rating of Odonata than specialist species (8/12 genera had a higher average S-rating for generalists than specialists; specialist= 2.9 ± 1.05, generalist= 3.6 ± 1.36; Wilcoxon Z= -1.73, P= 0.08). No significant trend was found within genera relative to primary habitat, although the sample size of appropriate genera was small (4/5 genera had a higher average S-rating for lentic species than lotic; lotic= 2.5 ± 1.15, lentic= 1.4 ± 2.89; Wilcoxon Z= 0.94, P= 0.34).

Table 1. The number of rare/uncommon species over the total number of Illinois Odonata species in that habitat category (percentage given in parentheses). Numbers given for both the entire order and individually for each suborder.

	Generalist	Specialist	Lotic	Lentic
Odonata	23/52 (44%)	56/84 (67%)	38/52 (73%)	41/84 (49%)
Anisoptera	15/35 (43%)	42/58 (72%)	27/32 (84%)	30/61 (49%)
Zygoptera	8/17 (47%)	14/26 (54%)	11/20 (55%)	11/23 (48%)

DISCUSSION

We found that lotic odonates in Illinois were more likely to be uncommon/rare than lentic species, a result also found by Korkeamaki and Suhonen (2002) for odonates in Finland. This pattern may be because the survival of lotic populations is lower (Korkeamaki and Suhonen, 2002), perhaps due to degradation of some lotic habitats (Olsvik and Dolmen 1992). However, the type of habitat (i.e. lotic or lentic) was often shared by all the species within a genus. Thus, it is possible that the connection between habitat type and rarity is affected by a group's evolutionary history instead of, or in addition to, the habitat characteristics (Kunin and Gatson, 1993). Our within-genus analysis yielded a trend toward lotic species being more rare, but so few genera had species with both habitat types that statistical significance was unlikely to be achieved.

Our results also indicate a relationship between habitat specificity and rarity. In the case of habitat specificity, both the overall analyses and the within-genus analysis suggested that specialist species were more likely to be rare than generalist species, a result that is again consistent with the results of Korkeamaki and Suhonen (2002). However, Anisoptera had a higher proportion of species falling into the specialist category than Zygoptera; therefore, the impact of evolutionary history cannot be ruled out.

In conclusion, we found that habitat type and specificity seem to be related to a species' commonness. Our analyses are necessarily dependent on current S-ratings for these species, and such ratings are at least partially dependent on documented occurrences for each species. Such information on Odonata is lacking in many parts of the world (Clausnitzer et al., 2009), and this is certainly true for some regions of Illinois. Clearly, better documentation for the species distributions within Illinois is necessary and this additional information may alter the patterns (or lack of pattern) found in our study. Because Odonata are useful in nature management and conservation (Olsvik and Dolmen, 1992; Corbet 1999; Kalman et al., 2007), it is imperative that biologists continue to investigate why certain odonate species are less common than others. Future studies should focus on gaining additional, detailed information on the natural history and distribution of Illinois' Odonata, so that more detailed analyses on factors influencing their commonness can be conducted. In addition, long term studies on the odonate communities of particular habitats, particularly those that are changing over time, would prove very useful.

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Estimating Occupancy of *Trachemys scripta* and *Chrysemys picta* with Time-Lapse Cameras and Basking Rafts: A Pilot Study in Illinois, USA

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ABSTRACT

We evaluated time-lapse cameras aimed at man-made basking rafts (camera traps) by estimating probabilities of occupancy and detection for *Trachemys scripta* and *Chrysemys picta* at 15 isolated ponds or wetlands in three regions of Illinois. Evaluation of camera traps relied on comparisons with hoop nets and published accounts of relative abundances of target species. After accounting for imperfect detection, occupancy probabilities for *C. picta* were 0.75 (SE = 0.18) using hoop nets and 0.91 (SE = 0.09) using camera traps. Occupancy probabilities for *T. scripta* were 0.96 (SE = 0.42) using hoop nets and 0.71 (SE = 0.17) using camera traps. The most-supported model of detection with camera traps included region and date of survey for both species, whereas the top model of detection with hoop nets included region and trap effort for both species. Regional differences in occupancy and detection for both survey methods were consistent with reports of relative abundances of target species. Daily rates of detection with camera traps varied during the 20-day sampling period, but in a predictable manner described by a single covariate (date of survey). Environmental variables were uninformative for predicting detection probability. Costs of labor and travel were lower (at least half) for camera traps than hoop nets, which required three or more surveys per site given observed rates of occupancy and detection. Camera traps require more evaluation, but show promise as an efficient, relatively inexpensive, and minimally invasive method to assess presence-absence of species of freshwater turtles that bask aerially.

Key words: camera trap; basking; occupancy; *Trachemys scripta*; Red-eared Slider; *Chrysemys picta*; Painted Turtle; Illinois

INTRODUCTION

Camera traps are useful tools for studies of wildlife ecology (Cutler and Swann 1999). Applications are now commonplace because of technological improvements to cameras, reasonable costs, and innovative approaches for analyzing data (O'Connell et al. 2011; Cox et al. 2012). Logistical advantages are another attractive feature. For example, camera traps can collect data during a long period of time with few visits whereas capture devices require regular checks to uphold standards of animal welfare.

Few herpetological studies have employed camera traps because heat- and motion-sensitive triggers tend to perform poorly for cold-blooded, slow-moving and often diminutive subjects (Dorcas and Peterson 2012). Exceptions include observations of Gopher Tortoises (*Gopherus polyphemus*; Boglioli et al. 2003), Timber Rattlesnakes (*Crotalus horridus*; Sadighi et al. 1995) and Grassland Earless Dragons (*Tympanocryptis pinguicolla*; McGrath et al. 2012). Camera traps have also been used to study nesting ecology of crocodilians (Hunt and Ogden 1991; Kermeen and Lemnell 2000) and freshwater turtles (Doody and Georges 2000; Geller 2012).

We evaluated camera traps for detecting patterns of presence-absence of freshwater turtles that bask aerially. If successful, the method could be applied economically at large spatial scales to estimate geographic distribution, habitat needs, population trends, and metapopulation processes via occupancy modeling (e.g., Rizkalla and Swihart 2006; Cosentino et al. 2010). We compared camera traps to hoop nets by estimating probabilities of occupancy and detection for two species (*Trachemys scripta*, Red-eared Slider; *Chrysemys picta*, Painted Turtle) in three regions of Illinois. Our objectives were: 1) identify and correct causes of camera malfunctions, 2) evaluate protocols for placement of rafts, 3) determine whether detection probabilities were similar for camera traps and hoop nets by testing the hypothesis $\rho \geq 0.5$ for each species with both methods, and 4) evaluate effects of region, date of survey, capture effort, and environmental variables on detection probabilities. We chose a threshold of $\rho \geq 0.5$ because both target species are common in much of the state (Phillips et al. 1999). Comparison of survey methods allowed "soft validation" of camera traps (Rodda 2012). We discuss attributes of these and other survey methods relative to costs and statistical constraints for estimating occupancy at large spatial scales.

MATERIALS AND METHODS

Study areas. Richardson Wildlife Foundation is located in Lee County near West Brooklyn, Illinois, USA. Managers of this private, 719–ha property have restored much of the area, including 24 wetlands. We randomly chose seven of these wetlands for our study; an eighth was sampled because *Emydoidea blandingii*, an endangered species in Illinois, had been encountered there earlier in the year. Individual wetland areas varied from 0.81–4.73 ha; all had emergent vegetation (e.g., *Typha latifolia*, *Scirpus* spp.) around their perimeters and submergent vegetation (e.g., *Pot-*

amogeton spp.) in open-water areas. For brevity, we designate this area as "North".

Our second study area ("Central") was a 23-ha private property located near Springfield, Illinois. The area was developed for aquaculture and fee fishing but currently is idle. We chose four of 11 man-made ponds based on similarities in size (0.15–0.44 ha) and presence of natural rather than concrete shorelines. Creeping water primrose (*Ludwigia peploides*) grew near margins of ponds. Our last study area ("South") was in Union County near Ware, Illinois. This 12-ha private property has a man-made pond (0.12 ha) and two man-made wetlands (0.11–0.21 ha), all of which were used for our study. The pond was bordered by turf on one side and forest on the other; wetlands were bordered by native grasses and small trees (*Salix* sp. and *Acer* sp.). Features used for basking at our study areas included bare shoreline, deadwood, floating mats of vegetation, and concrete rubble.

Equipment. Tops of rafts were constructed from exterior plywood (Length [L] = 120.7 cm; Width [W] = 28.4 cm; Depth [D] = 1.9 cm). We drilled two 2.54 cm-diameter (Diam) holes in the top, which were centered and 10.2 cm from each end. Two cedar boards (D = 2.54 cm; W = 15.2 cm [nominal dimensions]; L = 120.7 cm) were cut at a 22.5° angle along one edge, which was affixed to the top of the raft with exterior screws and polypropylene glue to create two wooden ramps. We stapled a piece of charcoal-colored pet-resistant screening (New York Wire, Mt. Wolf, Pennsylvania, USA) to the top and wooden ramps to provide a good purchase for turtles climbing aboard the raft. A piece of high-density R-10 insulation (D = 5.1 cm) was cut, trimmed, and affixed to the bottom of each raft with foam-board adhesive (PL300; Henkel Corp., Rocky Hill, Connecticut, USA) for flotation. Two wire extensions (19-guage hardware cloth; 1.27 X 1.27-cm mesh; W = 25.4 cm; L = 95.3 cm) were affixed to tops of wooden ramps with poultry staples (L = 1.9 cm). When rafts were deployed, ends of extensions dipped 2–4 cm beneath the water line to assist turtles attempting to climb aboard rafts. We left enough room under the staples so wire extensions could be folded over the top of the raft for transport. During deployment, we used two elastic cords (L = 55.2 cm) to secure each lower corner of the wire ramp on one side of the raft to that on the opposing side. Approximate cost for all materials was $10 US per raft; two fiberglass fence poles (Diam = 1.27 cm; L = 1.82 m; $5 US each) were used to anchor rafts in place.

To monitor each basking raft (Fig. 1) we used Timelapse Plantcam™ (Wingscapes®, Alabaster, Alabama, USA) with four-megapixel resolution. We set cameras to take high resolution photos (2560 X 1920 pixels) at three-hour intervals between a daily wake-up time of 0900 h and daily sleep at 1600 h (i.e., 0900, 1200 and 1500 h). Cameras were set to imprint photos with lapse interval, location, date, and time. Focus distance was set to infinity. Each camera was mounted approximately 1.25 m above the surface of the water on a piece of metal conduit (Diam = 1.9 cm; L = 3 m) located 2 m from the leading edge of the raft. We used a ladder to mount cameras and adjust the field of view to capture the entire basking raft. Where needed, we used a post driver constructed from metal conduit (Diam = 2.54 cm; L = 1 m) with an end cap to anchor mounting poles in hard substrates. Cost of camera, mounting pole and memory card was approximately $90 US.

For comparative data to time-lapse cameras, we captured turtles at each pond using two single-throated hoop nets (D = 0.61 m) with 3.8 X 3.8-cm mesh. Each hoop net cost $68 US. Bait (fresh fish changed daily) was suspended in a mesh bag tied to the hoop farthest from the throat.

Sampling methods. Given our objectives, we modified protocols during the study to optimize performance of camera traps. At Central, we used a crossover design to evaluate models as decoys on basking rafts (Red-eared Slider, Safari Ltd., Miami Gardens, Florida, USA). Decoys did not appear to increase detection rates, so we quit this practice at other sites. At Central, two ball-and-joint camera mounts crept out of position during sampling. Later, we secured cameras in position by running a cable tie through two apertures on the back of the case and anchoring the fastened cable tie to the mounting pole with electrical tape. At Central, we positioned rafts perpendicular to and 2 m away from shore. At other sites, water was too shallow to deploy our gear effectively

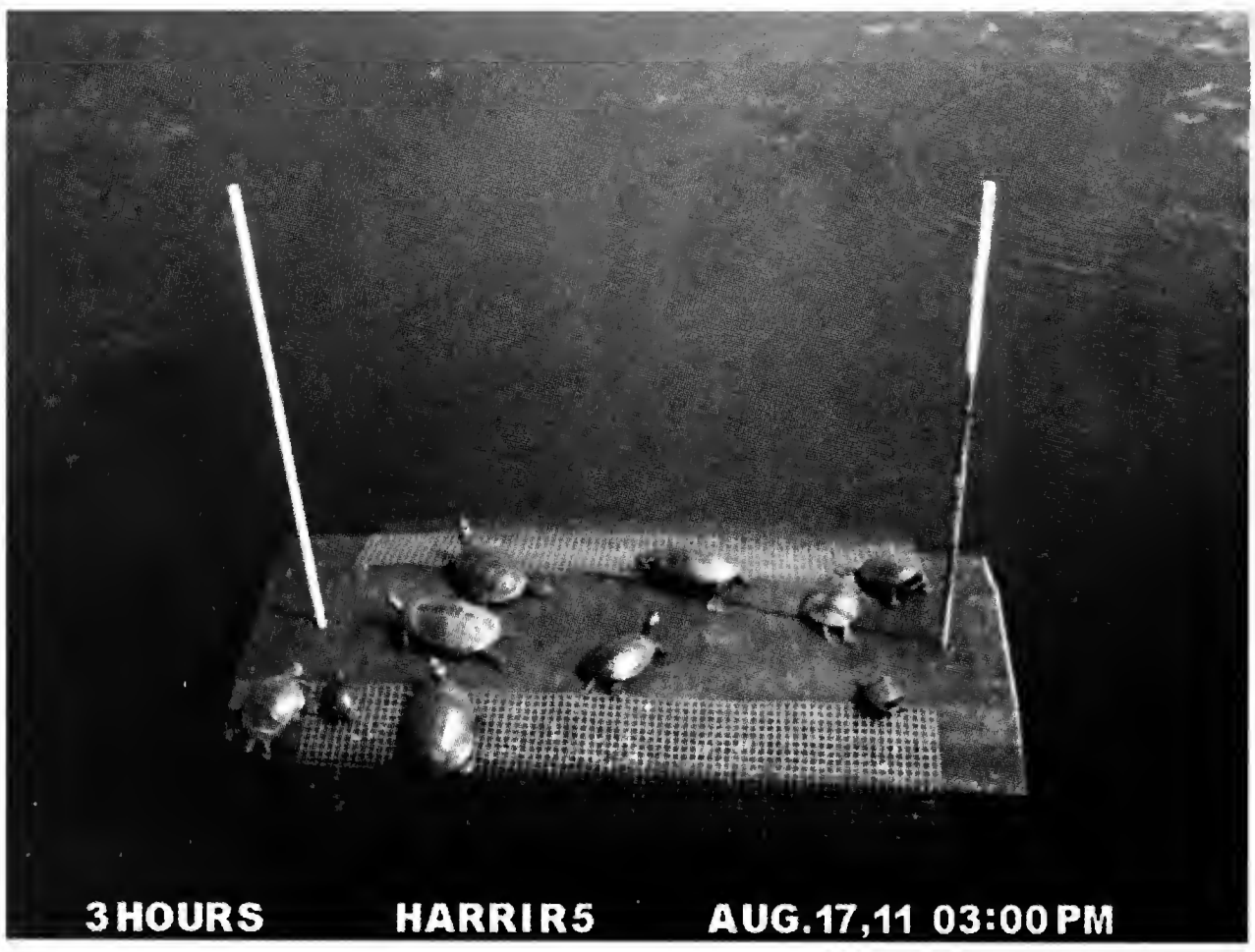

Fig 1. *Chrysemys picta* basking on a man-made raft and photographed with a time-lapse camera in Lee County, Illinois, USA, 2011.

at this distance, so we chose positions with deeper water regardless of distance from shoreline. At Central and South, we used two camera traps in each pond or wetland, placing them in quarters of the water body chosen randomly beforehand. At both locations, this restriction caused placement of two rafts where they were shaded by trees much of the day. We decided random placement of rafts within a water body was untenable, and use of two camera traps per wetland was unnecessary. At North, we used one raft per wetland, placing it opportunistically in full sunlight and open water deep enough for our gear (>40 cm).

Camera traps were deployed 13 May through 1 June 2011 (Central), 15 June through 4 July 2011 (South) and 10 through 29 August 2011 (North). At Central, hoop nets were set at each camera station (2 per pond) on 11 May 2011 and 2 June 2011 and checked the next day. We used the same protocol at South, but checked nets on three occasions (14 June, 6 July and 7 July 2011). At North, we set two nets per wetland and checked them twice (9 and 10 August 2011).

We used a drill to apply unique marks to marginal scutes of turtles captured in hoop nets. To avoid bias, a consultant with extensive herpetological experience (J. G. Palis, Palis Environmental Consulting, Jonesboro, Illinois) was hired to identify turtles in photographs using diagnostic features of heads, limbs, tails and carapaces. Individuals that could not be assigned confidently to species were classified as unknown.

We obtained data for weather variables (maximum temperature, total evaporation, total precipitation, total solar radiation) from meteorological stations of the Illinois Climate Network (http://www.isws.illinois.edu/warm/datatype.asp) at DeKalb, Illinois (North), Springfield, Illinois (Central), and Carbondale, Illinois (South).

Statistical analyses. We used occupancy modeling to estimate detection probabilities for camera trap and hoop net surveys at our study wetlands (N = 15). The program PRESENCE (v. 3.1) was used to build single-season models of detection probability (ρ) for each species and sampling method based on repeated surveys within wetlands (MacKenzie et al. 2006). Separate model sets were constructed for each sampling method. For camera trapping, a repeated survey was defined as all photos taken on a single day in a single wetland (North = 3 photos; Central and South = 6 photos). All wetlands were surveyed for 20 days. For trapping, a repeated survey was defined as a group of hoop traps in a single wetland open for one night. We surveyed wetlands for either two (North and Central) or three (South) days. Data for a third survey at wetlands in North and Central regions were coded as missing observations. All 15 wetlands were used in the analysis for *C. picta*, whereas only wetlands from the Central and South regions (N = 7) were used for *T. scripta*, as this species is generally not found in Lee County (B.J. Cosentino, unpublished data) and was not detected in North wetlands during our study.

Covariates were used to model variation in ρ among sites. We expected significant variation in abundance among regions, so we included an effect of region on ρ in all models. For camera trapping, we also evaluated models that included date of survey, maximum air temperature, total evaporation, total precipitation, and total solar radiation. For hoop nets, we evaluated models that included date of survey, trap effort, and maximum air temperature. Trap effort was calculated as the number of trap-hours for each wetland. For both camera trapping and hoop nets, we limited models of ρ to include only a single covariate beyond the inclusion of an effect of region. Occupancy probability (Ψ) was held constant in all models because of the limited number of wetlands in our study.

We used the Akaike Information Criterion corrected for small sample size (AIC_C) to rank the relative support of models for each combination of species and sampling method (Burnham and Anderson 2002). For each model, *i*, we estimated AIC_C differences ($\Delta AIC_C = AIC_{C,i}$ - minimum AIC_C) and Akaike weights (w_i). Models were considered to have competitive support when $\Delta AIC_C \leq$ two.

RESULTS

For *C. picta*, we captured 23 individuals (0.70 individuals/survey) at nine wetlands (naive Ψ = 0.6) using hoop nets, and

Table 1. Sampling effort, daily detections, and numbers of basking turtles observed with camera traps at 15 sites in Illinois, USA, 2011.

		Daily dectections (presence) and no. of turtles observed[a]					
		Trachemys scripta		*Chrysemys picta*		Unidentified emydids	
Site	No. cameras	Days	No. turtles	Days	No. turtles	Days	No. turtles
South	2	20	249	2	2	12	27
South	2	20	142	0	0	14	40
South	2	0	0	0	0	0	0
Central	2	10	58	8	14	6	6
Central	2[b]	0	0	0	0	0	0
Central	2[c]	12	23	4	9	0	0
Central	2	15	65	11	25	9	10
North	1	0	0	20	296	9	10
North	1	0	0	15	49	0	0
North	1	0	0	20	197	1	1
North	1	0	0	17	62	0	0
North	1	0	0	5	5	0	0
North	1	0	0	20	273	5	5
North	1	0	0	12	21	0	0
North	1	0	0	16	116[d]	0	0

[a]Observations of turtles are not independent; the same individual could have been photographed on multiple occasions during a day and on multiple days during a sampling session
[b]One camera inoperable for 9 days
[c]One camera inoperable for 2 days
[d]A portion of the basking raft (<25%) was out of view for 10 days after water level dropped; daily detections unaffected (all positive)

Table 2. Mean detection probabilities of *Chrysemys picta* and *Trachemys scripta* using camera traps and hoop traps in three regions in Illinois, USA.

Species	Trap Type	Region	Mean Detection Probability	SE
C. picta	Camera	North	0.78	0.01
		Central	0.38	0.02
		South	0.04	0.00
C. picta	Hoop	North	0.56	0.02
		Central	0.58	0.04
		South	0.13	0.01
T. scripta	Camera	Central	0.62	0.03
		South	1.00	-
T. scripta	Hoop	Central	0.69	0.01
	South	South	0.78	0.03

Table 3. Model selection statistics for detection probability of *Chrysemys picta* and *Trachemys scripta* using camera traps and hoop traps in 15 isolated ponds and wetlands in Illinois, USA. Main effects are included for each model. Summary statistics for each model include the relative difference between model AIC_C and AIC_C for the best model (ΔAIC_C), Akaike weights (w_i), the number of parameters estimated (K), and twice the negative log-likelihood (-2*l*).

Species	Trap Type	Model	ΔAIC_C	ω_i	K	2*l*
C. picta	Camera	R + D	0.00	0.98	5	255.28
		R + T	8.43	0.01	5	263.71
		R + Ev	12.04	0.00	5	267.32
		R	14.90	0.00	4	272.24
		R + S	15.16	0.00	5	270.44
		R + P	15.37	0.00	5	270.65
C. picta	Hoop	R + Ef	0.00	0.39	5	36.22
		R	0.08	0.38	4	39.09
		R + D	2.04	0.14	5	38.26
		R + T	2.85	0.09	5	39.07
T. scripta	Camera	R + D	0.00	0.98	4	63.49
		R + T	7.54	0.02	4	71.03
		R + Ev	14.74	0.00	4	78.23
		R + S	17.20	0.00	4	80.69
		R	22.65	0.00	3	88.26
		R + P	23.59	0.00	4	87.08
T. scripta	Hoop	R	0.00	0.50	3	20.11
		R + Ef	1.03	0.30	4	17.66
		R + T	2.87	0.12	4	19.50
		R + D	3.43	0.09	4	20.06

R = Region, D = Date, T = Temperature, Ev = Evaporation, P = Precipitation, S = Solar Radiation, Ef = Trap Effort

counted 1069 individuals (3.56/survey) at 12 wetlands (naive Ψ = 0.8) using camera traps (Table 1); in the latter case, some individuals were undoubtedly counted multiple times during the 20-day survey period. After accounting for imperfect detection, occupancy probabilities for *C. picta* were 0.75 (SE = 0.18) using hoop nets and 0.91 (SE = 0.09) using camera traps. For *T. scripta*, we captured 45 individuals (2.65 individuals/survey) at 6 wetlands (naive Ψ = 0.86) using hoop traps, and we counted 537 individuals (1.79/survey) at 5 wetlands (naive Ψ = 0.71) using camera traps (Table 1). After accounting for imperfect detection, occupancy probabilities for *T. scripta* were 0.96 (SE = 0.42) using hoop nets and 0.71 (SE = 0.17) using camera traps.

With a few exceptions, mean daily detection probabilities were high (> 0.5) for both methods and species (Table 2). The most-supported model for detection with camera traps included region and date of survey for both species (Table 3). Mean daily detection probabilities were greatest at North for *C. picta* and South for *T. scripta* (Table 2). Detection probability increased over time for *C. picta* (Fig. 2; beta estimate = 4.49, SE = 1.11) and *T. scripta* (Fig. 3; beta estimate = 11.56, SE = 2.47). At South, we detected *T. scripta* during every sampling occasion with camera traps (Fig. 3).

Using hoop nets, the most-supported model of detection probability included region and trap effort for *C. picta* and region for *T. scripta* (Table 3). However, trap effort was included in a competitive model for *T. scripta* (Table 3). Mean daily detection probabilities were equally high at North and Central for *C. picta* and South for *T. scripta* (Table 2). Detection probability was related positively to trap effort for both species (beta estimates: *C. picta* = 1.42, SE = 1.03; *T. scripta* = 0.73, SE = 0.56). Environmental variables were generally uninformative for both camera traps and hoop traps.

DISCUSSION

Estimates of occupancy are robust because they account for imperfect detection of target species (Mazerolle et al. 2007). As a rule of thumb, $\rho > 0.5$ is desirable while $\rho > 0.15$ is acceptable (MacKenzie et al. 2006; O'Connell et al. 2006). By these standards, camera traps and hoop nets performed

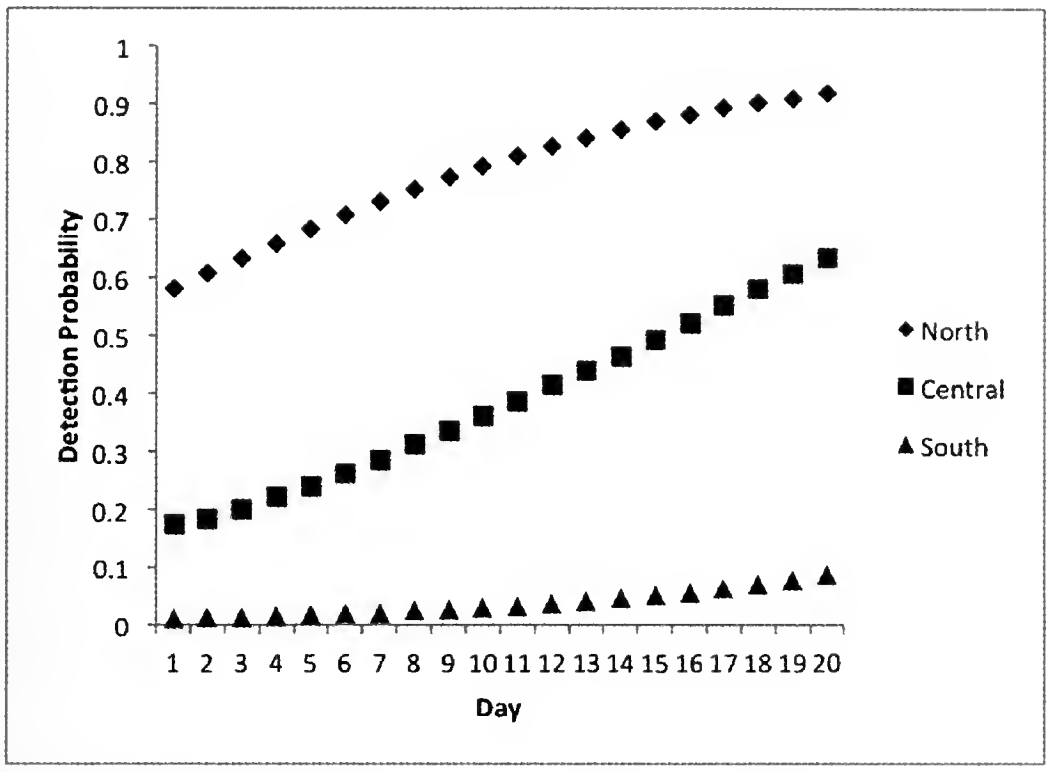

Fig. 2. Relationship of predicted detection probability of *Chrysemys picta* to date of survey (1-20). Julian dates for surveys were 13 May through 1 Jun 2011 for Central, 15 Jun through 4 Jul 2011 for South, and 10 through 29 Aug 2011 for North.

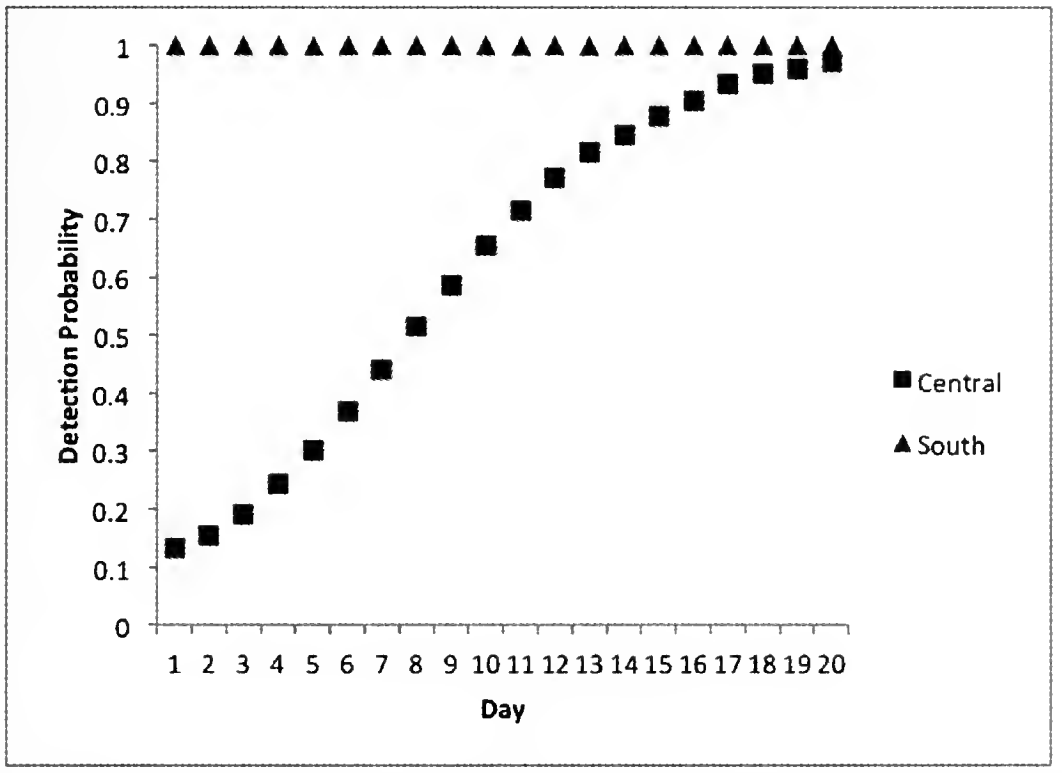

Fig. 3. Relationship of predicted detection probability of *Trachemys scripta* to date of survey (1-20). Julian dates for surveys were 13 May through 1 Jun 2011 for Central and 15 Jun through 4 Jul 2011 for South.

similarly for detection of target species.

Our data did not provide a direct test of the value of camera traps for describing spatial aspects of population ecology. However, we obtained a qualitative check on performance by comparing our results to reports of relative abundances of target species. Red-eared Sliders are rare or absent in northern Illinois, but abundant in the southern part of the state (Smith 1961; Readel et al. 2008). Painted Turtles occur throughout Illinois, but are more common in North than South (Dreslik and Phillips 2005). Thus, strong support for region in occupancy models was encouraging. We suspect regional differences in detection probabilities for camera traps also reflected our refinement of protocols. Presumably, this contributed to greater detection of *C. picta* at North, where we had one camera and three photos per wetland per day, than Central or South, where we had two cameras and six photos per wetland per day. In keeping with our protocol at North, we recommend placing one camera trap in deep (> 40 cm), open water with full sunlight most or all day when sampling small (< 5 ha) bodies of water.

Environmental variables were uninformative in models of detection with camera traps. This seems counter-intuitive, but we note varying degrees of support for effects of ambient conditions on basking behavior (Crawford et al. 1983; Enge and Wallace 2008; Selman and Qualls 2011). One possibility is that temporal differences in basking behavior were masked by overriding effects of acclimation to basking rafts during the 20-day surveillance period.

Our protocol of setting two hoop nets per wetland for two or three trap-nights affected detection of target species. This was not surprising, as observed rates of occupancy and detection suggested three or more surveys per site were best for sampling *T. scripta* and *C. picta* with hoop nets (MacKenzie and Royle 2005). Thus, hoop nets would have required at least twice as many trips (one to set gear and three to tend it) as camera traps (one to set gear and one to retrieve it). Savings on labor and travel must be weighed against costs of gear because hoop nets retrieved from one site after sampling could be deployed at four more during a 20-day period.

Variability caused by sampling methods can be problematic for occupancy modeling, which assumes rates of detection are constant among sites and visits unless heterogeneity is described by covariates (Pollock et al. 2002). Camera traps allowed collection of data simultaneously and consistently among sites and visits. This is a clear advantage over manual methods of sampling. For example, timing of visits to tend capture devices (and accrued effort) often varies with numbers of turtles processed earlier in the day. Camera traps also avoid heterogeneous rates of detection caused by multiple observers (e.g., differences in ex-

perience or acuity), behaviors of target species (e.g., differences in flushing distances), and other methodological sources of bias.

Our rate of non-identification (6.2%) was similar to Lindeman's (2000) surveys with spotting scopes (4.5%) at a site where *Graptemys* spp. and *T. scripta* dominated the assemblage. Gooley et al. (2011) identified 63% of emydid turtles to genus and 55% to species during visual surveys whereas Enge and Wallace (2008) identified 41% of turtles to genus and 58% to species. We suspect ability to identify species with photographs taken by camera traps would also vary with complexity of assemblages and subtlety of diagnostic traits of members. Therefore, we recommend using eight-megapixel cameras as marketed after we purchased our gear (e.g., Wingscapes® TimelapseCam 8.0™). Other suggestions include securing cameras to mounting poles to maintain positioning (see methods section), using cleansers designed specifically for plastics when treating clear ports on camera housings, and possibly raising the height of cameras to obtain a better field of view of rafts. Portions of rafts were not visible when water levels changed > 25 cm after cameras were positioned; this could be problematic for some applications (e.g., tidal and possibly lotic habitats).

Our study appears to be the first to use camera traps to detect freshwater turtles in aquatic settings. This was possible, in part, because we used time-lapse triggers to obtain simultaneous estimates of presence-absence for *T. scripta* and *C. picta* at multiple sites. Use of basking rafts was not innovative (e.g., Alvarez 2006), but provided an effective and standard means of attracting turtles into range of cameras. Camera traps need more evaluation, but show promise as an efficient, relatively inexpensive, and minimally invasive method to assess presence-absence and other traits of turtles that bask aerially.

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Changes Due to Fire Suppression in a *Quercus velutina* Lam. (Black Oak) Savanna at Sand Ridge State Forest, Mason County, Illinois

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ABSTRACT

Sand savannas in which *Quercus velutina* Lam. (black oak) dominated were common in the major sand deposits of Illinois. Most, however, are now dry sand forests that have been extensively degraded by fire suppression and invasion by native woody and exotic species. Degraded dry sand savannas, that are presently dry sand forests, are a dominant community of ridges and slopes on large stabilized dunes at Sand Ridge State Forest, Mason County, Illinois. In the community examined *Q. velutina*, with an importance value of 143.5, averaged 321.1 stems/ha, and accounted for 78% of the total basal area. *Quercus marilandica* Muench. (blackjack oak) was second followed by the exotic *Pinus strobus* L. (white pine) and *Carya texana* Buckl. (black hickory). Based on aerial photographs this dry sand forest had an open overstory in the early 1940s. Presently this community has a canopy exceeding 90% cove.

INTRODUCTION

In the prairie-forest interface of the prairie peninsula of Illinois the presence of prairie, savanna, woodland, and forest was determined largely by environmental factors, including extent and intensity of fire, climate, water bodies, and topography (Transeau 1935, Anderson 1991, Ebinger and McClain 1991, Abrams 1992). Other contributing factors important on a local level included soil texture, drought frequency, and browsing by large herbivores (Nuzzo 1986).

Savanna communities were extremely common in the landscape of Illinois in the 1800s, and are generally defined as having overstories of scattered, open-grown trees and a grass-dominated ground layer (Curtis 1959, Bray 1960, Nuzzo 1986, White and Madany 1978). Journals of many early travelers and settlers recount the open park-like landscape in much of the state (Bourne 1820, Engelmann 1863, Vestal 1936). Government Land Office (GLO) survey records also indicate that many "forests" were actually savanna and woodland communities based on distance of witness trees to corner posts (Cottam and Curtis 1949, Clements 1958, Hutchison 1988). Furthermore, many present day old-growth forests retain a few open-grown "wolf trees" with low branches and branch-scars, and fire scares, indicating they were formerly part of an open landscape (Curtis 1959, Ebinger and McClain 1991).

European man cleared most "black soil" savannas in Illinois soon after settlement. These savannas, with few trees, thinner sod, and often drier soil, were easier to cultivate with wooden plows of the settlers than the dense, thick prairie sod. The few remaining "black soil" savanna communities are extensively degraded due to a massive influx of exotic species and canopy closure due to fire suppression and subsequent woody invasion of native species. In contrast, sand savanna communities are still relatively common in the northern half of Illinois on major sand deposits. These deposits are mostly on outwash plains that resulted from erosional events associated with Wisconsin glaciation (Willman and Frye 1970, King 1981). Gleason (1910), and more recently Jenkins et al. (1991), Coates et al. (1992), McClain et al. (2002), and Phillippe et al. (2009) studied the structure and composition of the Illinois River sand deposit woodlands, while Rodgers and Anderson (1979) studied the presettlement vegetation of Mason County. Mostly modified by human activity, a few nature preserves and other good quality natural areas remain on these extensive sand deposits. The present study was undertaken to determine the woody overstory and understory species composition and structure of a degraded sand savanna at Sand Ridge State.

DESCRIPTION OF THE STUDY SITE

Sand Ridge State Forest is located in northwestern Mason County about 21 km northwest of Havana and just west of Forest City, Illinois (parts of townships T22N R7W and T23N R7W). This 3,035 ha (11.7 sq. miles) state forest, with initial land purchases starting in 1939, lies within the Illinois River Section of the Mississippi River and Illinois River Sand Area Natural Division in Mason and Cass counties (Schwegman 1973, Willman 1973). These deposits were formed about 14,500 years ago when glacial moraines and ice dams were breached. The resulting Kankakee Torrent carried extensive deposits of sand and gravel from glacial lakes in northeastern Illinois and adjacent Indiana. Most of this sand and gravel was deposited when the waters of the Kankakee Torrent slowed upon entering the broad lowlands of the Illinois River. Winds reworked these deposits, creating the present dune and swale topography (Willman 1973).

The original reason for purchasing the land for what is now the Sand Ridge State Forest was to stabilize soil on abandoned farmland, develop a wood product industry, and set land aside for recreation (Andrews 2004). During the early years, and into the 1950's, pine plantations were established, mostly on old pastureland and abandoned cultivated fields, but also in dry sand prairies and sand savannas. Presently, 1,012 ha of pine plantations exist with most of the remainder in oak-hickory dry sand forest and savanna (Andrews 2004).

Sand Ridge State Forest has a continental climate with warm summers and cold winters. Based on weather data from Havana, mean annual precipitation is 96.0 cm, with May having the highest rainfall (11.3 cm). Mean annual temperature is 10.8°C with the hottest month being July (average of 24.6°C), and the coldest January (average of -5.0°C). Frost-free days range from 140 to 206, averaging 173 days (Midwestern Regional Climate Center 2004). Soils are

primarily excessively drained Plainfield and Bloomfield sands (Calsyn 1995) that form the dune and swale topography known as the Parkland Formation (Willman and Frye 1970).

METHODS

During late summer of 2004 a 100 m by 300 m section of the state forest was surveyed by dividing the area into 48 contiguous quadrats 25 m on a side. This 3 ha area was located on a large stabilized dune having an east/west orientation, the centerline of the transect running along the ridge of the dune (N1/2 NW1/4 NE1/4 S4 T22N R7W). The GPS readings for the line transect at 0 m (40.39064°N/-089.89060°W), and at 300 m (40.39064°N/-089.89420°W) were recorded and marked with permanent metal stakes. All living and dead-standing woody individuals ≥10.0 cm dbh were identified and their diameters recorded. From this data, living-stem density (stems/ha), basal area (m^2/ha), relative density, relative dominance, importance value (IV), and average diameter (cm) were calculated for each species. Determination of the IV follows the procedure used by McIntosh (1957), and is the sum of the relative density and relative dominance (basal area). Dead-standing density (stems/ha) and basal area (m^2/ha) was also determined. Multiple stemmed trees (coppice) were recorded as separate individuals. Nomenclature follows Mohlenbrock (2002).

Woody understory composition and density (stems/ha) were determined using nested circular plots 0.0001, 0.001, and 0.01 ha in size located at 15 meter intervals along randomly located east-west line transects within the study area (48 plots). Four additional 0.0001 ha circular plots were located 7 m from the center points of each of the 48 plot centers along cardinal compass directions (240 plots). In the 0.0001 ha plots, woody tree seedlings (≤50 cm tall) and shrubs and vines were counted; in the 0.001 ha circular plots small saplings (>50 cm tall and <2.5 cm dbh) were recorded; and in the 0.01 ha circular plots large saplings (2.5-9.9 cm dbh) were tallied.

Changes in overstory cover within the state forest was measured using aerial photographs from 1939, 1957, 1969, 1988, and 1998 that were digitized to determine the extent of woody encroachment (trees and large shrubs). These photographs were borrowed from the University of Illinois Map Library and scanned with a Microtek ScanMaker. A total of 20 stratified randomly located 5 ha circular plots (100 ha total area), representing approximately 20% of the study sites, were interpreted and then digitized using ARC/INFO.

RESULTS

Eleven tree species were encountered in the overstory (Table 1). *Quercus velutina* Lam. (black oak) dominated all diameter classes with the 10-29 cm diameter classes accounting for more than 50% of all tallied individuals, with only three stems/ha greater than 60 cm dbh. This species had an IV of 143.5, averaged 321.1 stems/ha, averaged 23.6 cm dbh, and accounted for 78.1% of the total basal area. *Quercus marilandica* Muench. (blackjack oak), second in IV (34.7), was mostly restricted to smaller diameter classes, averaged 111.6 stems/ha, and averaged 16.5 cm dbh. The remaining species were mostly in the 10-39 cm diameter classes, *Carya texana* Buckl. (black hickory) averaged 26.3 stems/ha, while *Pinus strobus* L. (white pine) averaged 26.1 stems/ha. Coppice stems accounted for about 16% of the stems encountered. *Quercus velutina* accounted for the majority, averaging 27 coppice trees/ha with 57.7 stems/ha, and accounted for about 10% of the total basal area on the site (Table 2).

Dead-standing individuals averaged 24.6 stems/ha with a basal area of 1.01 m2/ha, nearly all being oaks. *Quercus velutina* averaged 15.6 dead-standing stems/ha while *Q. marilandica* accounted for nearly all of the remainder. Most of the dead-standing individuals were in the lower diameter classes. A few dead-standing *Q. velutina* exceeded 40 cm dbh.

The woody understory averaged 15,200 seedlings/ha, 1,775 small saplings/ha, and 295 large saplings/ha (Table 3). Seedling density was relatively high, but the majority was shrubby species. *Quercus velutina* and *Carya texana* accounted for nearly all tree seedlings. Because of the relatively few saplings, the woody understory was open. Again, *Q. velutina* and *C. texana* accounted for the majority of individuals (Table 3). Woody shrubs that were important in the understory included, *Rubus allegheniensis* Porter (common blackberry), *Rhus aromatica* Ait. (fragrant sumac), *Toxicodendron radicans* (L.) Kuntze (poison ivy), and *Cornus drummondii* C. A. Mey. (rough-leaved

Table 1. Densities (stems/ha), diameter classes, basal areas (m^2/ha), relative values, importance values and average diameters of the woody species at Sand Ridge State Forest, Mason County, Illinois. Other species include: *Carya tomentosa* (Poir.) Nutt., *Diospyros virginiana* L., *Juniperus virginiana* L., *Pinus banksiana* Lamb., *Pinus sylvestris* L., *Prunus serotina* Ehrh., *Ulmus americana* L.

Species	Diameter Classes (cm)						Total Stems/ ha	Basal Area m^2/ha	Rel. Den.	Rel. Dom.	I.V.	Av. Diam. (cm)
	10-19	20-29	30-39	40-49	50-59	60+						
Quercus velutina	145.3	107.7	37.7	20.7	6.7	3.0	321.1	16.995	65.4	78.1	143.5	23.6
Quercus marilandica	92.0	17.0	2.3	0.3	--	--	111.6	2.601	22.8	11.9	34.7	16.5
Pinus strobus	12.7	8.7	2.7	2.0	--	--	26.1	1.243	5.3	5.7	11.0	23.0
Carya texana	20.0	3.3	1.7	1.0	0.3	--	26.3	0.849	5.4	3.9	9.3	17.9
Others (7 spp.)	5.7	--	--	--	--	--	5.7	0.080	1.1	0.4	1.5	--
Totals	**275.7**	**136.7**	**44.4**	**24.0**	**7.0**	**3.0**	**490.8**	**21.768**	**100.0**	**100.0**	**200.0**	

Table 2. Density (#/ha) of coppice trees and stems, coppice stems per tree, average basal area (m^2/ha) of coppice stems, and the average diameter (cm) of coppice stems at Sand Ridge State Forest, Mason County, Illinois.

Species	Trees (#/ha)	Stems (#/ha)	Stems/tree	Basas Area (m^2/ha)	Avg. Diameter (cm)
Quercus velutina	27.0	57.7	2.1	2.721	23.4
Quercus marilandica	9.0	19.3	2.2	0.540	17.9
Carya texana	1.7	3.3	2.0	0.099	17.1
Totals	**37.7**	**80.3**		**3.360**	

Table 3. Density (individuals/ha) of woody understory species in a woodland community at Sand Ridge State Forest, Mason County, Illinois. (*exotic species)

Species	Seedlings	Small Saplings	Large Saplings
Quercus velutina	3750	575	100.0
Carya texana	2850	600	85.0
Prunus serotina	250	250	20.0
Quercus marilandica	250	25	30.0
Carya tomentosa	150	125	17.5
**Pinus strobus*	150	25	17.5
Juniperus virginiana	--	100	15.0
**Pinus sylvestris*	--	--	5.0
Ulmus americana	--	--	2.5
Celtis occidentalis	--	--	2.5
Rubus allegheniensis	2250	--	--
Rhus aromatica	1850	--	--
Toxicodendron radicans	1650	--	--
Cornus drummondii	1600	50	--
Rubus occidentalis	300	--	--
Ribes missouriense	100	--	--
Viburnum prunifolium	50	--	--
**Lonicera maackii*	--	25	--
Totals	**15200**	**1775**	**295.0**

dogwood) (Table 3). Woody exotic shrubs were uncommon with *Lonicera maackii* (Rupr.) Maxim. (Amur honeysuckle) occurred in a few plots.

In approximately 60 years the sand savanna at Sand Ridge State Forest became a closed forest. Based on an analysis of 1939 aerial photographs approximately 50.18% of the study area was covered by trees and large shrubs. Canopy cover increased dramatically by 1957 to 68.96%, followed by an increase of 78.66% by 1969, 88.08% by 1988, and 89.50% by 1998. Woody encroachment is most obvious where pine plantations were introduced in the 1940s and 1950s. The cover in 1939 lacked introduced conifers, and only the native *Juniperus virginiana* (red cedar) was present. Conifers were not observed in the 50 sites digitized from the 1939 aerial photographs, but they were found in 35 of the 50 digitized sites in the 1998 photographs.

DISCUSSION

The woody plant communities at Sand Ridge State Forest are very different today compared to the early 1800s, mostly due to the planting of pines and reduced fire frequencies followed by the total absence of fire in recent decades (Taft 1997). In presettlement times repeated fires were probably responsible for maintaining an open savanna with a sparse woody understory (Ebinger and McClain 1991, McClain and Elzinga 1994). The larger trees maintained an open-grown appearance with low branches and branch-scars. A few large, open-grown trees were still present in the study plots. Because of fire and droughty conditions, most of this present day forest was originally savanna communities with numerous prairie openings.

Presently, occasional fires and droughty conditions have allowed the perpetuation of oak species. *Quercus velutina* is reproducing with numerous seedlings and saplings in the understory (Table 3). *Quercus marilandica*, in contrast, has a very low rate of reproduction. The large number of seedlings, saplings, and small diameter trees of *Carya texana* suggests this species will increase in importance (Table 3). As canopy closure continues, shade-intolerant oaks may not effectively reproduce. *Carya texana*, a fire-sensitive but relatively shade-tolerant species, could become the dominant understory species and became more common in the lower diameter classes, particularly if management fires are not introduced on a regular basis.

Woody exotic species are common in Sand Ridge State Forest. At least 10 species of pine were planted in the 1940s and early 1950s, and many pine plantations are present (Maier 1976, Andrews 2004). The most commonly planted species was *Pinus strobus*. A few rows of this introduced exotic species were present in our study plots, indicating this species was also planted in native hardwood forests and savannas. Smaller individuals, plus occasional seedlings indicate that this species is reproducing.

Using GLO survey records, Rodgers and Anderson (1979) described the presettlement vegetation of Mason County. They found that tree density averaged 7.44 trees/ha with an average basal area of 1.19 m^2/ha in savanna communities. *Quercus velutina* was, by far, the dominant woody species, accounting for more than half of the IV. *Quercus marilandica* was second in IV followed by various *Carya* (hickory) species. The many small diameter witness trees reported in the GLO survey indicate that the relatively shade-intolerant oaks and hickories were reproducing, and were replacing themselves in savanna, woodland, and closed forest communities (Rodgers and Anderson 1979).

Most forests studied within the Illinois River sand deposits were closed canopy dry sand forests located on dune deposits where *Quercus velutina* and *Q. marilandica* were usually the leading dominants along with a few hickory species. *Carya texana* occasionally replaced *Q. marilandica* as second in IV in those forests (Jenkins et al. 1991, Coates et al. 1992, McClain et al. 2002). These forests probably represented sand savannas that have become closed forests due to fire suppression and woody species invasion (Considine et al. 2013). This study at Sand Ridge State Forests suggests that a combination of increased fire frequency, selective timber harvest, and possibly grazing will be necessary to restore and maintain the savanna communities that were once characteristic of this site.the 1998 photographs.

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Freshwater Mussels (Bivalvia: Unionidae) of the La Moine and Spoon Rivers, Illinois

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ABSTRACT

Understanding the distribution of current mussel communities within a basin is the initial step towards conserving these imperiled animals. Two basins in which little were known of the current mussel communities are the La Moine and Spoon Rivers in western Illinois. The mussel communities were sampled at 87 locations within these two basins between 2009-2011 and historical mussel communities served as a comparison within these basins. The current samples produced 1,171 live mussels representing 21 species from the La Moine River basin and 1,291 live individuals representing 21 species from the Spoon River basin. Forty-three species have been collected from the Spoon River basin since 1892. The La Moine River basin has not been sampled as thoroughly as the Spoon and only 25 species have been documented from this basin since the first samples in the late 1980's.

INTRODUCTION

Freshwater mussels (Bivalvia: Unionidae) are a crucial component of freshwater ecosystems (Howard and Cuffey, 2006; Vaughn and Hakenkampf, 2001). They improve water quality by removing suspended sediments from the water column (Howard and Cuffey, 2006), and filtering microscopic organisms and detritus from the water (Strayer and Smith, 2003). Due to their sessile feeding habits and relative inability to escape disturbances (e.g., pollutants and sedimentation), mussel populations may be an indicator of the 'health' of water bodies (Williams et al., 1993). Thus, lack of mussels in a stream may indicate poor water quality. In addition, mussels also are a food source for various vertebrates (Diggins and Stewart, 2000; Shively and Vidrine, 1984; Williams et al., 2008).

Eastern North America still has some of the most diverse freshwater mussel populations in the world, even though populations throughout the North America have declined drastically over the past century (Bogan, 1993; Williams et al., 1993). Of the approximately 300 species historically found in the United States, only 70 species are considered stable (Williams et al., 1993). The rivers of Illinois once provided habitat for 80 species of mussels, but these rivers have seen a decline in mussel populations similar to the decline world-wide (Cummings and Mayer 1997). Of the 80 historical species, 17 are no longer found alive in Illinois (6 due to extinction) and 29 species are listed as endangered, threatened or as a species of special concern (Tiemann et al., 2007; Cummings and Mayer, 1997; Illinois Endangered Species Protection Board, 2011).

The goal of our study was to provide documentation of the freshwater mussel species present in the Spoon and La Moine River basins. Through past surveys, a total of 41 species have been documented from the Spoon River basin and 23 species have been documented from the La Moine River basin (Tiemann et al., 2007). The number of live species in these basins appear to be declining, and since 1969, only 20 species have been found alive in the Spoon River basin and only 16 in the La Moine river basin (Cummings and Mayer, 1997; Tiemann et al., 2007). The current status of the missing species is unknown, and neither basin has been surveyed in recent years. The last mussel survey of the Spoon River basin was in 1971 (Starrett, unpublished); the La Moine River basin was last surveyed between 1989-91, but only in McDonough and Hancock counties (Baumgardner, 1995.

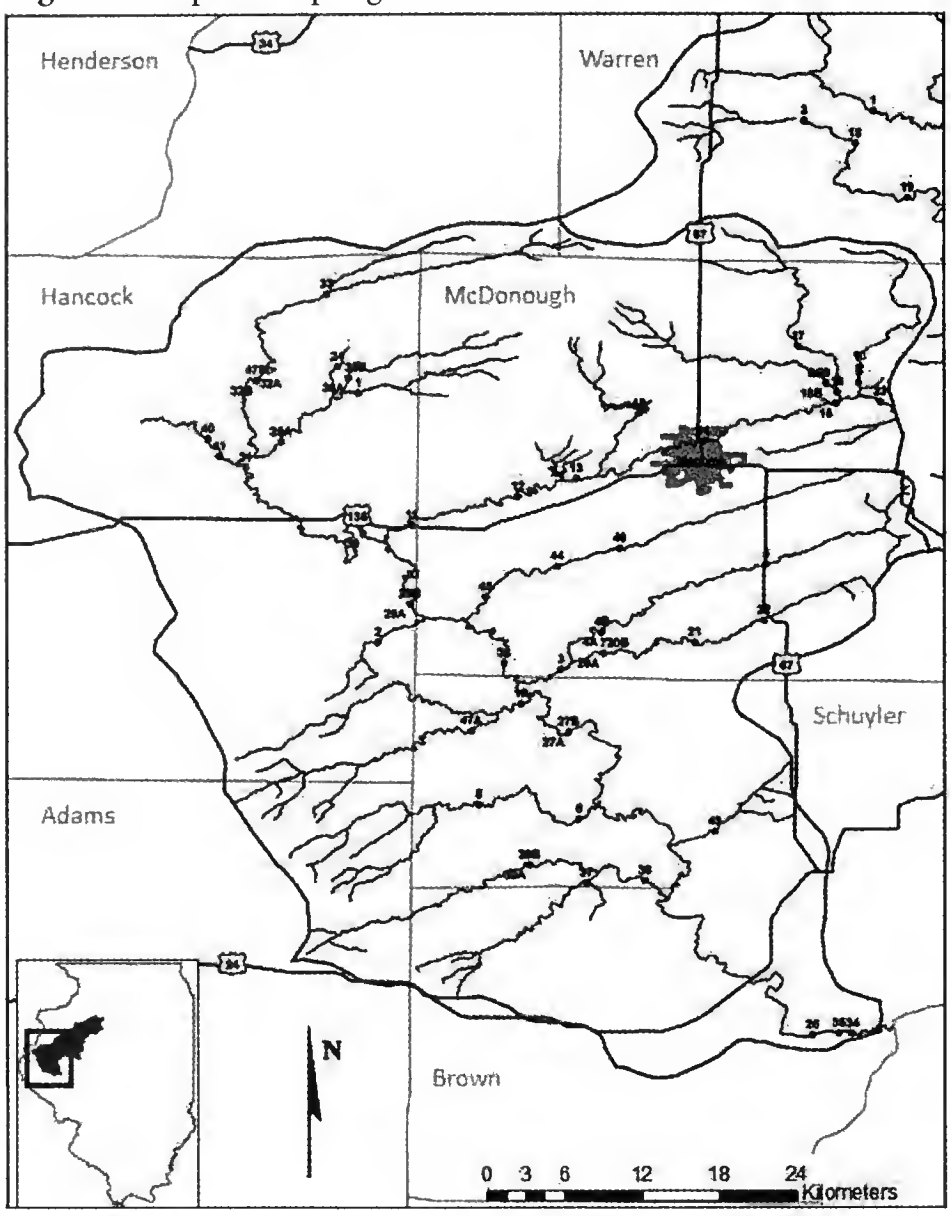
METHODS

The La Moine and Spoon River basins drain approximately 8300 km^2 of land between the Mississippi and Illinois Rivers in western Illinois (Figures 1 and 2). These rivers are of similar length and drainage area (La Moine: 203 km, 3,497 km^2, Spoon River: 260 km, 4,805 km.^{2}), and empty into the La Grange Pool of the Illinois River (IDNR, 2001; IDNR, 1998). Both rivers flow primarily through the Galesburg Section of the western forest-prairie natural division, although the headwaters of the Spoon River rise in the western section of the Grand Prairie Division (Schwegman, 1973).

Sites were selected throughout the La Moine and Spoon River basins based on the following criteria: 1) historical data was available for the site, 2) the site was part of the Illinois Department of Natural Resources and Illinois Environmental Protection Agency Intensive Basin Survey, 3) or because there was a lack of data from that portion of the stream.

At each site, a four-hour timed search method was implemented. While timed searches are not appropriate for assessing population density, abundance, or precise changes over time, they are appropriate for preliminary surveys and detecting species' presence at a site (Strayer and Smith, 2003). At most sites, based on site-specific conditions, live individuals and shell material were collected by hand-grabbing and visual sampling. Due to high water restrictions at three sites, mussels were collected using a brail (Sites 45, 46, and 47, Table 1). A haphazard sampling design was implemented during sampling, and an effort was made to sample all available habitat types. Following the four-hour search, live individuals were identified to species and total lengths (mm) were measured. The nomenclature employed in this report follows Turgeon et al. (1998), except for recent taxonomic changes to the gender ending of lilliput (*Toxolasma parvum*), which follows Williams et al. (2008). One representative of

Figure 1. Map of sampling locations in the La Moine River basin.



each species was kept from each location and sent to the Illinois Natural History Survey (INHS) Mollusk Collection for species confirmation. If only shell material was collected for a species, the shell was classified as recent dead (periostracum present, nacre pearly, and soft tissue may be present) or relict (periostracum eroded, nacre faded, shell chalky) based on condition of the best shell found. The remaining live individuals were returned to the stream.

Historical mussel sampling data was compiled for both basins to compare current mussel communities to past communities. Much of the historical data for both basins was gathered from the INHS Mollusk Collection, as well as Cummings and Mayer (1997) and Tiemann et al. (2007). Additional Spoon River basin data was found in Strode (1892) and an unpublished INHS survey performed by W.C. Starrett in 1971. Further La Moine River basin data were compiled from a survey of the La Moine River basin across McDonough and Hancock counties from 1989-1991 (Baumgardner, 1995).

Table 1. Sample locations in the La Moine River basin.

Site	Date	Stream	Location	Latitude	Longitude
1	10-Aug-10	Baptist Creek	4.3 mi S LaHarpe, 2850E bridge	40.521	-90.957
2	10-Jun-10	Bronson Creek	1.8 mi NW Plymouth, 2900E bridge	40.311	-90.941
3	6-Jul-10	Camp Creek	5.7 mi SSW Fandon, 50N Bridge	40.288	-90.789
4A	1-Sep-09	Camp Creek	3.4 mi S Fandon, 800E Bridge	40.320	-90.755
4B	10-Aug-10	Camp Creek	3.4 mi S Fandon, 800E bridge	40.320	-90.754
5	3-Sep-09	Camp Creek	3.4 mi N Industry, 1525E bridge	40.376	-90.619
6	5-Jul-10	Cedar Creek	0.6 mi NNW Camden, IL Route 99 bridge	40.162	-90.774
7	9-Aug-10	Cedar Creek	6.3 mi SE Augusta, Huntsville Rd bridge	40.302	-90.754
8	5-Jul-10	Cedar Creek*	4.8 mi WNW Camden, 250E bridge	40.174	-90.857
9	31-Aug-10	Drowning Fork	2.5 mi SW Bushnell, 1700N bridge	40.529	-90.542
10	3-Jul-10	Drowning Fork*	2.0 mi WSW Bushnell,1900N bridge	40.542	-90.541
11	14-Aug-09	E. Fork LaMoine River	6.4 mi W Colchester, Rt 136 bridge	40.410	-90.912
12	31-Aug-10	E. Fork LaMoine River	1.7 mi WNW Colchester, 1100N bridge	40.434	-90.824
13	17-Sep-09	E. Fork LaMoine River	1.8 mi NNE Colchester, 700E bridge	40.449	-90.776
14	13-Aug-09	E. Fork LaMoine River	1.4 mi N Macomb, Glenwood Park	40.480	-90.671
15	31-Aug-10	E. Fork LaMoine River	4 mi SW Bushnell, 1800E bridge	40.512	-90.561
16	23-Sep-09	E. Fork LaMoine River	3.6 mi SW Bushnell, 1650N bridge	40.521	-90.560
17	3-Jul-10	E. Fork LaMoine River	4.3 mi E Good Hope, Waco Rd bridge	40.559	-90.592
18A	3-Jul-10	Farmers Fork	3.7 mi WSW Bushnell, 1700N bridge	40.528	-90.569
18B	31-Aug-10	Farmers Fork	3.7 mi WSW Bushnell, 1700N bridge	40.528	-90.569
19	10-Jun-10	Flour Creek	5.6 mi ESE Plymouth, Flour Creek Rd bridge	40.260	-90.822
20A	15-Sep-09	Grindstone Creek	4.6 mi S Fandon, 800E bridge	40.302	-90.754
20B	9-Aug-10	Grindstone Creek	4.6 mi S Fandon, 800E bridge	40.302	-90.754
21	12-Aug-09	Grindstone Creek	3.9 mi WSW Industry, E 1200th St bridge	40.311	-90.678
22	3-Sep-09	Grindstone Creek	0.7 mi W Industry, 350N bridge	40.329	-90.620
23	12-Jul-10	Kepple Creek	2.9 mi SSW Bushnell, 2000E bridge	40.513	-90.524
24	2-Jul-10	La Harpe Creek	2.8 mi S La Harpe, 2750Ebridge	40.544	-90.974
25A	2-Jul-10	La Harpe Creek	7.5 mi NE Carthage, 1950N bridge	40.480	-91.020
25B	10-Aug-10	La Harpe Creek	7.5 mi NE Carthage, 1950N bridge	40.528	-90.569
26	15-Oct-10	La Moine River	4.2 mi SE Ripley, La Grange Lock Rd	39.981	-90.581
27A	11-Oct-10	La Moine River	5.7 mi N Camden, Guinea Rd bridge	40.235	-90.782
27B	29-Aug-11	La Moine River	5.7 mi N Camden, Guinea Rd bridge	40.236	-90.782
28	9-Sep-10	La Moine River	4.4 mi E Plymouth, 75N Bridge	40.294	-90.836
29A	7-Oct-10	La Moine River	3.6 mi N Plymouth, St. Mary's Rd bridge	40.344	-90.914
29B	29-Aug-11	La Moine River	3.6 mi N Plymouth, St. Mary's Rd bridge	40.344	-90.914
30	9-Sep-10	La Moine River	7.9 mi NNW Plymouth, 1420E bridge	40.403	-90.953
31	24-Aug-10	La Moine River	5.4 mi ENE Carthage, 1800E bridge	40.459	-91.050
32A	10-Oct-10	La Moine River	5.2 mi SW La Harpe, 2300N bridge	40.532	-91.041
32B	30-Aug-11	La Moine River	5.2 mi SW LaHarpe, 2300N bridge	40.532	-91.041
33	4-Jul-10	La Moine River	1.6 mi NNW La Harpe, Route 94 bridge	40.605	-90.983
34	15-Oct-10	La Moine River	7.0 mi WSW Beardstown	39.982	-90.548
35	15-Oct-10	La Moine River	7.5 mi WSW Beardstown	39.982	-90.559
36A	2-Jul-10	Little Creek*	3.4 mi S La Harpe 2300N bridge	40.534	-90.965
36B	10-Aug-11	Little Creek	3.4 mi S LaHarpe, 2300N bridge	40.534	-90.965
37	29-Jun-10	Little Missouri Creek	3.1 mi S Camden, IL Route 99 bridge	40.109	-90.768
38	6-Jul-10	Missouri Creek	4.0 mi SE Camden, Avery Rd bridge	40.111	-90.719
39A	6-Jul-10	Missouri Creek	3.1 mi SW Camden, Missouri Creek Rd bridge	40.124	-90.815
39B	9-Aug-10	Missouri Creek	3.1 mi SW Camden, Missouri Creek Rd bridge	40.124	-90.815
40	10-Aug-10	Rock Creek	4.8 mi ENE Ferris, 2200E bridge	40.483	-91.081
41	2-Jul-10	Rock Creek*	4.9 mi NE Carthage, 2250E bridge	40.468	-91.072
42	25-Aug-09	Spring Creek	4.1 mi NW Macomb,Spring Lake Park	40.503	-90.724
43	6-Jul-10	Stony Branch	5.6 mi WNW Rushville, Rattlesnake Ranch bridge	40.152	-90.661
44	31-Aug-10	Troublesome Creek	3.5 mi S Colchester, 600E bridge	40.375	-90.792
45	30-Sep-09	Troublesome Creek	4.9 mi WSW Fandon, 450N bridge	40.349	-90.851
46	1-Sep-09	Troublesome Creek	1.9 mi. NE Fandon, 875E bridge	40.390	-90.740
47A	10-Jun-10	Williams Creek	4.6 mi E Augusta, Williams Creek Rd ford	40.237	-90.863
47B	9-Aug-10	Williams Creek	4.6 mi E Augusta, Williams Creek Rd ford	40.532	-91.041

RESULTS

Forty-seven sites were sampled from the La Moine River basin (Figure 1, Table 1) and 40 sites from the Spoon River basin (Figure 2, Table 3). From the La Moine River basin, 1,169 live individuals were collected representing 21 species (Table 2) during 177 person hours of sampling. Twenty-four of the 47 sites sampled in the La Moine River basin produced live individuals. Wabash pigtoe (*Fusconaia flava*) was the most common species in the La Moine River basin, comprising 15.3% of all live individuals. Plain pocketbook (*Lampsilis cardium*) and pistolgrip (*Tritogonia verrucosa*) made up 12.7% and 11.9% of live individuals, respectively. No species found in the La Moine River basin were represented by shell material only, at least one live individual was found for each species.

Table 2. Species and number of live freshwater mussels found at each site in the La Moine River basin. Only sites where live individuals or shell material were found are listed. Numbers indicate the number of live individuals found, D represents only freshly deceased shells collected and R indicates only relic shell material found.

		Site																				
Species	**Common Name**	**1**	**3**	**4B**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**18A**	**18B**	**19**	**20A**	**20B**	**22**	**23**
Subfamily Ambleminae																						
Amblema plicata	threeridge										D	R										
Fusconaia flava	Wabash pigtoe							D		4	17	10	40	21	6	17	60					
Quadrula pustulosa	pimpleback							D	1	12	41	9	18	14		1	1					
Quadrula quadrula	mapleleaf			1					R	2	4	3	30	5	2	1	1					
Tritogonia verrucosa	pistolgrip			D						2	5	5	9	4					6	10		
Uniomerus tetralasmus	pondhorn					4	4	1	D									D				
Subfamily Anodontinae																						
Lasmigona complanata	white heelsplitter	R		2				D	D	1		1	1	1	1	2	R	D	3	23		D
Pyganodon grandis	giant floater		D					6	1				2	D		11	19			D		
Strophitus undulatus	creeper			1				D	D	5	1	7	30	13	4	7	14		2	21		
Utterbackia imbecillis	paper pondshell									D			1									
Subfamily Lampsilinae																						
Lampsilis cardium	plain pocketbook	22	1							9	43	71	11						3	7		
Lampsilis siliquoidea	fatmucket										6	11	5									
Lampsilis teres	yellow sandshell									1	2											
Leptodea fragilis	fragile papershell			R				D	D	2	D	1	2	R					1	3		
Ligumia subrostrata	pondmussel		1	2				9	D						1	2	10		2	6		
Obliquaria reflexa	threehorn wartyback																					
Potamilus alatus	pink heelsplitter																					R
Potamilus ohiensis	pink papershell																			R		
Toxolasma parvum	lilliput			D	D	D		23	D	1				5		D	64			2	D	
Truncilla donaciformis	fawnsfoot																					
Truncilla truncata	deertoe									2		2	2									
Total Live Individuals Collected		**0**	**2**	**6**	**0**	**4**	**4**	**39**	**2**	**41**	**119**	**120**	**151**	**63**	**14**	**41**	**169**	**0**	**17**	**72**	**0**	**0**
Live Species		**0**	**2**	**4**	**0**	**1**	**1**	**4**	**2**	**11**	**8**	**10**	**12**	**7**	**5**	**7**	**7**	**0**	**6**	**7**	**0**	**0**
Live + Fresh Dead Species		**0**	**3**	**6**	**1**	**2**	**1**	**9**	**8**	**12**	**10**	**10**	**12**	**8**	**5**	**8**	**7**	**2**	**6**	**8**	**1**	**1**
Total Species		**1**	**3**	**7**	**0**	**2**	**1**	**9**	**9**	**12**	**10**	**11**	**12**	**9**	**5**	**8**	**8**	**0**	**6**	**9**	**0**	**2**

		Site																				
Species	**Common Name**	**24**	**25A**	**25B**	**27B**	**28**	**29A**	**29B**	**30**	**31**	**32A**	**32B**	**36B**	**37**	**38**	**39B**	**40**	**42**	**44**	**45**	**47B**	**Total**
Subfamily Ambleminae																						
Amblema plicata	threeridge							1													R	1
Fusconaia flava	Wabash pigtoe		1		1			2													R	179
Quadrula pustulosa	pimpleback				1	1	D	6	D											1		106
Quadrula quadrula	mapleleaf				1	1		6	1	D		1						12		2		73
Tritogonia verrucosa	pistolgrip				2	3	2	75	8			8						R				139
Uniomerus tetralasmus	pondhorn	D									R		R				R		R			9
Subfamily Anodontinae																						
Lasmigona complanata	white heelsplitter	D	1	1				4			3	22			D		D	7	4	4	D	81
Pyganodon grandis	giant floater					1			1									6		3		50
Strophitus undulatus	creeper						D	D				1							9	12		127
Utterbackia imbecillis	paper pondshell				1			1										10				13
Subfamily Lampsilinae																						
Lampsilis cardium	plain pocketbook		1	D	1		R	1	1									R	R			149
Lampsilis siliquoidea	fatmucket																	1			R	23
Lampsilis teres	yellow sandshell		1	1	3	3	D	23	D	1												35
Leptodea fragilis	fragile papershell		1		1	9	D	5	2		D	R							R	D		27
Ligumia subrostrata	pondmussel									D							R	R				33
Obliquaria reflexa	threehorn wartyback					1		3														4
Potamilus alatus	pink heelsplitter							1							R							1
Potamilus ohiensis	pink papershell			R		1																1
Toxolasma parvum	lilliput		1	3								3	R	D		R	D	D	3		D	105
Truncilla donaciformis	fawnsfoot					3		2														5
Truncilla truncata	deertoe							2														8
Total Live Individuals Collected		**0**	**6**	**5**	**11**	**23**	**2**	**132**	**13**	**1**	**3**	**35**	**0**	**0**	**0**	**0**	**0**	**36**	**16**	**22**	**0**	**1169**
Live Species		**0**	**6**	**3**	**8**	**9**	**1**	**14**	**5**	**1**	**1**	**5**	**0**	**0**	**0**	**0**	**0**	**5**	**3**	**5**	**0**	**21**
Live + Fresh Dead Species		**2**	**6**	**4**	**8**	**9**	**5**	**15**	**7**	**3**	**2**	**5**	**0**	**1**	**1**	**0**	**2**	**6**	**3**	**6**	**2**	**21**
Total Species		**2**	**6**	**5**	**8**	**9**	**6**	**15**	**7**	**3**	**3**	**6**	**2**	**1**	**2**	**1**	**4**	**9**	**6**	**6**	**5**	**21**

Figure 2. Map of sample locations in the Spoon River basin.

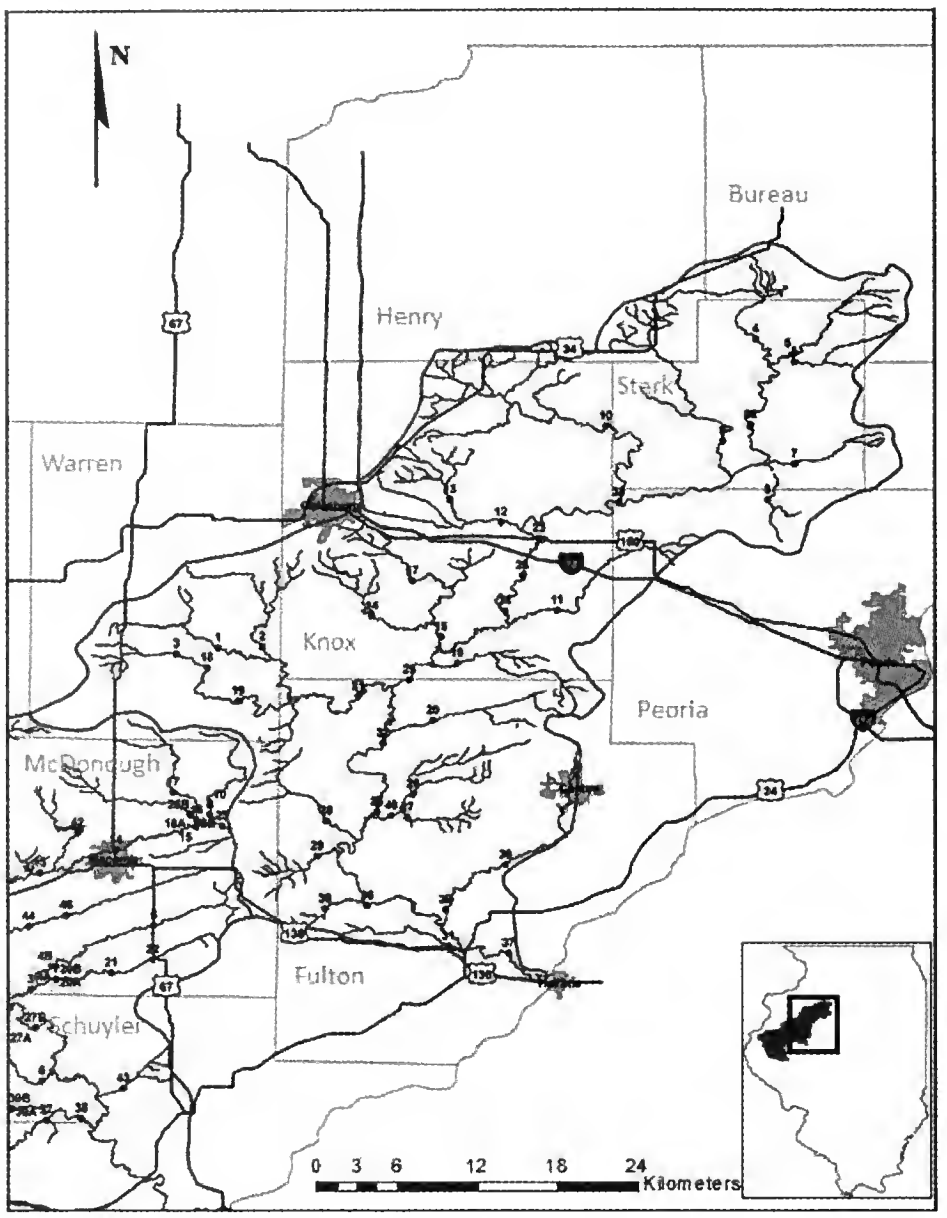


Table 3. Sample locations in the Spoon River basin.

Site	Date	Stream	Location	Latitude	Longitude
1	16-Jul-10	Cedar Creek	3.5 Mi SSE Berwick, 147th St bridge	40.758	-90.529
2	16-Jul-10	Cedar Fork	4 mi SE Berwick, 90th Ave bridge	40.760	-90.468
3	16-Jul-10	Negro Creek	4.2 mi NE Roseville, 105th St bridge	40.750	-90.587
4	19-Jul-10	W Fork Spoon River	2 mi E Elmira, Rt 93 bridge	41.181	-89.788
5	19-Jul-10	E Fork Spoon River	4 mi SW Bradford, 1300E bridge	41.161	-89.735
6	20-Jul-10	Coopers Defeat Creek	1.8 mi NE Modena, 1300E bridge	41.150	-89.735
7	20-Jul-10	Camp Creek	4 mi SSE Wyoming, 1300E bridge	41.009	-89.735
8	20-Jul-10	Prince Run	2 mi N Princeville, 22300N bridge	40.960	-89.772
9	21-Jul-10	Indian Creek	3.5 mi SW Wyoming, 450N bridge	41.041	-89.834
10	21-Jul-10	Walnut Creek	4.6 mi NW West Jersey, 2350E bridge	41.062	-89.995
11	21-Jul-10	French Creek	4 mi NW Yates City, 2000E bridge	40.809	-90.062
12	21-Jul-10	Court Creek	1.5 mi W Dahinda, 1600E bridge	40.930	-90.139
13	21-Jul-10	North Creek	5 mi ENE East Galesburg,1700N bridge	40.962	-90.210
14	22-Jul-10	Brush Creek	4 mi E Abingdon, 600N bridge	40.801	-90.318
15	22-Jul-10	Haw Creek	3.5 mi SW Maquon,400N bridge	40.772	-90.222
16	22-Jul-10	Littlers Creek	2 mi NW Rapatee, 1300E bridge	40.736	-90.200
17	22-Jul-10	Haw Creek	3 mi S Knoxville,950E bridge	40.850	-90.261
18	23-Jul-10	Negro Creek	6.3 mi E Roseville, IL 116 bridge	40.731	-90.545
19	23-Jul-10	Swan Creek	2.5 mi SE Greenbush, 1500E bridge	40.685	-90.502
20	2-Aug-10	Coal Creek	4 mi SE London Mills,1100E bridge	40.658	-90.233
21	2-Aug-10	Cedar Creek	3.5 mi SW London Mills,3400N bridge	40.691	-90.336
22	3-Aug-10	Spoon River	2 mi W Wyoming, Rt 17 bridge	41.063	-89.795
23	3-Aug-10	Spoon River	2.5 mi SE Dahinda, Rt 150 bridge	40.908	-90.087
24	3-Aug-10	Spoon River	5 mi NE Maquon, Hwy 17 bridge	40.857	-90.110
25	3-Aug-10	Spoon River	London Mills, 2nd St bridge	40.714	-90.266
26	4-Aug-10	Turkey Creek	1 mi SE Blyton, 900N bridge	40.557	-90.261
27	4-Aug-10	Put Creek	3 mi S Blyton, 2300N bridge	40.524	-90.269
28	4-Aug-10	Shaw Creek	1.5 mi NW Marietta, 325E bridge	40.520	-90.381
29	5-Aug-10	Barker Creek	1.8 mi S Marietta, 250E bridge	40.471	-90.393
30	5-Aug-10	Big Creek	2 mi SW Bryant, 1650E bridge	40.459	-90.133
31	5-Aug-10	Tater Creek	1.5 mi NW Duncan Mills	40.347	-90.213
32	26-Aug-10	Spoon River	0.5 mi E Ellisville, Rt 17 bridge	40.627	-90.302
33	30-Aug-10	Spoon River	Elmore, Mill Rd bridge	40.957	-89.977
34	30-Aug-10	Spoon River	0.8 mi ENE Maquon, 650N bridge 1	40.808	-90.134
35	30-Aug-10	Spoon River	3.5 mi NW Smithfield, 2350N bridge	40.532	-90.311
36	1-Sep-10	Spoon River	Bernadotte	40.403	-90.325
37	1-Sep-10	Spoon River	3 mi S Lewistown, Waterford Rd bridge	40.337	-90.130
38	22-Sep-10	Francis Creek	4.5 mi NW Ipava, E Holler Rd bridge	40.399	-90.383
39	24-Sep-10	Big Creek	3.3 mi W Lewistown, Co Rd 14 bridge	40.398	-90.216
40	25-Sep-10	Put Creek	5.8 mi WNW Cuba, Co Rd 2 bridge	40.527	-90.291

In the Spoon River basin, 1,291 live individuals of 21 species (Table 4) and shell material of an additional 8 species were collected in 160 person-hours of sampling. Live individuals were found at 34 of the 40 Spoon River basin sites. *L. cardium* was the most common species found in the Spoon basin and accounted for 21% of live individuals. *F. flava* accounted for 14% of live individuals and the white heelsplitter (*Lasmigona complanata*) accounted for 13%.

No threatened or endangered mussel species were collected alive during this survey although relict shells were collected. A relict shell of the state endangered snuffbox (*Epioblasma triquetra*) was found at Spoon River site 24. Relict shells of three state threatened species, slippershell mussel (*Alasmidonta viridis*), spike (*Elliptio dilatata*) and black sandshell (*Ligumia recta*), were also found in the Spoon River basin.

Historical mussel data for the La Moine River basin was divided into four time periods. The survey completed by Baumgardner (1995) was supplemented by additional INHS data and are the earliest samples known from the La Moine River basin, herein designated as "pre-1991." Surveys during this time period recorded 13 live species from the La Moine River basin, as well as shell material of 4 additional species (Table 5). Surveys completed between 1991-2000 entirely consisted of INHS collection data and also produced 13 live species, 3 of which were not found live in the previous time period. Shell material of *Utterbackia imbecillis*, which had not been previously recorded, was also found in this time period. The number of live species collected from the La Moine River basin increased to 18 from INHS surveys between the years 2001-2009. In this survey, 21 species were found live. Overall, 25 species have been documented from the La Moine River basin.

The mussels of the Spoon River basin have been studied more thoroughly than those in the La Moine River basin. The Spoon River basin historical data was divided into seven time periods. The first were samples performed by W.S. Strode between 1892-1912. In this time period, 36 species were collected from the Spoon River basin, all of which were represented by live individuals (Table 6). Surveys done in 1949 by J.M. Reed (INHS data) found only 14 species, also all represented by live individuals. Since 1957, the number of live species found in the Spoon River basin has ranged from 17 (1990s INHS surveys) to 21 (2000-2009 INHS surveys and W.C. Starrett 1971), but has remained relatively constant. In this survey, 21 species were found live. From over 100 years of sampling, a total of 43 species have been collected as either live individuals or shell material from the Spoon River basin.

Table 4. Species and number of live freshwater mussels found at each site in the Spoon River basin. Only sites where live individuals or shell material were found are listed. Numbers indicate the number of live individuals found, D represents only freshly deceased shells collected and R indicates only relic shell material found. Threatened or endangered species indicated next to species name (SE = State Endangered, ST = State Threatened).

		Site																			
Species	**Common Name**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Subfamily Ambleminae																					
Amblema plicata	threeridge					R		R		R											
Elliptio dilatata (SE)	spike						R	R			R										
Fusconia flava	Wabash pigtoe		14			19		R		11	33	8				12			5	7	
Pleurobema sintoxia	round pigtoe									1	10					3					
Quadrula metanevra	monkeyface										1										
Quadrula pustulosa	pimpleback					2				4	23	4				14	D			4	
Quadrula quadrula	mapleleaf															7					
Tritogonia verrucosa	pistolgrip		1			7														1	
Uniomerus tetralasmus	pondhorn																	1	1		
Subfamily Anodontinae																					
Alasmidonta viridis (ST)	slippershell mussel									R	R										
Anodontoides ferussacianus	cylindrical papershell				D	R	10	6	25		4	16		1							D
Lasmigona complanata	white heelsplitter	1	D	D	7	2			133			2		D	D		7	2	4	3	R
Lasmigona compressa	creek heelsplitter	3				2			6		D	9		D	D		D		4	2	
Lasmigona costata	flutedshell																				
Pyganodon grandis	giant floater					D					R						6				
Strophitus undulatus	creeper		3		2	1			1	1	7	12	1	D		1	3	2	5	1	D
Subfamily Lampsilinae																					
Actinonaias ligmentina	mucket																				
Epioblasma triquetra (SE)	snuffbox																				
Lampsilis cardium	plain pocketbook	3	1			45	D	R		42	8	12	15	3	D		3			22	
Lampsilis siliquoidea	fatmucket	D	5	1		9		R		2	6		2		1		1	1	1	14	
Lampsilis teres	yellow sandshell																				
Leptodea fragilis	fragile papershell	D	D		D	D					D										
Ligumia recta (SE)	black sandshell																				
Obliquaria reflexa	threehorn wartyback																				
Potamilus alatus	pink heelsplitter																				
Potamilus ohiensis	pink papershell																				
Toxolasma parvum	lilliput	1	D						D	D	R	1				1	1				D
Truncilla donaciformis	fawnsfoot																				
Truncilla truncata	deertoe																				
Venustaconcha ellipsiformis	ellipse																				
Total Live Individuals Collected		**8**	**24**	**1**	**9**	**87**	**10**	**6**	**165**	**61**	**92**	**64**	**18**	**4**	**1**	**38**	**21**	**6**	**20**	**54**	**0**
Live Species		**4**	**5**	**1**	**2**	**8**	**1**	**1**	**4**	**6**	**8**	**8**	**3**	**2**	**1**	**6**	**6**	**4**	**6**	**8**	**0**
Live + Fresh Dead Species		**6**	**8**	**2**	**4**	**10**	**2**	**1**	**5**	**7**	**10**	**8**	**3**	**5**	**4**	**6**	**8**	**4**	**6**	**8**	**3**
Total Species		**6**	**8**	**2**	**4**	**12**	**3**	**6**	**5**	**9**	**14**	**8**	**3**	**5**	**4**	**6**	**8**	**4**	**6**	**8**	**4**

		Site																			
Species	**Common Name**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**39**	**40**	**Total**
Subfamily Ambleminae																					
Amblema plicata	threeridge	R	1	D	R				R				R	R	R	R		R			1
Elliptio dilatata (SE)	spike	R	R	R	R									R			R				R
Fusconia flava	Wabash pigtoe	23	D	6	28		R							19	14	D					188
Pleurobema sintoxia	round pigtoe		1	7	13	2							D	27	3	R					67
Quadrula metanevra	monkeyface	3	2	14	91	3							D	34	D	D					148
Quadrula pustulosa	pimpleback	17	1	2	19				R				1	31	16	2		R	1		140
Quadrula quadrula	mapleleaf	2		3	19	1		5	1		D		D	3	8	2	1	D	2		52
Tritogonia verrucosa	pistolgrip	12	D					1			1			4							27
Uniomerus tetralasmus	pondhorn						D			D		D									2
Subfamily Anodontinae																					
Alasmidonta viridis (ST)	slippershell mussel										R	R									
Anodontoides ferussacianus	cylindrical papershell																				R
Lasmigona complanata	white heelsplitter	1							R					R	1						63
Lasmigona compressa	creek heelsplitter	1	3		2				1		1	R		1	D	2	D		D		172
Lasmigona costata	flutedshell		D											D							27
Pyganodon grandis	giant floater				R									R							R
Strophitus undulatus	creeper	11									D								R	R	6
Subfamily Lampsilinae																					
Actinonaias ligmentina	mucket				R										R	R	R				R
Epioblasma triquetra (SE)	snuffbox				R																R
Lampsilis cardium	plain pocketbook	13	6	34	D	3		D	2	D	D		3	59	1	3	R		3		278
Lampsilis siliquoidea	fatmucket	R	R	R	1		R	D						1		R					45
Lampsilis teres	yellow sandshell																R				R
Leptodea fragilis	fragile papershell	2	D	D	1	D		D			D		D	D	D	D	D	1	D		4
Ligumia recta (SE)	black sandshell													R							R
Obliquaria reflexa	threehorn wartyback																	1			1
Potamilus alatus	pink heelsplitter																	D			D
Potamilus ohiensis	pink papershell										1						1	4			6
Toxolasma parvum	lilliput						D		D	D		D									4
Truncilla donaciformis	fawnsfoot				1								1			D					2
Truncilla truncata	deertoe													1							1
Venustaconcha ellipsiformis	ellipse		R	R			R										R				R
Total Live Individuals Collected		**85**	**14**	**66**	**179**	**9**	**0**	**6**	**4**	**0**	**3**	**0**	**5**	**182**	**43**	**9**	**2**	**6**	**6**	**0**	**1291**
Live Species		**10**	**6**	**6**	**10**	**4**	**0**	**2**	**3**	**0**	**2**	**0**	**3**	**11**	**6**	**4**	**2**	**3**	**3**	**0**	**21**
Live + Fresh Dead Species		**10**	**11**	**9**	**11**	**6**	**3**	**5**	**5**	**3**	**7**	**2**	**8**	**13**	**10**	**8**	**4**	**5**	**5**	**0**	**23**
Total Species		**13**	**14**	**12**	**16**	**6**	**6**	**5**	**8**	**3**	**7**	**3**	**9**	**18**	**12**	**13**	**10**	**7**	**6**	**1**	**30**

Table 5. Comparison of current and historical mussel species collected from the La Moine River basin. "L" indicates species found alive and "X" represents only shell (dead or relict) of species found at time of collection.

Species	Common Name	pre-1991 (Baumgardner & INHS)	1991-2000 (INHS Data)	2001-2009 (INHS Data)	2009-2011 Current Survey
Subfamily Ambleminae					
Amblema plicata	threeridge	L	L	L	L
Fusconia flava	Wabash pigtoe		L	L	L
Megalonaias nervosa	washboard	X			
Quadrula nodulata	wartyback	X			
Quadrula pustulosa	pimpleback		L	L	L
Quadrula quadrula	mapleleaf	L	L	L	L
Tritogonia verrucosa	pistolgrip	L	L	L	L
Uniomerus tetralasmus	pondhorn	L	L	L	L
Subfamily Anodontinae					
Anodonta suborbiculata	flat floater			L	
Lasmigona complanata	white heelsplitter	L	L	L	L
Pyganodon grandis	giant floater	L	L	L	L
Strophitus undulatus	creeper	L	L	L	L
Utterbackia imbecillis	paper pondshell		X	L	L
Subfamily Lampsilinae					
Actinonaias ligamentina	mucket	X			
Lampsilis cardium	plain pocketbook	X	L	L	L
Lampsilis siliquoidea	fatmucket	L	L		L
Lampsilis teres	yellow sandshell	L		L	L
Leptodea fragilis	fragile papershell	L	L	L	L
Ligumia subrostrata	pondmussel			L	L
Obliquaria reflexa	threehorn wartyback				L
Potamilus alatus	pink heelsplitter	L			L
Potamilus ohiensis	pink papershell	L			L
Toxolasma parvum	lilliput	L	L	L	L
Truncilla donaciformis	fawnsfoot				L
Truncilla truncata	deertoe			L	L
Total Species 25	**Total Live Species**	**13**	**13**	**17**	**21**
	Total Species	**17**	**14**	**17**	**21**

DISCUSSION

Based on the historical data available for the Spoon River basin, many species have been extirpated from this drainage within the last century (Strode, 1892). Forty-three are known historically, yet only 21 have been collected alive within the last decade (Table 6). The loss of species in this basin should be no surprise, since the majority of mussel species in United States and Canada are extinct, endangered, threatened, or of special concern (Williams et al., 1993). The historical collection data we have available suggests that many species were lost between 1912 and 1949 (Table 6), although this is simply speculation.

The historical data available for the La Moine River basin indicates that 25 species were present at one time, although we do not have data for this basin before the late 1980's. The Spoon and La Moine River basins are similar in size, location, and present mussel communities, thus we believe that there were likely more than 25 species present in the La Moine River basin in the early 1900's, despite the lack of any shell material. Records from the Spoon River basin show that 12 species have not been collected, in any form, after 1990 (Table 6). It is possible that shell material from these species has been completely eroded, buried or washed downstream.

We found that the current mussel communities of the La Moine and Spoon River basins are similar to each other and consist primarily of common, widespread mussels found throughout Illinois. Seventeen mussel species are common to both the Spoon and La Moine River basins, all of which are considered stable in Illinois (Cummings and Mayer, 1992). Species with either federal or state conservation status were only represented in our surveys by relict shell material, and it is unlikely that viable populations exist in the Spoon or La Moine River basins at this time. Although species' loss has occurred in these basins over time, both basins still maintain over 20 live species of mussels.

Within each watershed, particular streams appear to support exceptional diversity in this geographical context. In the La Moine River basin, we collected more than ten live species at several sampling locations in the East Fork La Moine and La Moine River, just downstream of its confluence with the East Fork La Moine River. In the Spoon River basin, we found the greatest species diversity within the mainstem and its larger tributaries (e.g., Cedar, Indian, and Walnut Creek). Conversely, we found several headwater streams in the La Moine River basin containing only shell material. While mussel diversity often increases with stream size (Strayer, 1983), the absence of live mussels with shell material present may indicate that these headwater species can no longer persist here. It is unclear at this time whether this is due to current water quality issues, lack of habitat or if their decline was caused by past water quality issues and these tributaries are too far from stable populations for these species to recolonize. A similar pattern has been in observed in other Midwestern systems (Myers-Kinzie et al., 2001), and the documentation of headwater species' loss may be an important issue to consider in the future.

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Table 5. Comparison of current and historical mussel species collected from the Spoon River basin. "L" indicates species found alive and "X" represents only shell (dead or relict) of species found at time of collection. Threatened or endangered species indicated next to species name (FE = Federal Endangered, SE = State Endangered, ST = State Threatened).

		1892-1912	1949	1957	1971	1990s	2000-2009	2010
Species	**Common Name**	(Strode)	(Reed)	(Matteson)	(Starrett)	(INHS)	(INHS)	Current Survey
Subfamily Ambleminae								
Amblema plicata	threeridge	L	L	L	L	L	L	L
Cyclonaias tuberculata (ST)	purple wartyback	L						
Elliptio crassidens (ST)	elephantear				X			
Elliptio dilatata (ST)	spike	L			X	X	X	L
Fusconia flava	Wabash pigtoe	L	L	L	L	L	L	L
Megalonaias nervosa	washboard	L						
Plethobasus cyphyus (SE)	sheepnose	L						
Pleurobema sintoxia	round pigtoe	L	L	L	L	L	L	L
Quadrula fragosa	winged mapleleaf	L						
Quadrula metanevra	monkeyface	L	L	L	L	L	L	L
Quadrula nodulata	wartyback	L						
Quadrula pustulosa	pimpleback	L	L	L	L	L	L	L
Quadrula quadrula	mapleleaf	L		L	L	L	L	L
Tritogonia verrucosa	pistolgrip	L	L	L	L	L	L	L
Uniomerus tetralasmus	pondhorn						L	L
Subfamily Anodontinae								
Alasmidonta marginata	elktoe	L						
Alasmidonta viridis (ST)	slippershell mussel				X			X
Anodonta suborbiculata	flat floater	L						
Anodontoides ferussacianus	cylindrical papershell			L	L	L	L	L
Arcidens confragosus	rock pocketbook	L						
Lasmigona complanata	white heelsplitter	L	L	L	L	L	L	L
Lasmigona compressa	creek heelsplitter			L	L	L	L	L
Lasmigona costata	flutedshell	L	L	X			X	X
Pyganodon grandis	giant floater	L	L	L	L	L	L	L
Strophitus undulatus	creeper	L	L	L	L	L	L	L
Utterbackia imbecillis	paper pondshell	L						
Subfamily Lampsilinae								
Actinonaias ligamentina	mucket	L			L		X	X
Epioblasma triquetra (SE)	snuffbox							X
Lampsilis cardium	plain pocketbook	L	L	L	L	L	L	L
Lampsilis higginsi (FE)	Higgins eye	L			L			
Lampsilis siliquoidea	fatmucket	L		L	L	L	L	L
Lampsilis teres	yellow sandshell	L	L	L	L		X	X
Leptodea fragilis	fragile papershell	L	L	L	L	L	L	L
Ligumia recta (ST)	black sandshell	L		L			X	X
Obliquaria reflexa	threehorn wartyback	L						L
Obovaria olivaria	hickorynut	L			X			
Potamilus alatus	pink heelsplitter	L			X		L	X
Potamilus capax (FE)	fat pocketbook	L						
Potamilus ohiensis	pink papershell	L	L	L	L	L	L	L
Toxolasma parvum	lilliput	L		L	L	L		L
Truncilla donaciformis	fawnsfoot	L		L	L		L	L
Truncilla truncata	deertoe	L					L	L
Venustaconcha ellipsiformis	ellipse					X		X
Total Species 43	**Total Live Species**	**36**	**14**	**20**	**21**	**17**	**20**	**21**
	Total Species	**36**	**14**	**21**	**26**	**19**	**25**	**30**

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The Effects of the Herbicides Aminopyralid and Glyphosate on Growth and Survival of *Dipsacus laciniatus* (Dipsacaceae) Rosettes with Different Taproot Diameters

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ABSTRACT

Cutleaf teasel (*Dipsacus laciniatus*) is invasive to native flora in the northeastern United States. We compared the effectiveness of control by the herbicides aminopyralid (Milestone®) and glyphosate (Roundup®). We expected plants with smaller taproot diameters to be more susceptible to the herbicides, and aminopyralid to be more effective than the more general herbicide, glyphosate. We transplanted 228 plants into pots in the Millikin greenhouse and divided them into three groups according to taproot diameter. We randomly assigned plants of each size into three treatment groups to be sprayed with aminopyralid, glyphosate, or water only. Ten weeks after treatment, we dried and weighed all plants. All plants treated with aminopyralid died. Plants treated with glyphosate had higher survival with larger taproots. We conducted a second experiment to determine if aminopyralid was successful at half the concentration and again, all plants treated with aminopyralid died. Future studies could further decrease aminopyralid concentrations and test aminopyralid in the field.

INTRODUCTION

Dipsacus laciniatus, commonly referred to as cutleaf teasel, is an invasive monocarpic perennial in the Midwestern United States (Glass 2009) that has become a threat to native species (Solecki 1991, Huenneke and Thomson 1994) and is categorized as a noxious weed (USDA 2008). Teasel exists as a basal rosette for at least two years (Werner 1975) that reaches a diameter of approximately 30 cm which is effective in shading nearby growth. When conditions are optimal (Vitalis et al. 2004), a flowering stalk grows from the rosette and can produce 1,300 to 33,500 seeds (Bentivegna 2006). Between 28-86% of the seeds germinate, and 6% are still viable after three years (Bentivegna and Smeda 2011). Seeds are dispersed easily by means of mowing, bird feces (Werner 1979), and vehicular traffic (Solecki 1991). Its well-defined taproots reach depths of 75 cm with diameters of 5 cm (Werner 1975). As a common roadside plant, teasel has a competitive advantage because it can tolerate high levels of roadside contamination (Beaton and Dudley 2004).

As teasel abundance increases, development of an effective and inexpensive control method has become more essential. Methods include mowing, digging up the taproot, burning, and herbicides. The effectiveness of mowing is limited, as it must be completed mid-growing season, after the flowering stalk has bolted from the rosette, but before the seeds are viable (Dudley et al. 2009). Digging up the taproot is effective, but is unrealistic to use on large populations of teasel because it is too labor intensive (Glass 2009). Burning teasel is not an effective method because teasel rosettes resist fire (Solecki 1991). A prairie fire is actually beneficial to teasel because many other plants will die in the fire, decreasing the competition for teasel, which forms dense monocultures that are green early and late in the growing season. Natural control through insects, fungi, mites, viruses, and nematodes has been studied but further research is still necessary (Sforza 2004, Rector et al 2006). Further studies are also necessary on herbicide use as a control method for teasel, because results have been inconsistent (Werner 1979, Glass 1991, Dudley et al. 2009; Zimmerman et al. 2013).

We decided to further investigate herbicide use. We chose to study glyphosate, the active ingredient in widely used herbicides with low toxicity to mammals (Appleby 2005), such as Roundup®, because previous studies with glyphosate have shown inconsistent results of success (Werner 1979; Glass 1991; Zimmerman et al. 2013). We also included aminopyralid, the active ingredient in Milestone® in our study because of its specificity. Our first objective was to determine if there is a relationship between taproot diameter and ability of rosettes to survive herbicide treatment. We hypothesized that there would be a positive relationship between survival rates and increasing taproot diameter. Our other objective was to compare success of a general herbicide (glyphosate) and a specific herbicide (aminophyralid). As indicated on the herbicide labels, Milestone® is specifically formulated to target invasive broadleaf species, whereas Roundup® gives broad-spectrum control. Therefore, we hypothesized that aminopyralid would be more effective at killing teasel rosettes than glyphosate.

METHODS

From 15 September 2010 to 28 October of 2010, we collected and measured the diameter of 228 teasel rosettes from two collection sites in Illinois, the barrow pit on East Boyd Road, Macon County, and a field between Clinton Lake and 1700 East Road, DeWitt County. We transferred rosettes into 4L pots in the greenhouse of Leighty-Tabor Science Center on Millikin University's campus. All rosettes were given at least two weeks to recover from transplanting shock.

On 18 November 2010, we split the rosettes into three groups of 57 according to taproot diameter: small (0.1 cm - 1.0 cm), medium (1.5 cm – 2.5 cm) and large (≥ 3 cm). Within each size group, we randomly assigned rosettes to three treatments; sprayed with aminopyralid (n = 19), sprayed with glyphosate (n = 19), or sprayed with tapwater (n = 19). We calibrated two backpack sprayers and prepared the treatments by the recommended rate on the herbicide labels. We prepared one sprayer with 114 mL of glyphosate and 3.79 L of tapwater and the other sprayer with 3 mL of aminopyralid and 3.79 L of tapwater. We added 5 mL of Dawn® dishwashing liquid as a surfactant for each solution. We applied herbicide

until the rosette leaves were covered, but not dripping. Then we randomly placed all rosettes on three benches in the greenhouse to prevent positional effects. After 12 days, we quantified the damage to each rosette using a five-point damage scale. Ten weeks after the treatments, we dried and weighed the above ground rosettes and the roots.

For a second experiment, beginning 28 January 2011, we split our remaining unused 57 rosettes into small (0.1 cm – 1.5 cm) and large (≥ 1.6 cm) according to taproot diameter. Our sample size would have been low had we used three groups, as in the first experiment. Within each size group, we randomly assigned rosettes to be sprayed with Milestone® or to serve as a control (no spray). We used a previously calibrated sprayer to apply half the recommended rate of aminopyralid. The protocol for the rest of the second experiment followed that of the first experiment.

We used the same methods for statistical analysis in both experiments. We used a 3(sizes) x 3(treatments) x 2(plant parts) on SPSS to compare the herbicide treatments among the sizes for both rosettes and roots and multiple t-tests to compare means within treatments or sizes. Since we used multiple t-tests, we used $P < 0.03$ for significance.

RESULTS

In the first experiment, a visual inspection at 12 days showed glyphosate appeared to be the more effective herbicide. Rosettes were green only in the center, while rosettes sprayed with aminopyralid were merely curled. However, after 10 weeks, many of the rosettes sprayed with glyphosate had recovered. There were significant differences in biomass of the rosettes (Fig. 1) and the roots (Fig. 2) among treatments at all sizes. The control group had the highest biomass for roots and rosettes whereas aminopyralid had the lowest. There were also significant differences among size groups in each of the treatments (Fig. 1 and 2). Roots and rosettes that started out largest had the highest ending biomass. There was not a significant difference between large roots treated with glyphosate and large roots in the control group. All other t-tests between treatment groups of the same size classes showed significant differences for both roots and rosettes at $P < 0.03$. All controls survived while none sprayed with aminopyralid survived. In rosettes sprayed with glyphosate, the survival rate increased as the taproot diameter increased (small 64.7%; medium 77.8%; large 82.4%).

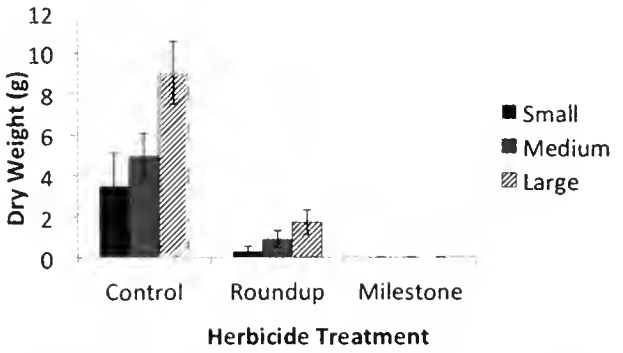

Figure 1. Dry weights ± 2 SE for *Dipsacus laciniatus* above ground rosettes 10 weeks after treatment. General Linear Model (3x3x2) on SPSS showed statistically significant differences among means for both herbicide treatments and taproot diameters ($P < 0.001$).

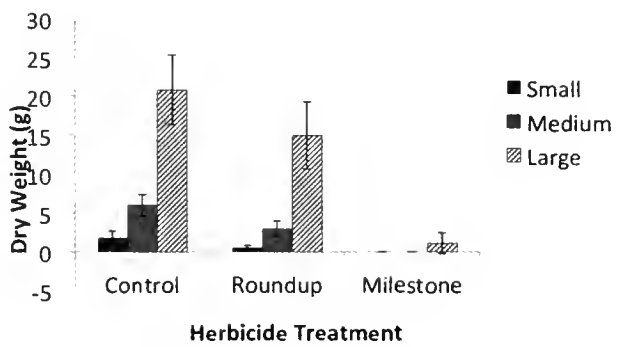

Figure 2. Dry weights ± 2 SE for *Dipsacus laciniatus* roots 10 weeks after treatment. General Linear Model (3x3x2) on SPSS showed statistically significant differences among means for both herbicide treatments and taproot diameter ($P < 0.001$).

In the second experiment with half the recommended concentration of aminopyralid, treatments were significantly different from controls for both roots and shoots at $P < 0.03$ (Fig. 3 and 4). Again, all controls survived and none sprayed with aminopyralid survived.

DISCUSSION

We expected plants with smaller taproot diameters to be more susceptible to the herbicides, and aminopyralid to be more effective than glyphosate in controlling teasel. Both hypotheses were supported. Glyphosate was not effective at killing rosettes,

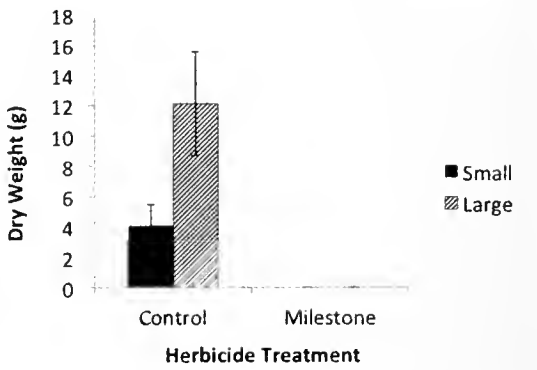

Figure 3. Dry weights ± 2 SE for *Dipsacus laciniatus* above ground rosettes from second experiment with half the recommended concentration of Milestone® (aminopyralid). General Linear Model (2x3x2) on SPSS showed statistically significant differences among means for both herbicide treatments and taproot diameters ($P < 0.03$).

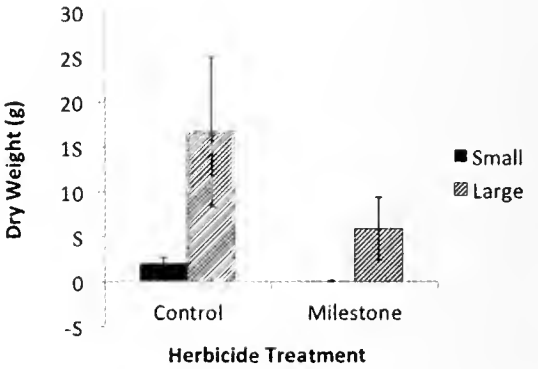

Figure 4. Dry weights ± 2 SE for *Dipsacus laciniatus* roots from second experiment with half the recommended concentration of Milestone® (aminopyralid). General Linear Model (2x3x2) on SPSS showed statistically significant differences among means for both herbicide treatments and taproot diameters ($P < 0.03$).

supporting results of an earlier field study (Zimmerman et al. 2013) and contradicting two earlier studies (Werner 1979; Glass 1991). There was a positive relationship between survival rates of rosettes sprayed with glyphosate and increasing diameter of taproot. Aminopyralid was effective at all taproot diameters at the recommended rate and at half the recommended rate.

We determined survival rates by dry weights of teasel rosettes. In each experiment, some of the large roots were still present even when rosettes were dead. Although we weighed these roots, we doubt they were capable of producing healthy new rosettes, because the roots showed signs of decay. The taproots were rubbery and the epithelial layer was gone or not secured to the root.

Herbicide labels suggested that effects of the herbicides would occur within two weeks. After 12 days, damage was more apparent in rosettes sprayed with glyphosate than rosettes sprayed with aminopyralid. However, over time, many of the rosettes sprayed with glyphosate recovered, while all the rosettes sprayed with aminopyralid died. Visual damage at 12 days was not predictive of survival rates. Many rosettes treated with glyphosate recovered, although in a deformed state. Further study over a longer duration is needed to determine whether those rosettes would be able to flower and produce seeds.

An effective teasel control strategy should cause little disturbance to the surrounding habitat. Herbicides often damage native, non-target species (Werner 1979; Glass 1991). Application of herbicides to rosettes in late fall or early spring may reduce effects on non-target species when most other plants are not photosynthetically active but teasel is (Bentivegna and Smeda 2008, Dudley et al. 2009). Since aminopyralid is effective on teasel at half the recommended rate, it may not be as harmful to native species, especially because it targets species such as teasel. With this specificity and low concentrations necessary for effective control, the treatments could be applied at any time of the year. When our teasel rosettes were transplanted, some of the surrounding vegetation was also transplanted, resulting in inadvertent inclusion of other species in the pots. In the second experiment, after rosettes in the treatment group died, other species in the pots continued to grow. Future studies should test lower concentrations of aminopyralid in the field and directly test its effects on non-target native vegetation. Our results provide support for aminopyralid use as an effective control agent for cutleaf teasel.

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Vascular Flora of the Sand Ridge State Forest, Mason County, Illinois

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ABSTRACT

The vascular plants of Sand Ridge State Forest, Mason County, Illinois, were surveyed between 2002 and 2006. This extensive forest tracts is the largest area of sand dominated plant communities owned and managed by the state of Illinois [3,035 ha (11.7 sq. miles)]. Dry sand forest and degraded dry sand savanna dominate the state forest along with a few dry sand prairies, ponds, and extensive cultural communities. The many anthropogenic-influenced areas include extensive pine plantations, a trail system exceeding 43 km, along with camping, picnicking, and other recreational sites. A total of 554 vascular plant species in 104 families were documented in the state forest, mostly with voucher specimens, though nearly 460 species were reported by earlier botanists, including some species that lack vouchers and could not be verified by the present study. A total of 141 non-native species (exotics) were found, mostly in the cultural communities, while two endangered species, *Astragalus distortus* Torr. & Gray (bent milk vetch) and *Lesquerella ludoviciana* (Nutt.) S. Wats. (silver bladderpod) were recorded along with one threatened species, *Cyperus grayoides* Mohlenbr. (sand prairie flatsedge). Active management will be needed to maintain and restore the quality of the plant communities at the Sand Ridge State Forest.

INTRODUCTION

Wind-blown sand deposits from glacial outwash are common in the northern half of Illinois. The result of erosion events associated with Wisconsian glaciation (Willman and Frye 1970, Schwegman 1973, King 1981), these deposits account for nearly 5% of the state's land surface. The most extensive of these sand regions are along the Kankakee River in northeastern Illinois, and the Illinois River in Mason and Cass counties in the central part of the state (Gleason 1910, Schwegman 1973, Willman 1973).

The most extensive sand deposits owned and managed by the State of Illinois are at Sand Ridge State Forest in northwestern Mason County. This 3,035 ha (11.7 sq. miles) area contains numerous natural areas, including two state nature preserves (McFall and Karnes 1995). Since the early studies of Gleason (1910) the present authors and their associates have published a few articles concerning the composition of the vegetation of Illinois sand deposits, including detailed studies of four nature preserves within or near Sand Ridge State Forest. Because of its size and continuity we decided to determine the vascular plant species composition of Sand Ridge State Forest. This study significantly increases the data base of vascular plants of the area, provides additional information about endangered and threatened plant species, and adds to our ability to `manage the botanical resources of this state forest.

STUDY AREA

History

Early settlers of the Mason County sand region tried to make a living off the hilly, sandy soils in the northwestern part of the county. Time proved that these deep sandy soils could not sustain agricultural crops, and by the early 1930's many homesteads were abandoned. Initial land purchases for Sand Ridge State Forest began in 1939 for the purpose of stabilizing soil of abandoned farmlands, developing a wood product industry, and setting land aside for public recreation. From the 1940s into the 1950's, pine plantations were established on old pasture-land and abandoned cultivated fields, but also in dry sand prairies scattered throughout the forest. Presently, 1,012 ha of marketable pine plantations are present while most of the remainder is dry oak-hickory sand forest and degraded dry sand savanna (Andrews 2004). Besides being managed as a sustainable forest, numerous recreation features have been added, including more than 43 km of trail, picnicking, camping, skiing, archery, and horse-back riding facilities (Andrews 2004).

Physiography

Sand Ridge State Forest is located in northwestern Mason County about 21 km northeast of Havana, and just west of Forest City, Illinois (parts of townships T22N R7W and T23N R7W). This 3,035 ha (11.7 sq. miles) state forest lies within the Illinois River Section of the Mississippi River and Illinois River Sand Area Natural Division (Schwegman 1973). Much of the Sand Ridge State Forest is located on hilly ground, actually a dune and swale topography created by strong westerly winds after the sand was deposited but before being stabilized with vegetation.

Climate

Central Illinois has a continental climate with warm summers and cold winters. Based on weather data from Havana mean annual precipitation is 96.0 cm, with May having the highest rainfall (11.3 cm). Mean annual temperature is 10.8°C with the hottest month being July (average of 24.6°C), and the coldest January (average of -5.0°C). Frost-free days range from 140 to 206, with the average being 173 days per year (Midwestern Regional Climate Center 2004).

Geology and Soils

The extensive sand deposits on the terraces of the Illinois River in parts of Putman, Marshall, Woodford, Peoria, Tazewell, Mason, Menard, Cass, Morgan, Scott, and Greene counties were formed during the Kankakee Torrents about 14,500 years ago (Willman 1973). At that time the Kankakee sand deposits of northeastern Illinois were formed when glacial lakes drained after glacial moraines and ice dams were breached, resulting in the Kankakee Torrent. The Illinois River sand deposits were formed when these waters of the Kankakee Torrent slowed on entering the broad lowlands of the Illinois River below present day Henne-

pin (Willman and Frye 1970, King 1981).

These windblown sand deposits, commonly referred to as Parkland Sands or The Parkland Formation, consist of dunes and sheet-like deposits between and bordering the dunes (Willman and Frye 1970, Calsyn 1995). The Parkland Formation is usually found on terraces along major river valleys in the northern half of Illinois and consists of medium-grained sands that are sorted by wind from the underlying glacial outwash. These sands were reworked by wind creating their characteristic dune and swale topography. Dunes 6 to 12 meters high are common and occasional dunes are 30 meters high. Some dunes have migrated onto the bluffs and uplands to the east of the river terraces.

Plant Communities

Dry Sand Forest: Forests are generally defined as communities dominated by trees having nearly closed overstories with more than 80% cover (Nuzzo 1986, White and Madany 1978). In these forests the soils of the sand deposits commonly had an A horizon with some accumulated leaf litter, the ground cover had some prairie species but native shade-tolerant forest species were more common, while prairie bunch-grasses were rare except in forest openings. The dune and swale topography plus other natural fire breaks limited the frequency and severity of fires within dry sand forests.

Bishop's Woods Natural Area, a dry sand forest located in the southern part of Sand Ridge State Forest, was surveyed in 1990. This forest had an average density of 247.5 stems/ha (≥10 cm dbh) and an average basal area of 16.1 m2/ha (Jenkins et al. 1991). *Quercus velutina* (black oak) dominated with an importance value (IV) of 144.9 (possible 200), averaged 150.1 stems/ha, and had an average basal area of 13.50 m^2/ha. *Carya texana* (black hickory), *Q. marilandica* (blackjack oak), and *C. tomentosa* (mockernut hickory) were the other common species in the overstory. Post-settlement fire exclusion has increased the acreage of sand forest at the expense of sand savannas (White and Madany 1978, Anderson and Brown 1986, Anderson 1991, Abrams 1992).

Dry Sand Savanna: Savanna communities are defined as having overstories of scattered, open-grown trees and a ground cover dominated by grasses (Curtis 1959, Bray 1960, White and Madany 1978, Nuzzo 1986). The soils in dry sand savannas are sandy with little or no A horizon; the ground cover is composed of prairie species with dominant bunch-grasses mostly less than 1 m tall; while the canopy was dominated by *Quercus velutina* with a cover that averaged between 10 and 50%. Dry sand savannas were associated with dune and swale topography which probably limited the severity of fires (White and Madany 1978, Anderson and Brown 1986, Anderson 1991, Abrams 1992, McClain and Elzinga1994).

Recent studies by Phillippe et al. (2013) indicate that sand savannas in which *Quercus velutina* was dominant, were common in the major sand deposits of Illinois. Most, however, have been extensively degraded by fire suppression and invasion by native woody species. Many are now dry sand forests that lack, or have a greatly reduced abundance of characteristic ground layer species. Degraded dry sand savannas, that are presently dry sand forests, are a dominant community of ridges and slopes on large stabilized dunes at Sand Ridge State Forest, Mason County, Illinois. In the community examined *Q. velutina* dominated with an IV of 143.5 (possible 200), averaged 321.1 stems/ha, and had an average basal area of 17.0 m^2/ha. *Quercus marilandica* was second followed by the exotic *Pinus strobus* (white pine) and *Carya texana*. Based on aerial photographs from the early 1940s this dry sand forest had an open overstory with only about 50% canopy closure (Phillippe et al. 2013).

Dry Sand Prairie: Common in pre-settlement times, these prairies were found on the upper slopes and ridges of dunes and other dry areas throughout the Illinois River sand deposits. In this community the soil lacks a dark A horizon and grasses, most of which were bunch-grasses, were mostly less than 1 m tall. This community, in the absence of recurring fires, developed into a dry sand savanna community (White and Madany 1978). Gleason (1910) was probably the first to quantify the species composition of the Mixed Consocies of the Bunch-Grass Association, which corresponds to the dry sand prairie community of White and Madany (1978). As described by Gleason (1910) this association was dominated by native bunch-grasses and sedges with most of the remaining species restricted to areas of bare soil between bunch-grasses. These secondary species were divided into ecological groups based on their habit and structure: large perennials and shrubs that competed with the bunch-grasses; matplants; interstitial herbs that were mostly annuals and were restricted to the bare sand between the bunch-grasses; and parasitic herbs.

Henry Allan Gleason Nature Preserve, located near the northwestern edge of Sand Ridge State Forest near the small village of Goofy Ridge, contains a small mature dry sand prairie. This small prairie remnant was dominated by dry sand prairie species (McClain et al. 2005). *Schizachyrium scoparium* (little bluestem) was the leading dominant with an IV of 84.6 (200 possible), followed by *Tephrosia virginiana* (goat's-rue), *Opuntia humifusa* (common prickly pear), *Ambrosia psilostachya* (western ragweed), and *Dichanthelium villosissimum* (hairy panic grass). Also, a few mature dry sand prairies, 2 to 5 ha in size, exist within the degraded savanna communities at Sand Ridge State Forest. Dominant species on two of these prairies were nearly identical. *Schizachyrium scoparium* had an IV of 40.1 (possible 200) on Quiver Prairie and 35.7 on Burns Prairie. *Tephrosia virginiana*, *Opuntia humifusa*, *Ambrosia psilostachya* were among the top five species on both prairies, while another common grasses was *Dichanthelium villosissimum* (Ebinger, unpublished data).

Cultural: This community class includes areas that were created by human disturbance. The many anthropogenic-influenced areas include extensive pine plantations, an extensive trail system, along with camping, picnicking, and other recreational sites. Also, a few ponds have been constructed, some which appear to be natural, but probably represent watering holes created for wildlife.

METHODS

Sand Ridge State Forest was visited more than 15 times in 2003 to 2006 to study the floristic composition of sand prairie and sand forest communities. From 2006 to 2012, occasional trips to the state forest

have been made to visit new areas. Voucher specimens were collected, identified, and deposited in the herbarium of the Illinois Natural History Survey, Champaign, Illinois (ILLS). Determination of non-native (exotic) species followed Mohlenbrock (2002) and Gleason and Cronquist (1991), nomenclature follows Mohlenbrock (2002), community classification follows White and Madany (1978), and information about threatened and endangered species follows Illinois Endangered Species Protection Board (2011).

RESULTS AND DISCUSSION

Flora

A total of 554 vascular plant species in 104 families were documented from the Sand Ridge State Forest. Of these, 11 were fern or fern-allies in eight families, 12 gymnosperms in three families, 401 dicots in 80 families, and 130 monocots in 13 families. The plant families with the most taxa were the Poaceae (78 species), Asteraceae (72 species), Fabaceae (31 species), and Cyperaceae (28 species) (Appendix I).

Rare Species

Only three rare species were found in the state forest: *Astragalus distortus* and *Lesquerella ludoviciana* are listed as state endangered while *Cyperus grayoides* is listed as threatened in Illinois. *Astragalus distortus* (bent milk vetch) has recently been rediscovered along a roadside in the state forest. This species is now known from only seven small populations in Illinois, all from disturbed habitats in the Illinois River sand deposits (McClain & Ebinger 2003). *Cyperus grayoides* (sand prairie flatsedge) is relatively common at the Henry Allan Gleason Nature Preserve where it is a dominant species in an active blow-out community (McClain et al. 2005). Also, it was encountered in low numbers at Burns Dry Sand Prairie Natural Area. *Lesquerella ludoviciana* (silvery bladderpod) is a common species of stabilized blow-out communities at Henry Allan Gleason Nature Preserve (McClain et al. 2005). It was first discovered in Illinois at that site in 1904 by H. A. Gleason (Jones and Fuller 1955).

Exotic Species

A total of 141 species (25.6% of the flora) are non-native (exotic). These exotic species commonly colonize all anthropogenic-disturbed habitats. The most notable of these aggressive species affecting Sand Ridge State Forest are: *Alliaria petiolata* (garlic mustard), *Elaeagnus umbellata* (autumn olive). *Festuca arundinacea* (tall fescue), *Lespedeza cuneata* (sericea lespedeza), *Lonicera x bella* (showy fly honeysuckle), *Lonicera maackii* (Amur honeysuckle), *Lonicera morrowii* (Morrow's honeysuckle), *Phalaris arundinacea* (reed canary grass), *Pinus strobus*, *Rosa multiflora* (multiflora rose), and *Saponaria officinalis* (bouncing bet). These exotic species, if not controlled, will continue the degradation of the plant communities at the Sand Ridge State Forest. Presently, the few remaining good quality dry sand prairies will need fire, and probably brush removal to decrease exotic species and control woody encroachment. Also, the combination of increased fire frequency, selective timber harvest, and possibly grazing will be necessary to restore and maintain the savanna communities that were once characteristic of this site.

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APPENDIX I

Vascular plant species encountered and collected at Sand Ridge State Forest, Mason County, Illinois are listed alphabetically by family under the major plant groups. An asterisk indicates non-native (exotic) species (*), but also includes a few native species that are planted in the sand areas and out of their natural range in Illinois. Collecting numbers are preceded by the initial of the collector's name: (B) Daniel T. Busemeyer, (E) John E. Ebinger, (F) Mary Ann Feist, (M) Paul B. Marcum, and (P) Loy R. Phillippe. Voucher specimens are deposited in the Illinois Natural History Survey herbarium (ILLS). The Illinois Natural History Survey herbarium (ILLS) and the University of Illinois herbarium (ILL) were also searched for past collections from Sand Ridge State Forest. Specimens were discovered that were collected by the following individuals: John K. Bouseman, Virginius H. Chase, Irene M. Cull, F. C. Gates, Steven R. Hill, Alfred C. Koelling, Chris T. Maier, Maison, Kenneth R. Robertson, Julian A. Steyermark, and David Voegtlin. C. T. Maier (1976) collected extensively at Sand Ridge State Forest in 1974-75, and his collections have the designation (Maier 1976) in the list. Most of these citations are vouchers, but a few could not be located at ILL.

PTERIDOPHYTA

ASPLENIACEAE

Asplenium platyneuron (L.) Oakes - B1817

DENNSTAEDTIACEAE

Pteridium aquilinum (L.) Kuhn - P37120

DRYOPTERIDACEAE

Cystopteris protrusa (Weatherby) Blasdell - B1816

Dryopteris carthusiana (Villars) H.P. Fuchs - P37136

Woodsia obtusa (Spreng.) Torr. - M2860

EQUISETACEAE

Equisetum hyemale L. - (Maier 1976)

ONOCLEACEAE

Onoclea sensibilis L. – (Maier 1976)

OPHIOGLOSSACEAE

Botrychium dissectum Spreng. – (Maier 1976)

Botrychium virginianum (L.) Sw. - P37147

OSMUNDACEAE

Osmunda claytoniana L. - B1839

THELYPTERIDACEAE

Thelypteris palustris Schott - B1838

GYMNOSPERMAE

CUPRESSACEAE

Juniperus virginiana L. - P36479

PINACEAE

**Pinus banksiana* Lamb. - M2673

**Pinus densiflora* Siebold & Zuccarini - (Maier 1976)

**Pinus echinata* Mill. - M3160

**Pinus resinosa* Ait. - P37183

**Pinus rigida* Mill. - M2645

**Pinus strobus* L. - P37175

**Pinus sylvestris* L. - P36481

**Pinus thunbergii* Parlatore - (Maier 1976)

**Pinus virginiana* Mill. - (Maier 1976)

**Pseudotsuga menziesii* (Mirbel) Franco – (Maier 1976)

TAXODIACEAE

**Taxodium distichum* (L.) Rich. - B1844

ANGIOSPERMAE - DICOTYLEDONAE

ACANTHACEAE

Ruellia humilis Nutt. - F2719

ACERACEAE

Acer negundo L. - B1630

Acer saccharinum L. - M2674

Acer saccharum Marsh. - M2822

AMARANTHACEAE

Amaranthus albus L. - B2088

**Amaranthus hybridus* L. - (Maier 1976)

Froelichia floridana (Nutt.) Moq. - M2629

Froelichia gracilis (Hook.) Moq. - M2803

ANACARDIACEAE

Rhus aromatica Ait. - P36767

Rhus glabra L. - F2803

Rhus hirta L. - B1845

Toxicodendron radicans (L.) Kuntze - P37138

APIACEAE

Cryptotaenia canadensis (L.) DC – (Maier 1976)

**Daucus carota* L. - M2871

Osmorhiza longistylis (Torr.) DC. var. *villicaulis* Fern. - B1699

**Pastinaca sativa* L - (Maier 1976)

Sanicula canadensis L. - M2655

APOCYNACEAE

Apocynum cannabinum L. - P37161

ASCLEPIADACEAE

Ampelamus albidus (Nutt.) Britt. - (Maier 1976)

Asclepias amplexicaulis Small - P36766

Asclepias hirtella (Pennell) Woodson - P36956

Asclepias incarnata L. – (Maier 1976)

Asclepias syriaca L. - F2806

Asclepias tuberosa L. - F2790

Asclepias verticillata L. - B2112

Asclepias viridiflora Raf. - (Maier 1976)

ASTERACEAE

**Achillea millefolium* L. - B1856

Ageratina altissima (L.) R. M. King. & H. Rob. - M2659

Ambrosia artemisiifolia L. - P37121

Ambrosia psilostachya DC. - P37172

Ambrosia trifida L. - P37123

Antennaria neglecta Greene – (Maier 1976)

Antennaria parlinii Fern. ssp. *fallax* (Greene) Bayer & Stebbins - B1664

**Arctium minus* Schk. - M3167

Arnoglossum atriplicifolium (L.) H. Rob. - P37143

Artemisia campestris L. – (Maier 1976)

Aster ericoides L. - M2866

Aster lanceolatus Willd. - B2117

Aster lateriflorus (L.) Britt. - B2117

Aster oblongifolius Nutt. - E28250

Aster ontarionis Wieg. – (Maier 1976)

Aster oolentangiensis Riddell - M2853

Aster pilosus Willd. - M2819

Aster sagittifolius Willd. - (Maier 1976)

Bidens bipinnata L. - M2675

Bidens frondosa L. - B2095

Brickellia eupatorioides (L.) Shinners - M2835

**Carduus nutans* L. – (Maier 1976)

Chrysopsis camporum Greene - F2780

Cirsium altissimum (L.) Spreng. - M2867

Cirsium discolor (Muhl.) Spreng. - P37140

**Cirsium vulgare* (Savi) Tenore - (Maier 1976)

Conyza canadensis (L.) Cronq. - M2832

Coreopsis lanceolata L. - B1722

Coreopsis palmata Nutt. - Bouseman s.n.

Erechtites hieracifolia (L.) Raf. - P37160

Erigeron annuus (L.) Pers. – (Maier 1976)

Erigeron strigosus Muhl. - F2778

Eupatoriadelphus purpureus (L.) R.M. King & H. Rob. - M2870

Eupatorium altissimum L. - M2868

Eupatorium perfoliatum L. – (Maier 1976)

Eupatorium serotinum Michx. - P37139

Euthamia graminifolia (L.) Nutt. – (Maier 1976)

**Helianthus annuus* L. - (Maier 1976)

Helianthus divaricatus L. – (Maier 1976)
Helianthus hirsutus Raf. - M2658
Helianthus occidentalis Riddell - M2852
Helianthus pauciflorus Nutt. – (Maier 1976)
**Helianthus petiolaris* Nutt. - M2631
Helianthus strumosus L. - M2795
Helianthus tuberosus L. - M2872
Heliopsis helianthoides (L.) Sweet – (Maier 1976)
Hieracium longipilum Torr. – (Maier 1976)
Hieracium scabrum Michx. - P37124
Ionactis linariifolius (L.) Greene – (Maier 1976)
Krigia virginica (L.) Willd. - B1667
Lactuca canadensis L. - M2842
Lactuca floridana (L.) Gaertn. - P37142
**Lactuca serriola* L. - (Maier 1976)
**Leucanthemum vulgare* Lam. - (Maier 1976)
Liatris aspera Michx. – (Maier 1976)
**Matricaria discoidea* DC. - B1828
Pseudognaphalium obtusifolium (L.) Hilliard & Burtt. - M2837
Ratibida pinnata (Vent.) Barnh. - M2858
Rudbeckia hirta L. - F2787
Senecio plattensis Nutt. - P36749
Solidago altissima L. - B2090
Solidago canadensis L. - M2863
Solidago gigantea Ait. - (Maier 1976)
Solidago juncea Ait. – (Maier 1976)
Solidago nemoralis Ait. - M2833
Solidago speciosa Nutt. - Maier (1976)
Solidago ulmifolia Muhl. - M2864
**Taraxacum officinale* Weber - B1633
**Tragapogon dubius* Scop. - B1723
**Tragapogon pratensis* L. - (Maier 1976)
Vernonia missurica Raf. – (Maier 1976)
Xanthium strumarium L. – (Maier 1976)

BERBERIDACEAE

Podophyllum peltatum L. – (Maier 1976)

BETULACEAE

**Alnus glutinosa* (L.) Gaertn. – (Maier 1976)
Betula nigra L. - B1840

BIGNONIACEAE

Campsis radicans (L.) Seem. - (Maier 1976)
**Catalpa speciosa* Warder - P37135

BORAGINACEAE

**Buglossoides arvense* (L.) I. M. Johnston; - B1693
**Cynoglossum officinale* L. – (Maier 1976)
Hackelia virginiana (L.) I. M. Johnston - M2653
Lithospermum canescens (Michx.) Lehm. - B1660
Lithospermum croceum Fern. - P36740
Lithospermum incisum Lehm. – (Maier 1976)
Mertensia virginica (L.) Pers. - (Maier 1976)
Myosotis verna Nutt. - B1736

BRASSICACEAE

**Alliaria petiolata* (Bieb.) Cavara & Grande - B1676
**Arabidopsis thaliana* (L.) Heynh. - B1726
Arabis canadensis L. - P36747
Arabis glabra (L.) Bernh. - B1694
**Barbarea vulgaris* R. Br. - M3174
**Brassica nigra* (L.) Koch - (Maier 1976)
**Capsella bursa-pastoris* (L.) Medic. - B1666
Descurainia pinnata (Walt.) Britt. – (Maier 1976)
Draba reptans (Lam.) Fern. - B1628
Erysimum capitatum (Dougl.) Greene - B1665
**Hesperis matronalis* L. - (Maier 1976)
**Lepidium campestre* (L.) R. Br. - (Maier 1976)
**Lepidium densiflorum* Schrad. - P36746
Lepidium virginicum L. - B1730
Lesquerella ludoviciana (Nutt.) S. Wats. - E27791
Rorippa palustris (L.) Besser var. *fernaldiana* (Butters & Abbe) Stuckey - P37155
Rorippa sessiliflora (Nutt.) A. Hitchc. - B1830
**Sisymbrium altissimum* L. – (Maier 1976)
**Sisymbrium loeselii* L. - M3171
**Sisymbrium officinale* (L.) Scop. - (Maier 1976)
**Thlaspi arvense* L. - M3175

CACTACEAE

Opuntia humifusa (Raf.) Raf. - P36755

CAESALPINIACEAE

Cercis canadensis L. - (Maier 1976)
Chamaecrista fasciculata (Michx.) Greene - M2663
Gleditsia triacanthos L. - (Maier 1976)
Gymnocladus dioicus (L.) K. Koch - M2625
Senna marilandica (L.) Link – (Maier 1976)

CALLITRICHACEAE

Callitriche heterophylla Pursh - M3180

CAMPANULACEAE

Campanulastrum americanum (L.) Small - M2687
Triodanis perfoliata (L.) Nieuwl. - B1834

CANNABINACEAE

**Cannabis sativa* L. - Robertson 1301

CAPPARACEAE

Polanisia dodecandra (L.) DC. - M2635

CAPRIFOLIACEAE

**Lonicera x bella* Zabel - P37129
**Lonicera maackii* (Rupr.) Maxim. - B1690
**Lonicera morrowii* Gray - B1659
Sambucus canadensis L. - P37130
Symphoricarpos orbiculatus Moench – (Maier 1976)
**Viburnum opulus* L. - M2799
Viburnum recognitum Fern. - M2800

CARYOPHYLLACEAE

**Arenaria serpyllifolia* L. - B1682
**Cerastium fontanum* Baum. – (Maier 1976)
**Cerastium semidecandrum* L. - B1683
**Dianthus armeria* L. - M2620
**Holosteum umbellatum* L. - B1625
Paronychia canadensis (L.) Wood - M2652
Paronychia fastigiata (Raf.) Fern. - M2855a
**Saponaria officinalis* L. - F2813
Silene antirrhina L. - B1829
**Silene pratensis* (Spreng.) Gordon & Gren. - B1837
Silene stellata (L.) Ait. f. - M2654
**Stellaria media* (L.) Cyrillo - B1717

CELASTRACEAE

Celastrus scandens L. - B1708
Euonymus atropurpureus Jacq. – (Maier 1976)

CERATOPYLLACEAE

Ceratophyllum demersum L. - B2106

CHENOPODIACEAE

**Chenopodium album* L. - Koelling 649
**Chenopodium ambrosioides* L. - (Maier 1976)
Chenopodium standleyanum Aellen - M2665
Cycloloma atriplicifolium (Spreng.) Coult. - M2632
**Kochia scoparia* (L.) Roth - (Maier 1976)
**Salsola tragus* L. - E28134

CISTACEAE

Helianthemum bicknellii Fern. - M3158
Helianthemum canadense (L.) Michx. - B1737
Lechea tenuifolia Michx. – (Maier 1976)

CONVOLVULACEAE

**Ipomoea hederacea* (L.) Jacq. - M2621
Ipomoea lacunosa L. - (Maier 1976)

CORNACEAE

Cornus drummondii C.A. Mey. - P36790
Cornus florida L. – (Maier 1976)
Cornus obliqua Raf. - M2798
Cornus racemosa Lam. - B1826

CORYLACEAE

Corylus americana Walt. - P37153

CUCURBITACEAE

Sicyos angulatus L. – (Maier 1976)

CUSCUTACEAE

Cuscuta cuspidata Engelm. - (Maier 1976)

EBENACEAE

Diospyros virginiana L. - M2824

ELAEAGNACEAE

**Elaeagnus umbellata* Thunb. - B1669

EUPHORBIACEAE

Acalypa rhomboidea Raf. - (Maier 1976)
Acalypha virginica L. - M2820
Chamaesyce geyeri (Engelm.) Small - Hill 28809
Chamaesyce maculata (L.) Small - B2086

Chamaesyce nutans (Lag.) Small - B2089
Croton glandulosus L. - F2800
Crotonopsis linearis Michx. - M2626
Euphorbia corollata L. - F2786
**Euphorbia marginata* Pursh - (Maier 1976)
Poinsettia dentata (Michx.) Kl. & Garcke - P37165

FABACEAE

Amorpha canescens Pursh - M2804
Amorpha fruticosa L. - F2789
Amphicarpaea bracteata (L.) Fern. - M2857
Apios americana Medic. - M3161
Astragalus distortus Torr. & Gray - (Maier 1976)
Baptisia bracteata Ell. - M3191
Crotalaria sagittalis L. - Chase 18444
Dalea candida (Michx.) Willd. - (Maier 1976)
Dalea purpurea Vent. - (Maier 1976)
Desmodium glutinosum (Muhl.) A. Wood - M2657
Desmodium illinoense Gray - M2642
Desmodium paniculatum (L.) DC. - M2818
Desmodium sessilifolium (Torr.) Torr. & Gray - M2851
**Glycine max* (L.) Merr. - (Maier 1976)
**Kummerowia stipulacea* (Maxim.) Makino - P37168
Lespedeza capitata Michx. - P37179
**Lespedeza cuneata* (Dum.-Cours.) G. Don - B2115
**Medicago lupulina* L. - B1684
**Medicago sativa* L. - P37154
**Melilotus albus* Medic. - F2815
**Melilotus officinalis* (L.) Pallas - F2814
**Robinia pseudoacacia* L. - B1733
**Securigera varia* (L.) Lassen - (Maier 1976)
Strophostyles helvula (L.) Ell. - M2634
Strophostyles leiosperma (Torr. & Gray) Piper - M2843
Tephrosia virginiana (L.) Pers. - M2841
**Trifolium hybridum* L. - (Maier 1976)
**Trifolium pratense* L. - M3172
**Trifolium repens* L. - M3169
**Vicia villosa* Roth - B1729
**Vigna unguiculata* (L.) Walp. - Steyermark 68854

FAGACEAE

Quercus x bushii Sarg. - E28112
Quercus marilandica Muench. - M2667
Quercus velutina Lam. - P37171

FUMARIACEAE

Corydalis micrantha (Engelm.) Gray - B1678
Dicentra cucullaria (L.) Bernh. - F2528

GERANIACEAE

Geranium carolinianum L. - P36792

GROSSULARIACEAE

Ribes missouriense Nutt. - P36482
**Ribes odoratum* Wendl. f. - (Maier 1976)

HAMAMELIDACEAE

**Liquidambar styraciflua* L. - B2116

HYDROPHYLLACEAE

Ellisia nyctelea L. - B1680

HYPERICACEAE

Hypericum gentianoides (L.) BSP - (Maier 1976)
Hypericum mutilum L. - B2102
**Hypericum perforatum* L. - B1855
Hypericum punctatum Lam. - M2650
Hypericum sphaerocarpum Michx. - Cull s.n.

JUGLANDACEAE

Carya ovalis (Wangenh.) Sarg. - B2114
Carya texana Buckl. - B1850
Carya tomentosa (Poir.) Nutt. - F2820
Juglans nigra L. - B1721

LAMIACEAE

Agastache nepetoides (L.) Ktze. - M2671
Hedeoma hispida Pursh - (Maier 1976)
Hedeoma pulegioides (L.) Pers. - Maison s.n.
**Lamium amplexicaule* L. - M3170
**Leonurus cardiaca* L. - M2874
Lycopus americanus Muhl. - B2094
Lycopus virginicus L. - B2101
Monarda fistulosa L. - (Maier 1976)
Monarda punctata L. - F2797
**Nepeta cataria* L. - (Maier 1976)
Physostegia virginiana (L.) Benth. - E30369
Prunella vulgaris L. - (Maier 1976)
Pycnanthemum pilosum Nutt. - (Maier 1976)
Scutellaria lateriflora L. - B2092
Scutellaria leonardii Epling - M3156
Stachys tenuifolia Willd. - Cull s.n.
Teucrium canadense L. - P37177

LAURACEAE

Sassafras albidum (Nutt.) Nees - M2670

LYTHRACEAE

Rotala ramosior (L.) Koehne - B2099

MAGNOLIACEAE

Liriodendron tulipifera L. - B2116

MALVACEAE

Callirhoe triangulata (Leavenw.) A. Gray - M2641
**Sida spinosa* L. - P37125

MELASTOMACEAE

Rhexia virginica L. - M2646

MENISPERMACEAE

Menispermum canadense L. - P37137

MOLLUGINACEAE

**Mollugo verticillata* L. - P36765

MORACEAE

**Maclura pomifera* (Raf.) Schneider - M2876
**Morus alba* L. - B1711
Morus rubra L. - (Maier 1976)
**Morus tatarica* L. - P36789

NYCTAGINACEAE

**Mirabilis nyctaginea* (Michx.) MacM. - B1727

OLEACEAE

**Syringa vulgaris* L. - B1670

ONAGRACEAE

Circaea lutetiana L. - P37146
Gaura biennis L. - M2617
Ludwigia alternifolia L. - M2647
Ludwigia palustris (L.) Elliott - B2098
Oenothera biennis L. - P37122
Oenothera clelandii W. Dietr., Raven, & W.L. Wagner - P36957
Oenothera laciniata Hill - M2633

OXALIDACEAE

Oxalis fontana Bunge - M2862
Oxalis stricta L. - B1718
Oxalis violacea L. - P36754

PHRYMACEAE

Phryma leptostachya L. - M2656

PHYTOLACCACEAE

Phytolacca americana L. - M2618

PLANTAGINACEAE

Plantago aristata Michx. - M2813
**Plantago lanceolata* L. - M3173
**Plantago patagonica* Jacq. - P36751
Plantago rugelii Decne. - M2619
Plantago virginica L. - B1687

PLATANACEAE

Platanus occidentalis L. - M2875

POLEMONIACEAE

Phlox bifida Beck - P36484

POLYGALACEAE

Polygala polygama Walt. - (Maier 1976)
Polygala sanguinea L. - M2649

POLYGONACEAE

Antenoron virginianum (L.) Roberty & Vautier - P37145
**Fagopyrum esculentum* Moench - (Maier 1976)
**Fallopia convolvulus* (L.) A. Love - P37252
Fallopia cristata (Engelm. & Gray) Holub - M2640
Fallopia scandens (L.) Holub - M2873
Persicaria amphibium (L.) S.F. Gray - (Maier 1976)
**Persicaria cespitosa* (Blume) Nakai - P37131
Persicaria coccinea (Muhl.) Greene - (Maier 1976)
Persicaria hydropiperoides (Michx.) Small - B2105
Persicaria pensylvanica (L.) Small - P37134
Persicaria punctata (Ell.) Small - P37132
Polygonella articulata (L.) Meisn. - Hill 28805

**Polygonum aviculare* L. - (Maier 1976)

Polygonum tenue Michx. - M2827

**Rumex acetosella* L. - B1734

**Rumex crispus* L. - F2819

Tracaulon sagittatum (L.) Small - (Maier 1976)

PORTULACACEAE

Claytonia virginica L. - B1698

**Portulacca oleracea* L. - B2085

Talinum rugospermum Holz. - P36764

PRIMULACEAE

Androsace occidentalis Pursh - B1627

Lysimachia lanceolata Walt. - F2810

RANUNCULACEAE

Anemone caroliniana Walt. - (Maier 1976)

Anemone cylindrica Gray - M3189

Anemone virginiana L. - M2854

Aquilegia canadensis L. - B1661

Ranunculus abortivus L. - B1688

RHAMNACEAE

Ceanothus americanus L. - B1862

**Rhamnus cathartica* L. - B2113

ROSACEAE

Agrimonia gryposepala Wallr. - P37148

Agrimonia parviflora Sol. - B2103

Agrimonia pubescens Wallr. - P37150

Fragaria virginiana Duchesne - B1663

Geum canadense Jacq. - P36778

Malus ioensis (Wood) Britt. - B1841

**Potentilla norvegica* L. - M3186

**Potentilla recta* L. - B1857

Potentilla simplex Michx. - B1701

Prunus americana Marsh. - (Maier 1976)

Prunus hortulana Bailey - B1629

**Prunus persica* (L.) Batsch - (Maier 1976)

Prunus serotina Ehrh. - B1685

Prunus virginiana L. – B1636

**Pyrus communis* L. - (Maier 1976)

Rosa carolina L. - P36786

**Rosa multiflora* Thunb. - M2805

Rosa palustris Marshall - F2808

Rubus allegheniensis Porter - B1706

Rubus flagellaris Willd. - (Maier 1976)

Rubus hispidus L. - B1705

Rubus occidentalis L. - B1689

Rubus pensilvanicus Poir. - M3163

RUBIACEAE

Cephalanthus occidentalis L. - (Maier 1976)

Diodia teres Walt. - M2636

Galium aparine L. - B1686

Galium circaezans Michx. - F2807

**Galium pedemontanum* (Bellardi) All. - B1858

Galium pilosum Ait. - M2651

RUTACEAE

Ptelea trifoliata L. - B1728

Zanthoxylum americanum Mill. - B1631

SALICACEAE

Populus deltoides Marsh. - B1732

Salix amygdaloides Anderss. - B1731

Salix eriocephala Michx. - (Maier 1976)

Salix humilis Marsh. var. *microphylla* (Anderss.) Fern. - B1632

Salix interior Rowlee - Voegtlin 82-69

Salix nigra Marsh. - B2107

SANTALACEAE

Comandra umbellata (L.) Nutt. - M2669

SCROPHULARIACEAE

Aureolaria grandiflora (Benth.) Pennell - (Maier 1976)

**Linaria genistifolia* (L.) Mill. - (Maier 1976)

Lindernia anagallidea (Michx.) Pennell - M2678

Nuttallanthus canadensis (L.) D. Sutton - B1668

Penstemon pallidus Small - P36748

Scrophularia lanceolata Pursh - B1696

**Verbascum thapsus* L. - M3166

**Veronica arvensis* L. - B1671

Veronica peregrina L. var. *xalapensis* (HBK) St. John - B1836

SOLANACEAE

**Datura stramonium* L. - (Maier 1976)

Physalis heterophylla Nees - F2795

Physalis virginiana Mill. - B1827

Solanum carolinense L. - P36791

**Solanum dulcamara* L. - M3177

Solanum ptychanthum Dunal - P36787

TILIACEAE

Tilia americana L. - M3165

ULMACEAE

Celtis occidentalis L. - B1635

Ulmus americana L. - M2672

Ulmus rubra Muhl. - M2794

URTICACEAE

Boehmeria cylindrica (L.) Sw. - B2110

Parietaria pensylvanica Muhl. - P36745

VERBENACEAE

Phyla lanceolata (Michx.) Greene - (Maier 1976)

Verbena hastata L. - Cull s.n.

Verbena stricta Vent. - F2816

Verbena urticifolia L. - M2690

VIOLACEAE

Viola fimbriatula Smith - (Maier 1976)

Viola lanceolata L. - B1843

Viola palmata L. - M2856

Viola pedata L. - P36753

Viola pratincola Greene - B1702

**Viola rafinesquei* Greene - B1626

Viola sagittata L. - B1842

VITACEAE

Parthenocissus quinquefolia (L.) Planch. - M2796

Vitis aestivalis Michx. - (Maier 1976)

Vitis riparia L. - B1714

Vitis vulpina L. - M2861

ZYGOPHYLLACEAE

**Tribulus terrestris* L. - P36794

ANGIOSPERMAE – MONOCOTYLEDONAE

COMMELINACEAE

Commelina erecta L. - F2781

Tradescantia ohiensis Raf. - P3675

CYPERACEAE

Bulbostylis capillaris (L.) C. B. Clarke - P36952

Carex albicans Willd. - M3183

Carex blanda Dewey - B1709

Carex brevior (Dewey) Mack. - B1849

Carex cephalophora Muhl. - B1821

Carex davisii Schwein. & Torr. - (Maier 1976)

Carex festucacea Schk. - B1823

Carex grayi Carey - M3176

Carex meadii Dewey - M3190

Carex muhlenbergii Schk. - P36736

Carex pellita Willd. - (Maier 1976)

Carex pensylvanica Lam. - B1713

Carex rosea Schk. - B1719

Carex scoparia Schkuhr - M3181

Carex tonsa (Fern.) Bickn. - B1677

Carex vulpinioidea Michx. - M3184

Cyperus erythrorhizos Muhl. - (Maier 1976)

Cyperus esculentus L. - (Maier 1976)

Cyperus grayoides Mohlenbr. - M2684

Cyperus lupulinus (Spreng.) Marcks - F2784

Cyperus schweinitzii Torr. - F2794

Cyperus strigosus L. - B2100

Eleocharis acicularis (L.) Roem. & Schultes - (Maier 1976)

Eleocharis erythropoda Steud. - P36955

Eleocharis ovata (Roth) Roem. & Schultes - P36953

Fimbristylis autumnalis (L.) Roem. & Schultes - B2096

Hemicarpha micrantha (Vahl) Pax - (Maier 1976)

Schoenoplectus pungens (Vahl) Palla - B2093

DIOSCOREACEAE

Dioscorea villosa L. - M3187

IRIDACEAE

**Iris x germanica* L. - (Maier 1976)

Sisyrinchium campestre Bickn. - (Maier 1976)

JUNCACEAE

Juncus acuminatus Michx. - P36951

Juncus interior Wieg. - P36763

Juncus tenuis Willd. - M2821

LEMNACEAE

Lemna minor L. - B2111

Spirodela polyrhiza (L.) Schleiden - (Maier 1976)

Wolffia brasiliensis Weddell - B2109

LILIACEAE

**Allium vineale* L. - B1835

**Asparagus officinalis* L. - (Maier 1976)

Polygonatum commutatum (Schult.) A. Dietr. - B1700

Smilacina racemosa (L.) Desf. - B1703

Smilacina stellata (L.) Desf.- E28323

ORCHIDACEAE

Cypripedium pubescens Willd. - B1825

Spiranthes cernua (L.) Rich. - (Maier 1976)

POACEAE

Agrostis gigantea Roth - (Maier 1976)

Agrostis hyemalis (Walt.) BSP - B1831

Andropogon gerardii Vitman - M2638

Andropogon virginicus L. - (Maier 1976)

Aristida desmantha Trin. & Rupr. - M2811

Aristida purpurascens Poir. - (Maier 1976)

Aristida tuberculosa Nutt. - M2848

**Avena sativa* L. - (Maier 1976)

Bouteloua curtipendula (Michx.) Torr. - M2826

Bouteloua hirsuta Lag. - M2660

Bromus ciliatus L. - (Maier 1976)

**Bromus inermis* Leyss. - P37163

**Bromus japonicus* Thunb. - (Maier 1976)

**Bromus racemosus* L. - F2817

**Bromus tectorum* L. - B1662

Buchloe dactyloides (Nutt.) Engelm. - M2808

Calamovilfa longifolia (Hook.) Scribn. - M2685

Cenchrus longispinus (Hack.) Fern. - M2676

Cinna arundinacea L. - M2859

**Dactylis glomerata* L. - B1720

Danthonia spicata (L.) Roem. & Schultes - B1853

Dichanthelium acuminatum (Sw.) Gould & Clark var. *implicatum* (Scribn.) Gould & Clark - M2825

Dichanthelium depauperatum (Muhl.) Gould - B1735

Dichanthelium oligosanthes (Schult.) Gould - B1725

Dichanthelium perlongum (Nash) Freckm. - P36735

Dichanthelium praecocius (Hitchc. & Chase) Mohlenbr. - (Maier 1976)

Dichanthelium villosissimum (Nash) Freckm. - P36739

**Digitaria ciliaris* (Retz.) Koeler - P37159

Digitaria filiformis (L.) Koeler - M2869

**Digitaria ischaemum* (Schreb.) Schreb. - M2806

**Digitaria sanguinalis* (L.) Scop. - (Maier 1976)

**Echinochloa crus-galli* (L.) P. Beauv. - P36954

Echinochloa muricata (Michx.) Fern. var. *wiegandii* (Fassett) Mohlenbr. - P37157

**Eleusine indica* (L.) Gaertn. - B2082

Elymus canadensis L. - M2688

Elymus hystrix L. - M2816

**Elytrigia repens* (L.) Desvaux - (Maier 1976)

**Eragrostis cilianensis* (All.) Vign. - M2810

Eragrostis hypnoides (Lam.) BSP - (Maier 1976)

Eragrostis pectinacea (Michx.) Nees - B2084

Eragrostis spectabilis (Pursh) Steud. - M2839

Eragrostis trichodes (Nutt.) Wood - M2845

**Festuca arundinacea* Schreb. - M3168

Heterostipa spartea (Trin.) Barkworth - B1724

Hordeum pusillum Nutt. - B1681

Koeleria macrantha (Ledeb.) Spreng.- (Maier 1976)

Leersia oryzoides (L.) Swartz - B2091

Leersia virginica Willd. - P37152

Leptoloma cognatum (Schult.) Chase - M2683

Muhlenbergia frondosa (Poir.) Fern. - (Maier 1976)

Muhlenbergia racemosa (Michx.) BSP - (Maier 1976)

Muhlenbergia schreberi J. F. Gmel. - P37127

Panicum capillare L. - B2083

Panicum dichotomiflorum Michx. - P37158

Panicum virgatum L. - M2639

Paspalum bushii Nash - M2630

Paspalum setaceum Michx. - (Maier 1976)

**Phalaris arundinacea* L. - M3185

**Phleum pratense* L. - F2818

**Poa annua* L. - B1715

**Poa compressa* L. - M2815

**Poa nemoralis* L. - B1695

**Poa pratensis* L. - F2799

Poa sylvestris Gray - (Maier 1976)

Schizachyrium scoparium (Michx.) Nash - M2829

**Setaria faberi* R.A.W. Herrm. (Maier 1976)

**Setaris glauca* (L.) P. Beauv. - M2809

**Setaria viridis* (L.) P. Beauv. - B2087

Sorghastrum nutans (L.) Nash - M2834

Sphenopholis obtusata (Michx.) Scribn. - B1863

Sporobolus clandestinus (Biehler) Hitchc. - M2838

Sporobolus cryptandrus (Torr.) Gray - M2802

Sporobolus vaginiflorus (Torr.) A. Wood - (Maier 1976)

Tridens flavus (L.) Hitchc. - M2623

Triplasis purpurea (Walt.) Chapm. - M2847

**Triticum aestivum* L. - (Maier 1976)

Vulpia octoflora (Walt.) Rydb. - P36751

**Zea mays* L. - (Maier 1976)

POTAMOGETONACEAE

**Potamogeton crispus* L. - M3179

Potamogeton diversifolius Raf. - (Maier 1976)

SMILACACEAE

Smilax lasioneuron Hook. - P37149

Smilax tamnoides L. - B1704

TYPHACEAE

Typha angustifolia L. - B2097

XYRIDACEAE

Xyris torta Sm. - M2648

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Longitudinal Structuring of Turtle Assemblages in an Altered River in Central Illinois, USA: Implications for Conservation

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ABSTRACT

Longitudinal gradients in stream conditions affect structuring of assemblages of many aquatic organisms. Common patterns include downstream additions of species and shifts in functional groups. We speculated these patterns would be evident in turtle assemblages of the Sangamon River in central Illinois. Using baited hoop nets, we captured 1,060 turtles during 441 trap-nights along a 357-km reach of the river. Number of species captured increased from two in the fourth stream order (Snapping Turtle, *Chelydra serpentina*; Spiny Softshell, *Apalone spinifera*) to eight in the seventh. Two generalists (Painted Turtle, *Chrysemys picta*; Red-eared Slider, *Trachemys scripta*) became established near an impoundment in the fifth stream order and were encountered regularly thereafter. Two lotic specialists (Smooth Softshell, *Apalone mutica*; Ouachita Map Turtle, *Graptemys ouachitensis*) first appeared in lower reaches of the fifth stream order, and another (Northern Map Turtle, *Graptemys geographica*) in the seventh. Longitudinal structuring calls for basin-wide approaches to conservation because threats such as siltation and pollution can originate in terrestrial settings and accumulate downstream.

Key Words: turtle; assemblage; river; lotic; longitudinal; conservation; Illinois; Sangamon

INTRODUCTION

Longitudinal gradients in stream conditions affect structuring of assemblages of aquatic organisms. For example, diversity of fishes increases from a river's headwaters to its terminus (Smith and Kraft 2005). This pattern is caused by addition of species (i.e., few species drop out of assemblages located downstream from their first appearance) and is accompanied by shifts in relative importance of members composing assemblages (Sheldon 1968). Exceptions to these patterns are common enough to warrant mention (e.g., Mathews 1986; Palic et al. 2007). However, most debates concern processes driving patterns rather than their tendency to occur in a wide range of ecological settings (e.g., Naiman et al. 1987; Edds 1993) and taxonomic groups such as fishes, mussels (Haag and Warren 1998), gastropods (Minton et al. 2008) and macroinvertebrates (Heino et al. 2005).

Evidence of longitudinal structuring in assemblages of turtles is sparse. Moll and Moll (2004) supported the concept, but noted difficulty distinguishing effects of longitudinal structuring from climatic, geologic, evolutionary and anthropogenic influences on distributions of species in the Mississippi River. DonnerWright et al. (1999) found strong relationships between structuring of assemblages and gradients in stream morphology on a 100-km reach of the St. Croix River, including addition of one species near the downstream extent of their study area. Support for longitudinal structuring can also be inferred from distributions of individual species of turtles that vary with velocity and depth of water, substrate, availability of basking sites, and other traits that change along a river's course (Shively and Jackson 1985; Fuselier and Edds 1994; Reese and Welsh 1998; Lindeman 1999; Riedle et al. 2009; Kornilev et al. 2010).

Our study area spanned 357 of 386 km of the main channel of the Sangamon River in four of its seven stream orders. This allowed us to sample assemblages in a wide range of stream conditions to assess longitudinal changes without confounding effects of other factors that shape distributions of species. Our hypotheses mirrored prevailing theories: diversity varies positively with stream order; changes in the composition of assemblages are caused by additions of species; and changes in the composition of assemblages are accompanied by shifts in functional groups. Our findings have implications for conservation of turtles in the Sangamon River, which has been altered dramatically by human activities.

MATERIALS AND METHODS

Methods

We captured turtles in hoop nets (diameter 60.96 cm; mesh 3.81cm; single throat). Fresh frozen fish (400–600 g) was placed in a nylon-mesh bag attached to the hoop farthest from the throat, which faced downstream when set. We replaced baits daily when we checked nets, recorded the number of each species captured and released turtles unharmed. We did not mark turtles because we anticipated too few recaptures for robust estimates of abundance.

Sampling occurred from May–September, 2006–2011. We did not sample stream orders 1–3 (Fig. 1) because private ownership limited access and depths were generally too shallow to set nets with openings of throats underwater. We attempted to distribute effort proportionately to length and width of the channel in each of the remaining stream orders. Effort in the fourth stream order was meager, but turtles were likely to encounter our nets in the narrow channel (Fig. 2) and species we captured were typical of streams in the region (Major et al. 2009).

Each trapping session consisted of 8–24 nets set for 2–3 nights. Sampling locations within a stream order were chosen opportunistically based on ease and legality of

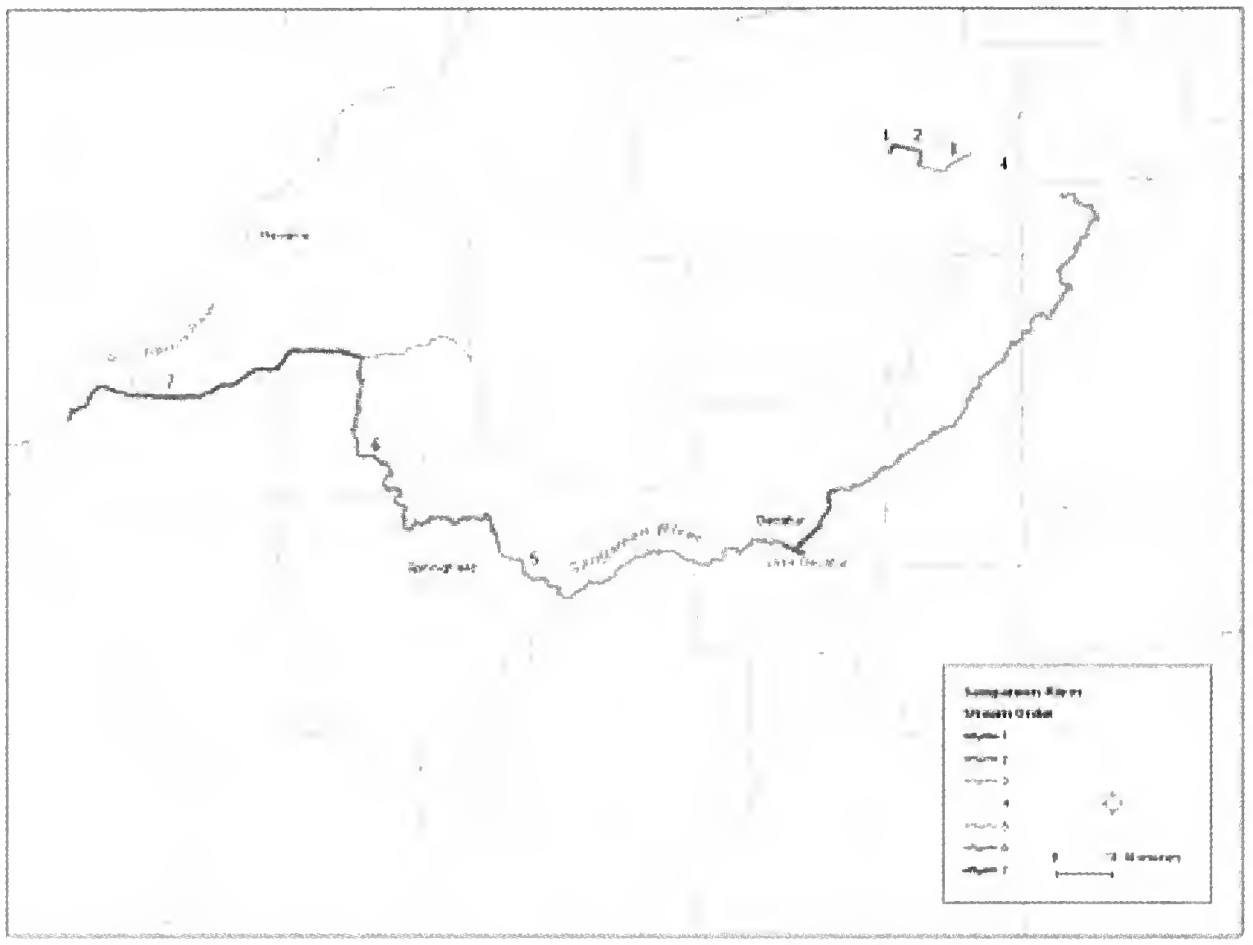

Figure 1. Stream orders of the Sangamon River in central Illinois, USA.

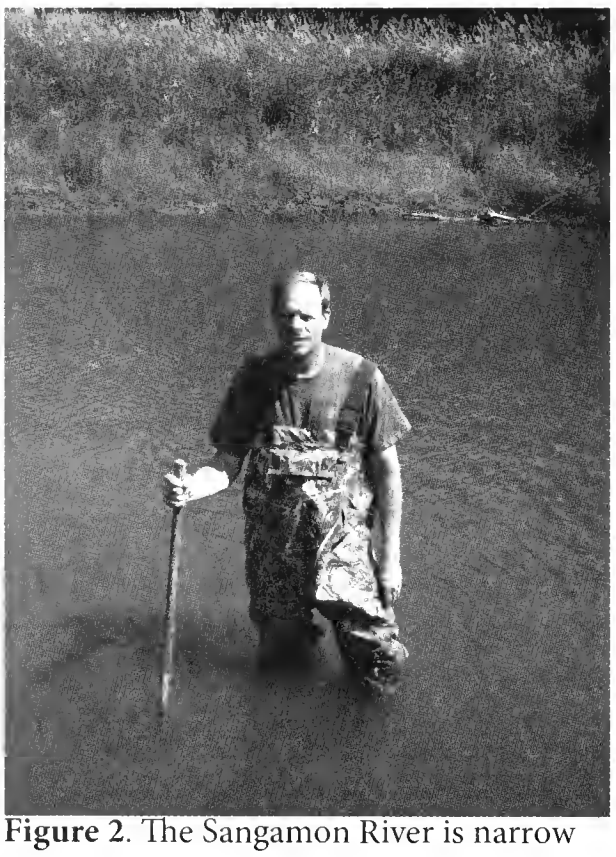

Figure 2. The Sangamon River is narrow and wadeable in its fourth stream order.

access. Some portions of our study area (stream orders 4–5) were accessible only by foot; others (stream orders 5–7) were sampled from a canoe or motorboat. We set nets in diverse habitats representative of each reach (e.g., pools and runs in the open channel and near features such as sandbars, logjams, deadwood and confluences of tributaries).

Metrics used to describe assemblages were derived from Krebs' (1989) calculations for observed species richness (S_{obs}), Horn's index of overlap (R_0) and Shannon-Wiener functions for diversity (H') and evenness (J'). We did not attempt to correct S_{obs} because estimators perform poorly when the number of species in an assemblage is small (e.g., <15–20; Melo et al. 2003). This was the case in our study area, where we captured all but one species known to occur in lotic habitats of the lower Illinois River basin (Phillips et al. 1999). Collecting representative samples of assemblages (i.e., proportionate to each species' relative abundance) is difficult because probabilities of capture vary among species (Cagle 1942). We acknowledge this problem, but note bias was consistent among stream orders, allowing for valid comparisons.

Study Area

The Sangamon River originates in McLean County, Illinois. Its main stem flows 386 km before emptying into the Illinois River (Illinois Department of Natural Resources 2000a). This 7th-order stream drains 14,985 km^2 (c.a. 10% of the state; Illinois Department of Natural Resources 2001).

Substrates in our study area varied from clay to cobble. Upper reaches were generally dominated by gravel or sand and gravel whereas substrates in lower reaches were mostly sand. Banks were incised deeply (1–5 m) and bordered by a narrow, intermittent riparian corridor along much of the study area (Fig. 3).

Figure 3. A reach of the sixth stream order of the Sangamon River in central Illinois, USA. Photo by Chris Young.

Our study was the first inventory of turtles inhabiting the Sangamon River. Based on distributions and habitat preferences (Phillips et al. 1999), we considered nine species to be possible residents: Snapping Turtle (*Chelydra serpentina*), Painted Turtle (*Chrysemys picta*), Northern Map Turtle (*Graptemys geographica*), Ouachita Map Turtle (*Graptemys ouachitensis*), False Map Turtle (*Graptemys pseudogeographica*), Red-eared Slider (*Trachemys scripta*), Eastern Musk Turtle (*Sternotherus odoratus*), Smooth Softshell (*Apalone mutica*) and Spiny Softshell (*Apalone spinifera*). All records of map turtles (*Graptemys* spp.) and *A. mutica* were from the Illinois River, so we were unsure about residency in the Sangamon.

Human activities have altered nearly every aspect of the ecology of the Sangamon River. These changes began in the early to mid-1800s and were entrenched by the early 1900s (Herget 1978; Illinois Department of Natural Resources 1994, 2000b; Prince 1997). Approximately 28% of the Sangamon River's main stem is channelized (Mattingly et al. 1993). Levees occur along 12% of the river's channel, with a disproportionate amount in lower reaches (Mattingly et al. 1993).

Crops such as corn and soybeans are produced in 76% of the river basin (Illinois Department of Natural Resources 2001). Silt and nutrients carried by run-off from farm fields affect the river (Illinois Environmental Protection Agency 1995; Illinois Department of Natural Resources 2000a) and its fauna (Smith 1971; Schanzle and Cummings 1991). Sub-surface drainage (i.e., tiling) is a common practice (Zucker and Brown 1998) that contributes to nutrient loads (Wiley et al. 1990) and abrupt changes in water levels (Sangunett 2005). An agricultural matrix supports high densities of nest predators such as raccoons (*Procyon lotor*; Gehrt et al. 2002). Exotic species are problematic in both terrestrial and aquatic environments [e.g., Amur honeysuckle (*Lonicera maackii*), common carp (*Cyprinus carpio*); Illinois Department of Natural Resources 2000b; Carney 2010].

Springfield (population 116,250), Decatur (population 76,122) and smaller cities along the main stem of the Sangamon River affect its water quality, which is classified as "fair" (Illinois Environmental Protection Agency 1995). The main stem of the Sangamon River was dammed in 1922 to provide a municipal water supply for Decatur. Low-head dams that once occurred at Springfield, Petersburg and New Salem are no longer functional. Impoundments on major tributaries such as Salt Creek, Clear Creek, Sugar Creek, and South Fork of the Sangamon River supply water for cities and power plants.

RESULTS

We captured 1,060 turtles during 441 trap-nights. Observed species richness increased with stream order (Table 1), as did diversity (Table 2). Evenness was high in all stream orders. Community overlap differed greatly between uppermost and lowermost stream orders but not adjacent or intervening stream orders (Table 3).

Some patterns we observed on reaches within stream orders were noteworthy. One was absence of *C. picta* and near absence of *T. scripta* (1 capture during 107 trap-nights of effort) in all but the last reach of the 5th stream order we sampled above Lake Decatur; both species were encountered regularly in reaches sampled below the lake. We first observed *A. mutica* and *G. ouachitensis* in the second-to-last (but not the last) downstream reach sampled in the 5th stream order; both species were represented by captures of one individual. We first encountered *G. geographica* in the last reach of the 7th stream order near the Sangamon's confluence with the Illinois River.

Table 1. Capture effort (no. trap-nights) and observed species richness (S_{obs}) on four stream orders of the Sangamon River in central Illinois, USA, 2006–2011.

Stream order	Effort	S_{obs} Based on all captures	S_{obs} Based on captures of ≥2 individuals per species
4	16	2	2
5	163	6	4
6	124	6	6
7	138	8	8

DISCUSSION

Longitudinal Structuring

Patterns of diversity and community overlap were indicative of longitudinal structuring of assemblages. We did not observe a shift in functional groups, as the number of species with morphological adaptations to flowing water (e.g., flattened carapace)

Table 2. Numbers of turtles captured, relative abundances (in parentheses), diversity, and evenness on four stream orders of the Sangamon River in central Illinois, USA, 2006–2011.

	Stream order				
Species	4	5	6	7	Total
Apalone spinifera	19 (0.679)	238 (0.515)	42 (0.186)	126 (0.366)	425 (0.401)
Chelydra serpentina	9 (0.321)	80 (0.173)	13 (0.058)	19 (0.055)	121 (0.114)
Trachemys scripta	--	129 (0.279)	119 (0.527)	113 (0.328)	361 (0.341)
Chrysemys picta	--	13 (0.028)	15 (0.066)	6 (0.017)	34 (0.032)
Apalone mutica	--	1 (0.002)	33 (0.146)	31 (0.090)	65 (0.061)
Graptemys ouachitensis	--	1 (0.002)	4 (0.018)	40 (0.116)	45 (0.042)
Graptemys geographica	--	--	--	6 (0.017)	6 (0.006)
Sternotherus odoratus	--	--	--	3 (0.009)	3 (0.003)
Total captures	28 (0.026)	462 (0.436)	226 (0.209)	334 (0.315)	1060
Species diversity (H')	0.628	1.129	1.347	1.543	1.443
Evenness (J')	0.906	0.630	0.752	0.742	0.694

Table 3. Percent change in species diversity, evenness and community overlap among four reaches of the Sangamon River in central Illinois, USA.

Community descriptor	Percent change among stream orders					
	4-5	4-6	4-7	5-6	5-7	6-7
Species diversity	79.8	114.5	145.7	19.3	36.7	14.6
Evenness	-30.5	-17.0	-18.1	19.4	17.8	-1.3
Community overlap (R_o)	0.903	0.598	0.080	0.813	0.857	0.870

matched those without in each stream order. "True river turtles" (e.g., *G. ouachitensis*, *A. mutica*; Lindeman 2000) were absent from the 4th stream order, first appeared in lower reaches of the 5th, and were captured with increasing frequency in higher stream orders. This pattern was consistent with reach-scale studies that found "feathered" rather than sharp limits of upstream distribution for lotic specialists (*Graptemys* spp.; Shively and Jackson 1985; DonnerWright et al. 1999; Killebrew et al. 2002).

Detection of *S. odoratus* in the 7th stream order was not surprising given the species' preference for slow-moving water (Ernst et al. 1994) and presence in the broader landscapes of the Illinois and Sangamon rivers (Moll 1977; Tucker et al. 2008; Bluett et al. 2011a). Captures of *G. geographica* in the last reach of the 7th stream order might have reflected a change in suitability of the Sangamon River, proximity to the Illinois River or both. Admixtures of assemblages of fishes are often observed for short distances (c.a. 20 km) upstream from the confluence of a tributary with a larger stream or river (Thornbrugh and Gido 2010).

Lake Decatur was a clear "break point" for *C. picta* and *T. scripta*. Major et al. (2009) observed a similar phenomenon in streams of west-central Illinois, where *C. picta* and *T. scripta* joined *C. serpentina* and *A. spinifera* near impoundments. Relationships between the dam's location and our first encounters of *A. mutica* and *G. ouachitensis* were equivocal, partly because of gaps in sampling.

Implications for Conservation

We encountered 53% of species of freshwater turtles native to Illinois, and approximately 17% of those in North America. Species richness in the 7th order of the Sangamon was greater than that reported for all but two Midwestern rivers, both of which are larger than the Sangamon (Table 4). Thus, the Sangamon River is a significant resource despite channelization, isolation from its floodplain, alteration of hydrological regimes, urban development and intensive agricultural production. We conclude altered rivers should not be overlooked when developing regional or continental strategies for conservation of freshwater turtles.

Table 4. Observed species richness (S_{obs}) reported for assemblages of turtles in Midwestern rivers (USA).

River	Vicinity	S_{obs}	Study
Mississippi	Itasca, MN	2	Moll and Moll (2004)
Mississippi	Lake City, MN	7	Moll and Moll (2004)
Mississippi	LaCrosse, WI	7	Moll and Moll (2004)
Mississippi	Bellevue, IA	7	Moll and Moll (2004)
Mississippi	Alton, IL	9	Moll and Moll (2004)
Mississippi	Cape Girardeau, MO	7	Moll and Moll (2004)
Mississippi	Tiptonville, TN	6	Moll and Moll (2004)
Mississippi	St. Louis, MO to Cairo, IL	6	Barko et al. (2004)
Mississippi	Hamilton, IL	6	Anderson et al. (2002)
Illinois	Havana, IL	7	Paglia (2004)
Illinois	Havana, IL	7[a]	Moll (1977)
Illinois	Havana, IL	9	Tucker et al. (2008)
Big Muddy	Grand Tower, IL	7	Bluett et al. (2011b)
Embarras	Charleston, IL	6	Douros (2010)
Wabash	Allendale/Mt. Carmel, IL	5	Pierce (1992)
St. Croix	Danbury, WI to Stillwater, MN	7	DonnerWright et al. (1999)
Des Moines	Not specified	5	Vandewalle & Christiansen (1996)
Missouri	Not specified	5	Vandewalle & Christiansen (1996)
Sangamon	Beardstown, IL	8	This study

[a]Study did not distinguish *Graptemys pseudogeographica* from *G. ouchitensis*; presumably both occurred for a total of 8 species.

The diverse assemblage we observed in the last stream order of the Sangamon is a product of ecological processes that begin in its headwaters (Saunders et al. 2002; Meyer et al. 2007) and extend past its confluence with the Illinois River (Osborne and Wiley 1992). As with fishes, this widens the scope of turtle conservation to the whole basin as well as reaches and sites (Saunders et al. 2002; Wang et al. 2002; Allen 2004; Cowx and van Zyll de Jong 2004). Past achievements suggest this goal is attainable. For example, regulatory provisions of the Clean Water Act of 1972 have reduced point sources of pollution (e.g., untreated sewage, industrial waste), and innovations in agricultural practices have mediated non-point sources (e.g., silt, nutrients) through widespread adoption of conservation tillage (Illinois Department of Agriculture 2006), targeted applications of chemicals, and use of pesticides with brief environmental persistence (Yates et al. 2006; Renwick et al. 2008). Positive changes in water quality have aided recovery of native fishes and mussels in the Illinois River (Sietman et al. 2001; Pegg and McClelland 2004) and Salt Creek, a tributary of the Sangamon (Retzer 2005).

Agricultural policies have benefitted turtles since 1985, when the Food Securities Act first offered financial incentives to producers who converted highly erodible croplands to permanent vegetative cover for the life of easements, typically 10–15 years [i.e., Conservation Reserve Program (CRP); Gray 2009)]. During 2011, 5,527 ha of cropland in the Sangamon River Basin were enrolled in CRP with 1,803 ha protected by permanent easements under the Conservation Reserve Enhancement Program (Illinois Department of Natural Resources, unpubl. data). Restoration of riparian forests, wetlands and stream banks on lands enrolled in CRP is good for turtles (Burke and Gibbons 1995; Bodie 2001; Moll and Moll 2004; Nowalk 2010; Sterrett et al. 2010) and the broader environment (Haufler 2007; Marshall et al. 2008; United States Department of Agriculture 2010).

CONCLUSION

Our findings provide a benchmark for evaluating responses of turtle assemblages to changes in environmental quality of the Sangamon River. Monitoring programs should include stream network position (e.g., stream order or link) as a stratum when sampling assemblages of turtles and their environment. Characterizing spatial and temporal attributes of a complex and dynamic ecosystem is a challenging task (Thorp et al. 2006). For example, early reports of longitudinal structuring of assemblages of fishes led to more attempts to document the pattern (Platts 1979). Confirmations, exceptions and variations were

noted, as were possible causes (Mathews 1986; Hitt and Angermeier 2006). This fostered an appreciation for spatial and temporal scales, theories to describe relationships, models to test them, and integration with broader aspects of stream ecology (Lammert and Allan 1999; Grenouillet et al. 2004; Smith and Kraft 2005; Thorp et al. 2006; Parsons and Thoms 2007). Progress in other fields of study will aid chelonian ecologists as they seek causes of longitudinal structuring and refine strategies for conservation to suit life cycles of turtles.

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Barred Owl Pellet Contents in Michigan

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ABSTRACT

Owl pellets from the Barred Owl were collected and analyzed for prey remains. Twelve small mammals and one invertebrate were identified.

INTRODUCTION

Among the larger owl species in the Midwest the Barred Owl (*Strix varia*) is perhaps the best known because of its easily identifiable vocalizations. Presence of the owl can be determined by these unique vocalizations especially during the breeding season and again at the time of dispersal of young from a nest site. In some locations Barred owls live in close association with human activity, especially in locations where activity is centered on summer recreation, and the balance of the year is with decreased human presence (Pers. Obser.). In Michigan this species has been characterized as widespread and locally common (Postupalsky et al. 1995).

MATERIALS AND METHODS

One such location is north of Pentwater, MI (43.7817 N, 86.4331 W) in a mixed evergreen and deciduous forest consisting of a variety of oak species, maple, pine, hemlock, and spruce in a barrier dune formation adjacent to Lake Michigan. Through 2005, Barred owls regularly were heard and seen in a several hundred acre protected area. Nesting and rearing of young occurred on a regular basis. On rare occasions recently fledged young were observed at close range as they begged for food. Adults not infrequently came to a forest water source and sometimes foraged near it. Adult owls were sometimes observed in the early morning perched over the water. Small fish and woodland amphibians including wood frogs (*Rana sylvatica*) and American toads (*Bufo americanus*) were present there. Smith et al. (1983) has reported similar observations about foraging and perching.

During the early spring of 2005 pellets were collected from an Eastern Hemlock (*Tsuga canadensis*) roost site in this area. A total of fourteen intact pellets were collected. Additional pellet remains were present but were not collected due to deterioration. Pellets were dried at 40 degrees C. for seven to ten days without washing, then weighed and measured prior to dissection. Pellet contents, including hair samples, skeletal parts and invertebrate remains were separated and preserved as dry specimens and cataloged after identification. Identification was made with the aid of a dissecting binocular microscope using available reference skeletal material as well as field guides (Burt, 1948; Burt, 1972; Elbroch, 2006; Knox-Jones and Manning, 1992; Roest, 1986; Tekiela, 2005).

RESULTS AND DISCUSSION

Fourteen intact pellets weighed on average 4 gms (X = 4.01; SD = 2.07). The castings ranged from 40 to 60 mm in length (X = 43.69; SD = 13.56) and between 20 and 50 mm in width (X = 25.61; SD = 10.83). The number of individual animals per pellet averaged 3 with a range of 1 - 4 (N =13; X = 2.69; SD = 1.54). The number of species per pellet averaged 3 with a range of 1 – 4 (N = 13; X = 2.30; SD = 1.37). A total of one invertebrate and eleven small mammal species were present in the pellets. There was a small amount of unidentifiable plant material in one casting. Prey items are listed in Table 1.

Blakemore (1940) in describing thirty six winter collected Barred owl pellets from Minnesota described these as oval in shape; ranging in size from 37-70 mm in length and from 20-27 mm in width. The average length was 54 mm; width 24.5. The average number of food items per pellet was 2.04. The pellets described here were shorter; about the same width and the average number of food items per pellet was higher.

Wilson (1938) in collections made in coniferous stands at a central Michigan site determined that owl pellets remain whole for eight to ten weeks and then deteriorate.

Table 1. Species used as food by Barred owls (*Strix varia*) in Michigan.

Common Name	Scientific Name	Number of Individuals
Masked Shrew	*Sorex cinereus*	8
Northern Short-tailed Shrew	*Blarina brevicaudata*	2
Eastern Mole	*Scalopus aquaticus*	2
Short-tailed Weasel	*Mustela ermine*	1
Eastern Chipmunk	*Tamias striatus*	3
Red Squirrel	*Tamiasciurus hudsonicus*	2
Southern Flying Squirrel	*Glaucomys volans*	2
White-footed Mouse	*Peromyscus leucopus*	7
Southern Red-backed Vole	*Clethrionomys gapperi*	1
Meadow Vole	*Microtus pennsylvanicus*	1
House Mouse	*Mus musculus*	2
North American Porcupine	*Erethizon dorsatum*	1
Unidentified Crayfish	*Cambarus* sp.	2

[Mammal Taxonomy according to Burt and Grossenheider 1976]

Further he reported winter regurgitated pellets remain whole for 3 to 5 months. Given the collection site and date of the pellets reported here it is reasonable to assume that the sampled pellets fell within the 8 – 10 week range and that the site had been in use for some time.

The diet of Barred Owls is composed largely of small mammals as reported in a range of studies across North America and reviewed by Snyder and Wiley (1976) as cited in Mazur and James (2000). A total of 2,234 prey items were represented by 76% mammals, 15.8% invertebrates, 5.8% birds and 2.5% lower vertebrates. Most recently, Livezey (2007) has reviewed and summarized the literature including identification of prey items using six different methodologies. A total of 7,077 samples by composition 71.9% mammals, 10.1% invertebrates, 9.5% birds, reptiles 0.6%, and amphibians 6.0 %. Elderkin (1987) reported winter diets consisted primarily of small mammals.

In this report, mammals represented 92.3% and invertebrates 6.7%. One pellet contained only the quills of a young North American porcupine as judged by quill size and structure. We found no other published reports identifying this species as food.

While the number of pellets in this sample is small the results provide insight to the diet of the Barred Owl at this Michigan location.

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New distribution record for *Fundulus diaphanous* (LeSueur), family Fundulidae in Illinois

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ABSTRACT

While conducting a general survey in a small tributary of the Rock River, two individuals of banded killifish (*Fundulus diaphanous*) were found. This species was sampled during October, 2012, in Rock Island County, Illinois. The banded killifish may be expanding its range to northwest Illinois.

FINDINGS

The banded killifish is a topminnow that grows to an average length of 75 mm (Smith, 1979). The key characteristics are the dorsal fin origin which is in advance of the anal fin insertion, and the numerous dark vertical bars. The bars contrast sharply over a light olive coloration above, and silver below (Figure 1) (Smith, 1979).

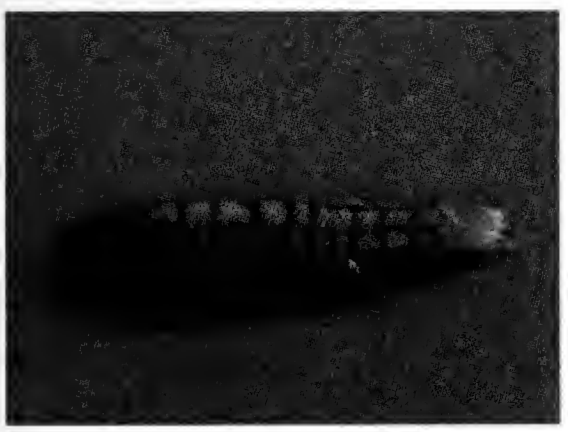

Figure 1. Banded killifish sampled at Mill Creek, Rock Island County, Illinois, November, 2012.

Banded killifish typically inhabit shallow cool water with abundant aquatic vegetation (Osborne and Brazil, 2006). This species is an opportunistic feeder, eating a wide variety of aquatic invertebrates in all levels of the water column (Osborne and Brazil, 2006). Vegetation is also important spawning habitat, where they attach their eggs to aquatic macrophytes (Richardson, 1939; Chippet, 2003).

The native range of this species is from Newfoundland to South Carolina, west across the northern Great Lake states into the central Dakotas, and as far southwest as central Iowa. In Illinois it was historically found only in the northeastern portion of Lake, Cook, and McHenry Counties (Page and Burr, 1991). The banded killifish is listed as an Illinois threatened species (Illinois Endangered Species Protection Board, 2011).

Two banded killifish were collected in early November of 2012, while the authors were conducting a general survey near the mouth of Mill Creek in Rock Island County, Illinois. The sample was collected using a 120 volt AC electric seine for a total sample time of 53 minutes. Several dippers followed the seine using quarter inch mesh dip nets to collect the stunned fish. Over 10,000 fish were collected during the sampling, representing 19 species. Common species collected with the banded killifish included sand shiner (*Notropis ludibundus*), spotfin shiner (*Cyprinella spiloptera*), and emerald shiner (*Notropis atherinoides*). Mosquito fish (*Gambusia affinis*), known to compete with top minnows, were also abundant (Meffe et al., 1983). Bottom substrates consisted of 60% sand, 5% gravel, 30% cobble, and 5% boulders. The average width of the stream was 11 meters with an average depth of 20 cm. Aquatic vegetation was abundant and consisted mostly of filamentous algae and pondweeds.

It is not known if these individuals are part of a larger population or were relocated from other populations during previous Mississippi River flood events. Based on the size of the individuals (28 mm, 32 mm) they were most likely young of the year. No significant flooding has occurred in the area since 2011 (USGS, 2013), which may indicate that a resident population exists in the Rock Island County, Illinois area.

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Induction of Apoptosis to Control Drug-Induced Gingival Overgrowth: An *In Vitro* Study

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ABSTRACT

Gingival overgrowth is an adverse effect of several classes of drugs including anticonvulsants, calcium channel blockers and the immunosuppressant cyclosporine A (CsA). Current treatment options of drug-induced gingival hyperplasia include both nonsurgical and surgical interventions. Surgical interventions have a high rate of recurrence and are not the most appropriate treatment options in immunocompromised patients. The preferred nonsurgical interventions are symptomatic and do not resolve the condition, and as yet, there is no effective, nonsurgical option for its treatment. Gingival tissue is constantly involved in cycles of tissue resorption, remodeling and replacement by apoptotic pathways. Apoptosis and cell clearance are necessary for constant tissue remodeling, and a lack of these processes plays a critical role in gingival overgrowth. We hypothesized that CsA-induced gingival overgrowth can be controlled by the use of specific agents to induce apoptosis. An *in vitro* cell culture model of gingival cells was overproliferated using CsA to mimic gingival overgrowth, following which, the cells were exposed to either 100ng/ml or 500ng/ml of Cytochrome C to induce apoptosis at 3, 6 and 9 day time points. Cell densities were calculated both pre and post Cyt C treatment. Cells were also immunostained with DAPI to visualize the nuclei and laser scanning confocal microscopy was used to image and record the features of apoptotic nuclei. Statistical analyses were carried out. Our data indicate that following treatment with Cyt C, cell densities at 3, 6 and 9 day time points showed statistically significant decreases. This study is an important first step in determining if inducing apoptosis could be a viable, nonsurgical method of managing cellular proliferative disorders like drug-induced gingival overgrowth.

INTRODUCTION

Gingival overgrowth is an undesirable and well recognized side-effect of oral, intramuscular, or intravenous use of various drugs, including phenytoin, phenobarbital, valproate, nifedipine, verapamil and cyclosporine (Beveridge et al., 1981). Cyclosporine A (CsA) is a lipophilic, cyclic endecapeptide, isolated as an antifungal and used as an immunosuppressant. It functions to greatly reduce T-helper cell proliferation during organ transplants, so that the body will accept the foreign tissue successfully (Britton et al., 1982). It has been estimated that 25-80% of patients on a regimen of CsA experience gingival hyperplasia (Lawrence et al., 1994), an overgrowth of gingival tissue resulting from an inhibition of normal apoptotic pathways. Apoptosis and cell clearance are necessary for constant tissue remodeling, and a lack of these processes plays a critical role in gingival overgrowth. Drug-induced gingival overgrowth begins as an enlargement of the papillary gingiva, which is more pronounced on the labial surfaces and less on the palatal and lingual surfaces (Tyldesley et al., 1984). Although the overgrowth is initially restricted to the width of the gingiva, in extremely severe cases, the overgrowth can completely extend over and cover the crowns of the teeth. In such extreme cases, the gingival overgrowth interferes with occlusion, mastication and speech in affected patients (Lawrence et al., 1994). Hyperplastic gingival tissue readily bleeds on probing, and is much more susceptible to infections (Seymour and Jacobs, 1992). Current management of drug-induced gingival overgrowth typically is carried out through surgical procedures like gingivectomies. Surgical procedures are associated with inherent risks, including but not limited to, complications of anesthesia, severe post-operative bleeding, prolonged healing periods in immunocompromised patients and increased risk of infection. Other methods to reduce gingival overgrowth include the use of electrocautery or CO_2 lasers, but these procedures can be costly and have similar adverse consequences (Hegde et al., 2012).

The purpose of the current study was to explore a nonsurgical method to manage CsA-induced gingival overgrowth. We hypothesized that CsA-induced gingival overgrowth can be controlled by the use of specific agents to induce apoptosis. Apoptotic cell death is preferred over necrotic cell death, since necrosis is associated with sustained inflammatory cell damage caused when necrosed cells swell and undergo lysis to spew their cytoplasmic contents. When a cell commits "cell suicide" by apoptosis, it undergoes cell shrinkage, chromatic condensation, nuclear fragmentation and cytoplasmic budding, with a resultant noninflammatory clearance from the tissue (Potten et al., 2004). The current study used an *in vitro* cell culture model to test our hypothesis.

MATERIALS AND METHODS

A commercially available Human Gingival Epithelial Progenitor cell line (HGEP, ZenBio, Research Triangle Park, NC) obtained from a single donor was expanded using routine cell culture techniques. Specifically, HGEP cells were aseptically cultured in 12-well plates (Corning Incorporated, Corning, NY) using a specialized, progenitor cell targeted, culture medium (CnT-24 media, ZenBio, Research Triangle Park, NC) in a 5% CO_2 environment at 37°C. Supplements provided by the manufacturer were added to the media as per manufacturer's directions. Cells were grown until they reached 80% confluency and then subcultured as shown in Figure 1.

The subcultured HGEP cells were grown either directly on the bottom of the 12-well plates or onto glass coverslips placed into the 12-well plates till they reached 80% confluency. Cells were then exposed

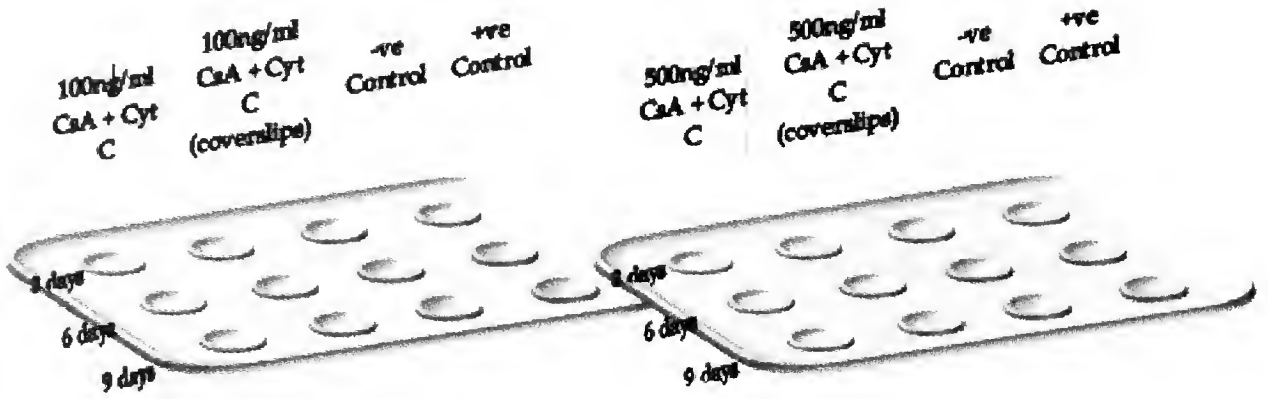


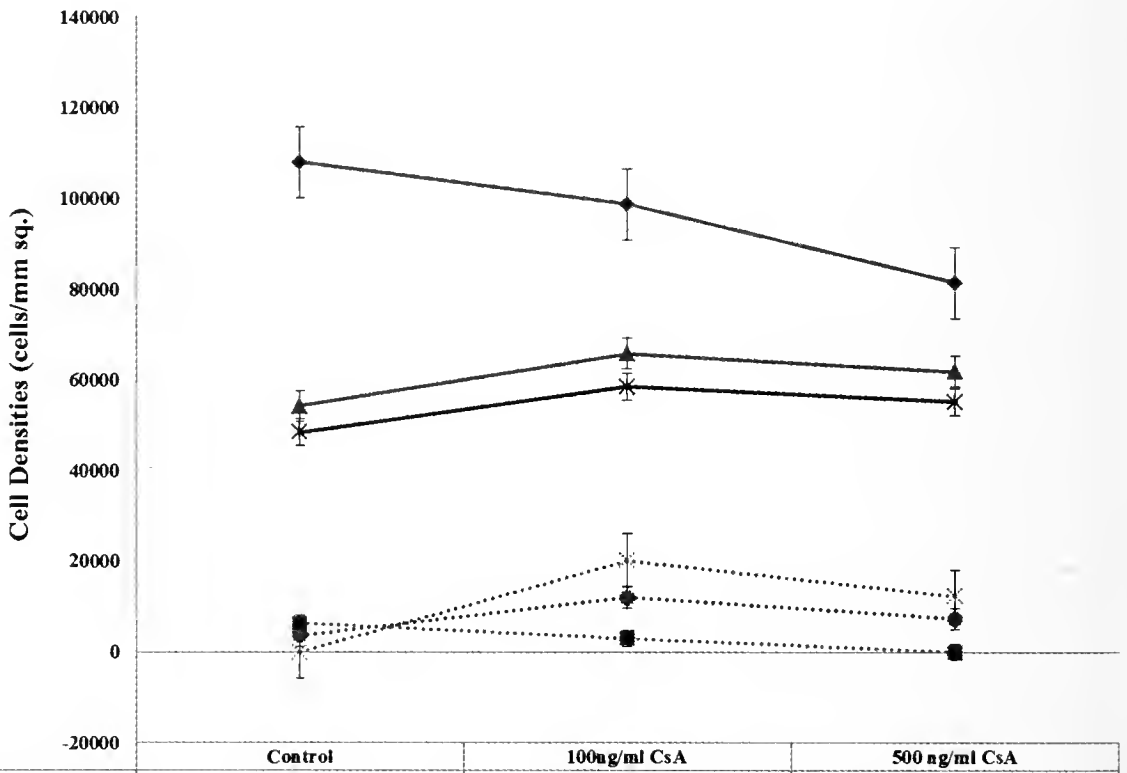
Figure 1. Summary of experimental design. Cells were subcultured into 12-well plates, with or without glass coverslips, exposed to 100ng/ml or 500 ng/ml CsA for 3, 6 and 9 days. At the three time-points, cells were exposed to exogenous Cyt C for 30 minutes. Cell counts were obtained from wells without cover slips using Trypan Blue technique, while cells on cover slips were immunoreacted with DAPI to visualize nuclear apoptotic changes.

to either 100ng/ml or 500ng/ml CsA (Sigma-Aldrich, USA) and allowed to overproliferate for 3, 6, and 9 days. At the three time-points, cells in the experimental groups were incubated in exogenous Cytochrome C (Cyt C from bovine heart, Sigma-Aldrich, USA) for 30 minutes, following which, cell counts were obtained from wells which did not contain the glass cover slips using the Trypan Blue dye exclusion technique in a hemocytometer. In order to assess apoptotic changes, HGEP cells grown on cover slips were fixed in 4% paraformaldehyde, nuclei stained with DAPI, cover slips mounted on glass slides and imaged using a laser scanning confocal microscope (Fluoview FV1200, Olympus, USA). Corresponding control cultures were maintained at all three time points; the negative control was incubated only in Cyt C treatment and the positive control was exposed to CsA but did not receive the Cyt C treatment. All cell counts were expressed as cell density in cells/ml and the experiment was carried out in triplicate.

Data were analyzed with multivariate repeated measures analysis of variance (MANOVA) with two within-subject (repeated-measures) factors [(1) day (3, 6, or 9) and (2) pre or post] and one between group factor (control arm versus treatment arm (100 or 500 ng/ml CsA). An advantage of MANOVA is that it does not require that the assumptions of compound symmetry and sphericity to be fulfilled. As part of this analysis, summary statistics and plots were created. The Tukey honestly significant difference test was used for post-hoc testing. Statistical testing was performed with Statistica Release 10 (StatSoft, Inc., Tulsa, OK).

RESULTS

Following treatment with Cyt C, cell densities at 3, 6 and 9 day time points showed statistically significant decreases (Figure 2). Mean cell densities on day 3, prior to Cyt C treatment was 54333, 65833 and 61833 for controls, 100ng/ml CsA and 500ng/ml CsA groups respectively. Following Cyt C treatment, these cell densities dropped significantly to 0, 20166 and 12333 respectively. On day 6, prior to Cyt C treatment, mean cell densities were 48500, 58500 and 55166 for control, 100ng/ml and 500ng/ml groups respectively. Following Cyt C treatment, mean cell densities decreased significantly to 3666, 12000 and 7333 respectively. The day 9 time point followed a similar trend with pre Cyt C treatment levels at 108000, 98666 and 81333 and post Cyt C levels at 6333, 3000 and 0 mean cells for control, 100ng/ml and 500ng/ml groups respectively (Data shown in tabular form within Figure 2). Percentage decreases in mean cell densities of post Cyt C treatment



	Control	100ng/ml CsA	500 ng/ml CsA
3 days Pre-CytC	54333.33333	65833.33333	61833.33333
3 days Post-CytC	0	20166.66667	12333.33333
6 days Pre-CytC	48500	58500	55166.66667
6 days Post-CytC	3666.666667	12000	7333.333333
9 days Pre-CytC	108000	98666.66667	81333.33333
9 days Post-CytC	6333.333333	3000	0

Figure 2. Overproliferated gingival (HGEP) cells show significant decrease in cell density post Cytochrome C treatment. Statistically significant decreases in cell densities were seen at all three time points between pre Cyt C treatment and post Cyt C treatment groups ($p \leq 0.01$). Significant differences were also seen within each group at the three time points ($p \leq 0.01$). Line plots at 3, 6 and 9 days are shown for pre (solid lines) and post (dotted lines) Cyt C treatment. Mean values of cell densities are shown in the included table for control, 100ng/ml CsA and 500ng/ml CsA exposed cells. Data are shown as mean ±SE.

Table 1. Significant percentage decreases in mean cell densities at the three time points post Cytochrome C treatment (values are calculated compared to pre Cyt C levels).

	Control	100ng/ml CsA	500ng/ml CsA
3 days Post-CytC	100%	69.36%	80.05%
6 days Post-CytC	92.43%	79.48%	86.70%
9 days Post-CytC	94.13%	96.95%	100%

as compared to pre Cyt C treatment were also calculated (Table 1). Cell densities post Cyt C treatment decreased within a range of 69.36% to 100% compared to pre Cyt C treatment at the various time points.

DAPI staining of nuclei with concomitant confocal imaging showed cells in various stages of apoptosis, with characteristic apoptotic features. The apoptotic features noted included, chromatin condensation (white arrows-Figure 3), nuclear pyknosis (white arrowheads-Figure 3) and nuclear fragmentation (bottom panels-Figure 3).

DISCUSSION

The current study investigated if cyclosporine A (CsA) can be used to control drug-induced gingival overgrowth by inducing apoptosis in gingival epithelial cells, using an *in vitro* cell culture model. Two experimental conditions using specific CsA doses, 100ng/ml and 500ng/ml, were chosen to reflect the serum-levels of CsA that are typically maintained in patients over time (Chaudary et al., 2008).

Cytochrome C (Cyt C) is an enzyme that is stored in the mitochondria and is involved in the apoptotic protease activating factor 1/"Apaf-1" pathway of programmed cell death or apoptosis. When the mitochondrial membrane potential is disturbed by a large calcium uptake or other triggers such as physiological stress, the mitochondrial permeability transition pore/ MPTP opens up and releases Cyt C. Upon release, Cyt C binds to Apaf-1, forming apoptosomes. The apoptosomes bind to and cleave caspase-9, releasing the mature activated form of the pre-proteins. Subsequent caspases are then stimulated which initiate a cascade committed to the process of apoptosis. When gingival cells are exposed to Cyclosporine A, the drug binds to the cyclophillin-D proteins of the mitochondrial MPTP and results in a conformational change, thus blocking the MPTP. The blockage of the MPTPs prevents the release of Cyt C into the cytosol in response to pro-apoptotic stimuli. Cyt C cannot therefore combine with Apaf-1 in the cytosol to activate caspase-9, which in turn cannot activate caspase-3 and caspase-7 to initiate the apoptotic cascade (Walter et al., 1998).

We overproliferated human gingival cells (HGEP cells) by exposure to CsA and then induced apoptosis by the introduction of exogenous Cyt C into CsA-treated gingival cells. Our results indicate a significant reduction in cell numbers at 3, 6 and 9 days post-Cyt C treatment. Data show that incubation with 100ng/ml CsA and 500ng/ml CsA caused a statistically significant overproliferation of HGEP cells as compared to control cells at all three time points. Within each of the three groups (control, 100ng/ml CsA, 500ng/ml CsA), mean cell density at day 6 was the lowest, and as expected, mean cell density at day 9 was the highest. Decreased cell proliferation of pre Cyt C cells at day 6 compared to day 3 resulted in a consequent decrease in the mean cell density post Cyt C treatment at day 6 as well. Since this phenomenon was encountered across all experimental repetitions at the day 6 time point, we speculate that experimental/cell culture conditions alone might not have caused it. The HGEP cells could have potentially exhibited a transient growth in-

Figure 3. Montage of laser scanning confocal images of gingival epithelial cells in various stages of apoptosis, post-CytC treatment. HGEP cells cultured on glass coverslips, were immunostained with DAPI after treatment with Cyt C to visualize nuclei. Apoptotic nuclear features seen include, chromatin condensation (white arrows), pyknotic nuclei (white arrowheads) and scattered nuclear fragments/karyorrhexis of varying sizes (bottom panels).

hibition induced by CsA at this time point (Lauer G et al., 2006). This phenomenon was transient since cells at day 9 exhibited a dramatic increase in cell numbers on exposure to CsA. It is also possible, that after the immediate overproliferation caused by CsA up to 3 days, the cells potentially activated internal pathways to regulate the cell cycle as a temporary compensatory mechanism. By day 9, the balance tipped back in favor of cell overproliferation. Future investigation into specific cellular pathways that could have been triggered is warranted.

Cells incubated in 100ng/ml and 500 ng/ml CsA showed statistically significant increases in cell density when compared to control cells at day 3 and day 6 time points. At day 9, pre Cyt C cell density was less than control group, and could be attributed to the potential transient growth inhibition. Cells incubated in 500ng/ml CsA also showed statistically significant decrease in cell densities as compared to cells incubated in 100ng/ml at all three time points. These data corroborate the previously documented evidence that higher concentrations of CsA (500ng/ml) results in growth inhibition (Lauer et al., 2006; Tyldesley et al., 1984, Walter et al., 1998). With both the experimental groups, we noted that long term exposure coupled with the high doses of CsA tipped the balance in favor of cell overproliferation, mimicking the condition seen *in vivo*.

Following treatment with Cyt C, decrease in cell numbers was seen as expected. Data clearly show a statistically significant decrease in cell densities at 3, 6 and 9 days post Cyt C treatment in the controls, and both experimental conditions (100ng/ml and 500ng/ml). Cell densities were also significantly decreased when compared between groups (i.e. 100ng/ml CsA vs. controls and 500ng/ml CsA vs. controls). The rapid and dramatic decrease at day 3 could be attributed to the sudden intracellular influx of Cyt C. Around day 6, the cells seem to have stabilized to the Cyt C treatment and show less decrease in cell densities when compared to the day 3 time point. Independent of the control cell density, at the day 9 time point, there was significant cell density decrease from pre Cyt C to post Cyt C treatment following incubation in both 100ng/ml and 500ng/ml CsA. This indicates that Cyt C treatment could be effective in inducing apoptosis and decreasing cell densities in this *in vitro* model.

Apoptosis is characterized by a series of morphological changes of the cell and nuclei (Kerr et al., 1972; Kerr et al., 1994). Onset of apoptosis is indicated by cell shrinkage and condensation of chromatin. The process continues with eventual formation of pyknotic nuclei. Ultimately, the nuclei fragments and breaks down, a process known as karyorrhexis. We stained gingival cells grown on cover slips with DAPI to visualize the nuclei. Our data clearly show the condensation of chromatin (white arrows-Figure 3) and the formation of pyknotic nuclei along the margins of the nuclear membrane (white arrowheads-Figure 3). As expected, DAPI staining of gingival nuclei also showed nuclear fragmentation and blebbing, consistent with apoptotic cell death (bottom panels-Figure 3).

Taken together, the data from these experiments constitute an important first step in determining if inducing apoptosis could be a viable, nonsurgical method of managing cellular proliferative disorders like drug-induced gingival overgrowth. Future studies in our laboratory will elaborate the current study to correlate apoptotic features with apoptotic pathways. We will also test the hypothesis using gingival tissue models that will more closely simulate the clinical condition.

ACKNOWLEDGEMENTS

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BOOK REVIEW - 2003 - #2

Book: *Steyermark's Flora of Missouri-Volume 3. Dicots, Fabaceae (subfamily Faboideae) through Zygophyllaceae* (Revised Ed., 2013) by George Yatskievych.
(ISBN: 978-0-915279-13-5), hbk). Missouri Botanical Garden Press (P.O. Box 299 St. Louis, MO 63166-0299) in cooperation with the Missouri Department of Conservation (P.O. Box 180, Jefferson City, MO 65201-0180); xvii + 1382 pp. $65.00. 194 plates of black and white line drawings; 20 figures, including 27 individual black and white photographs; 798 distribution maps.

Reviewer: Dr. Paul M. McKenzie, U.S. Fish & Wildlife Service, Columbia MO, 65203.
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REVIEW

The long awaited and anticipated Volume 3 of the revision to Julian Steyermark's (1963) *Flora of Missouri* by the state's premier botanist George Yatskievych has finally been published and what a masterpiece it is! Volume 3 covers the Fabaceae (where volume 2 left off) through the Zypophyllaceae and includes treatments on 1,031 species, 65 infra-specific taxa, and 134 hybrids. All told, the entire three volume set is no less than 3,554 pages long and includes 582 plates and 2,726 county distribution maps involving 2,839 species and 3,166 taxa. As in volumes 1 and 2, volume 3 is extremely thorough and includes information on recent changes in taxonomy, potential confusion with similar or closely related taxa, and provides some of the most complete descriptions and measurements of plant habitat and reproductive features found in any botanical flora. Additionally, each treatment includes a wealth of information on history, natural history, economic and commercial value, status in cultivation, invasiveness, conservation value, chemical properties, medicinal value and changes in distribution where applicable. The magnitude of data provided is reflected in the fact that the author cited no less than 1,369 references!

Because the taxonomy of dicots is in a constant state of flux and there is a lack of consensus on the alignment and division of various taxa, the author utilized the expertise and assistance from specialists on some groups (e.g. Jay Reveill on various legumes, James B. Phipps on *Crataegus*, and Mark P. Widrlechner on *Rubus*, etc.). The author fully acknowledges that additional studies, especially those involving molecular techniques, will be necessary to further clarify taxonomic relationships for some groups. Even then it is unlikely that there will be total agreement on some taxonomic entities but such is the nature of botanical study and research.

Another highlight of the book is the high quality of the 194 plates that provide excellent detail and enlargement of flowers, fruits, leaf vestiture, and habit. Despite the individuality of the 10 contributors who were contracted to do the illustrations, there is amazing continuity throughout the book. Another plus is that the genus *Rubus* includes subgeneric and sectional keys using a combination of primocanes and floricanes as well as inflorescence characters. Similarly, keys to *Lespedeza*, *Populus*, and *Salix* include both vegetative and reproductive characters involving flowers and fruit.

Despite the superior quality of the book, it is not without its faults. The most noticeable flaw is the fact that there is no family key but simply a statement on what would be page xviii; "The key to dicot families will appear in a supplementary publication." This is most unfortunate because no time table has been given when such a publication will ever be completed. We can only hope that it is sooner rather than later, especially given so many taxonomic changes in various dicot families; without a family key and knowledge of what genus a particular taxon occurs in, it will difficult for some to navigate to the correct location in the book. Interestingly, the author states on page vii in the preface that "the next logical step for the Flora Project will be an effort to update and condense the information in the three-volume encyclopedia into a one-volume manual." There is no mention of the importance of first completing a key to families. While there would be obvious benefit for a condensed update on changes for the entire flora, it would not be nearly as critically important as a familial key.

Another negative mark is that the key to legume subfamilies is not repeated in volume 3. Anyone needing to key out an unknown legume must potentially use both Volume 2 and Volume 3, especially if the unknown taxon is in the subfamily covered in Volume 3 (i.e. Faboideae). A similar situation occurs for members of the genus *Acer* that has been moved from the Aceraceae covered in Volume 2 to the Sapindaceae covered in Volume 3. Anyone attempting to key out an unknown *Acer* spp. after reaching that genus in the Sapindaceae key must then use the key to the genus in Volume 2. Obviously, the taxonomy of plants is in a constant state of flux so the unfortunate set of circumstances involving the genus *Acer* is no fault of the author but it would have been helpful to repeat the key to the genus in Volume 3. That, however, was surely not possible due to scheduled deadlines. Finally, it would have been useful to include a short discussion in the introduction or preface on some of the more recent and divergent taxonomic changes in some genera such as some *Desomodium* to *Hylodesmum*, some *Lespedeza* to *Kummerowia*, *Psoralea* to *Orbexilum* or *Pediomelum*, *Coronilla* to *Securigera*, *Bumelia* to *Sideroxylon*, *Saxifraga* to *Micranthes*, *Dodecatheon* to *Primula*, *Hybanthus* to *Cubelium*, etc. The author does provide a short summary of some of the major familial changes in the preface to the book, but it is difficult to comprehend the magnitude of such changes without the help of a table that would list the old and new names for families, genera, and in some cases, species. The author does provide a summary of the new families that have emerged from Scrophulariaceae and genera that are now merged into this family on page 1106 but as noted above, the changes would have been best represented in a comparison table.

Some amateur botanists and naturalists are likely to have difficulty with many of the technical terms used in family, genera and species accounts, especially those associated with molecular genetics, but the author provides a glossary in the back of the book that provides definition for the overwhelming majority of sophisticated botanical language. Due to scheduling deadlines, it is unfortunate that some species are not illustrated (e.g. *Aeschynomene rudis*, *Centrosema virginianum*, *Cotoneaster acutifolius*, *Dalea gattingeri*, *D. villosa*, *Lablab purpureus*, *Lathyrus tuberosus*, *Rhodotypos scandens*, multiple species of *Rubus* spp., *Spirea japonica*, etc.). As with any botanical compilation, however, it is impossible to keep up with new additions of taxa to state floras and the author mentions in the preface that an average of nine species are added to the Missouri flora each year. Several species of *Crataegus* spp. have been reduced to varietal rank but the lack of county distribution maps for the different variants prevents a visual evaluation of areas of the state where such varieties may be found or a cursory examination of the conservation status of rare taxa based on the number of counties where they have been documented.

Overall, any negative comments on the book are significantly outweighed by the outstanding quality of the content. As with Volumes 1 and 2, Volume 3 of the *Flora of Missouri* should be on the book shelf of every botanist, naturalist and plant enthusiast in the Midwest. I suppose there may be a few individuals who will complain about the $65 price tag, but the book is a bargain when compared to the information provided. The late Julian Steyermark is someone the author has always looked up to and a quote from Yatskievych's acknowledgements is worth repeating here. "Julian Steyermark is a model of what a botanist should be, and his high standards of scholarship are something I continue to aspire to, but fear I will never reach." In completing all three volumes of the revision to Missouri's flora, not only has Yatskievych reached Steyermark's standards, he has exceeded them and if Julian was still with us I am sure he would concur.

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Individual Recognition in the Olive Nerite Snail *Neritina reclivata* (Neritopsina: Neritidae) as Determined by Clustering Behavior

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ABSTRACT

We tested the ability of the olive nerite snail (*Neritina reclivata*) to discriminate between familiar and unfamiliar individuals by observing the individual with which they formed clusters with. Our control group consisted of 15 snails that were housed together in the same tank throughout the experiment. We used the control group to observe the clustering behavior of the snails without exposing them to unfamiliar conspecifics or unfamiliar territories. The control group set the benchmark for our expectations of clustering among other individuals. For the experimental group, we placed five familiarized snails of the same color into a tank with 10 unfamiliar snails of a different color. Five out of seven clusters (on average) during a given phase had excessive amounts of minority colored snails. This indicates that, when placed in a new territory with novel individuals, snails tend to form clusters with familiar individuals and thus provides the first evidence of individual recognition in *N. reclivata*. This work presents new insight into the ecology of *N. reclivata*, with special emphasis on intraspecific interactions.

INTRODUCTION

Individual recognition is the ability of an organism to recognize a familiar individual (whether related or not) using cues learned through prior association with that individual; the individual can then be identified as a competitor, neighbor, mate, offspring, or sibling (Gherardi et al., 2010). Individual recognition can be adaptive in relation to parental care, schooling behavior, aggressive behaviors (including cannibalism), nepotism, and mate choice (Schausberger, 2007) as well as predator avoidance and communal breeding behaviors (Carreno et al., 1996). Kin recognition is the biased treatment of conspecific individuals based on genetic relatedness (Schausberger, 2007). Kin recognition is adaptive in avoiding inbreeding, reducing aggression between relatives, raising young, and securing resources. Individual recognition and kin recognition may overlap in the mechanisms used to identify them, which include prior association (or familiarity) and phenotype matching (Schausberger, 2007). Phenotype matching occurs when an individual learns something about its own phenotype based on odor, vision, etc. and compares it to others to determine whether they are related or unrelated (van der Jeugd et al., 2002).

Kin recognition occurs in many invertebrate species, but individual recognition is less extensively researched. Gherardi and Tiedemann (2004) demonstrated binary individual recognition in the hermit crab *Pagurus longicarpus* by demonstrating that they could categorize individuals into two subgroups. Additionally, big-clawed snapping shrimp (*Alpheus heterochelis*) are capable of discriminating between former mates and unfamiliar conspecifics (Ward et al., 2004). Although many animals exhibit kin or individual recognition, few studies have examined these abilities in snails.

Many animals, social or nonsocial, have been observed forming aggregates. Clustering behaviors decrease vulnerability to dehydration and predation, which increases mate availability (Prokopy and Roitberg, 2001). Stimuli known to evoke grouping among cockroaches include light, temperature, and relative humidity (Prokopy and Roitberg, 2001). Male cockroach nymphs exhibit significantly faster development when grouped with conspecific males than when alone (Holbrook and Schal, 1998). Clustered males have a higher probability of encountering females compared to isolated males, and this is particularly prevalent when the overall population density is low (Prokopy and Roitberg, 2001).

The olive nerite snail, *Neritina reclivata*, is irregularly distributed along coastal regions in the Gulf of Mexico and Caribbean Sea (Lehman and Hamilton, 1981). Detailed information about snail dispersal is limited (Zealand and Jeffries, 2009), but snail movement and clustering can be determined by tidal rhythms (Moulton, 1962). Three species of *Nerita* (*N. polita*, *N. japonina*, *N. taxis*) form clusters, and trail following has been demonstrated in many intertidal mollusks (Focardi et al., 1985). Dispersal ability depends on landscape structure which can create movement barriers and/or corridors. Landscape composition also influences the rate of movement between populations, and snails have relatively low rates of movement (Wilmer et al., 2008). For example, only 28 of 1130 spring snails were identified as immigrants from one connected spring to another (Wilmer et al., 2008). Therefore, it is not likely that there is selection pressure for individual recognition based on dispersal rate. However, it could be advantageous for snails to recognize familiar individuals to decrease inbreeding.

Our study addresses individual recognition in *N. reclivata* snails by examining clustering behavior. The purpose of our study is to determine whether *N. reclivata* can recognize familiar individuals and form clusters based on these identifications. We tested whether snails could discriminate between familiar and unfamiliar individuals by observing whether snails formed clusters with familiar (previously associated) individuals as opposed to clustering with unfamiliar snails.

METHODS

We conducted our research at Millikin University in Decatur, IL in 2011. We obtained *N. reclivata* from the Carolina Biological Supply Company. We maintained snails in de-chlorinated water and fed them fish food *Ad libitum* once per week. After two weeks of acclimation, we randomly as-

signed each snail into one of three groups designated Batch 1, Batch 2, or control. Each snail was marked on its shell with non-toxic purple, orange, or green paint as follows. Batch 1 consisted of three aquaria (19.05 cm L x 11.43 cm W x 13.97 cm H) - one designated purple, one orange, and one green - with 15 snails each. Batch 2 was an exact replica of Batch 1: it contained three tanks, designated purple, orange and green, with 15 snails in each tank labeled as described above. The seventh tank was the control tank, which contained 15 snails labeled 1-15 in purple.

We tested the experimental groups in seven different phases (Table 1). The experiment began with phase 1 (referred to as the home phase). The first time we performed the home phase, 15 snails of the same color were given 48 hours in their original tank (tank of their designated color) to familiarize themselves with like-colored individuals. In every other phase, we moved 5 individuals from their original tank and introduced them to a new tank of 10 snails for 48 hours. Each phase involved the movement of 5 individual snails from their original tank to an unfamiliar tank. When initially placed in a novel tank, we positioned individuals in the same corner of the tank but not close enough together to be considered a cluster. After we moved the first 5 individuals to a new tank for 48 hours, we repeated the home phase, and returned snails to their original tank for 24 hours. After 24 hours back in their original tank, we moved those same 5 individuals to a second unfamiliar tank for 48 hours. For example, in phase 2, purple individuals 1-5 were moved to the green tank for 48 hours, then returned back to the purple tank for 24 hours, then moved to the orange tank for 48 hours (Table 1). Every three hours for the duration of the research, we observed and recorded the interactions and clusters formed between snails. Each phase lasted 48 hours, with the exception of the home phase. We repeated the home phase at the completion of every phase to allow the snails to re-acclimate. The snails in the control group remained in the same tank for the duration of the experiment.

During each observation period, we photographed and drew all individuals in each tank to document snail positions. For ease of recording, we divided each tank into seven regions. For statistical purposes, we defined a cluster as two or more snails in a group and set our significance level at $P < 0.025$. We adopt $P < 0.025$ instead of 0.05 because we reused majority snails in some trials (see Materials and Methods). To overestimate the impact of this reuse, we applied the simplest and most conservative adjustment to account for multiple comparisons – the Bonferroni correction (Dunn, 1961). In this case, we apply a Bonferroni correction of 2, leading to the more restrictive significance criterion of $P < 0.05/2$.

Table 1. Experimental phases 1-7 with *Neritina reclivata* individuals that were transferred listed as 1-5, 6-10, 11-15. Each phase lasted 48 hours, with phase 1 (home phase) being repeated for 24 hours between each phase.

Phase 1 (**home phase**)	Purple (**1-15**)	Green (**1-15**)	Orange (**1-15**)
Phase 2	1-5 **purple** moved to **green tank**	1-5 **green** moved to **orange tank**	1-5 **orange** moved to **purple tank**
Phase 3	1-5 **purple** moved to **orange tank**	1-5 **green** moved to **purple tank**	1-5 **orange** moved to **green tank**
Phase 4	6-10 **purple** moved to **green tank**	6-10 **green** moved to **orange tank**	6-10 **orange** moved to **purple tank**
Phase 5	6-10 **purple** moved to **orange tank**	6-10 **green** moved to **purple tank**	6-10 **orange** moved to **green tank**
Phase 6	11-15 **purple** moved to **green tank**	11-15 **green** moved to **orange tank**	11-15 **orange** moved to **purple tank**
Phase 7	1-15 **purple** moved to **orange tank**	11-15 **green** moved to **purple tank**	11-15 **orange** moved to **green tank**

Table 2. Batch 1 experimental Phases 2-7 where orange snails (*Neritina reclivata*) accounted for 1/3 of the population. Columns 3 and 6 show the number of instances in which statistically significant clusters formed, and the total number of snails of colors 1 and 2 that were part of each cluster group in the following format: number of significant clusters (number of majority color: number of minority color). The *P*-values in Columns 4 and 7 indicate the likelihood of these results happening by chance.

Phase	**Color 1** (10 individuals)	**Color 1 excess**	***P*-value 1**	**Color 2** (5 individuals)	**Color 2 excess**	***P*-value 2**
2	Purple	1 (16:0)	$1.52*10^{-3}$	Orange 1-5	4 (3:0), (2:0), (2:2), (2:2)	$3.61*10^{-4}$
3	Green	3 (17:2), (36:9), (6:0)	$3.49*10^{-5}$	Orange 1-5	1 (11:0)	$5.60*10^{-6}$
4	Purple	1 (4:0)	0.20	Orange 6-10	1 (9:0)	$5.08*10^{-5}$
5	Green	2 (59:2), (6:0)	$7.28*10^{-10}$	Orange 6-10	3 (10:4), (2:0), (2:1)	$8.27*10^{-5}$
6	Purple	2 (25:0), (8:0)	$1.55*10^{-6}$	Orange 11-15	3 (19:0), (2:0), (5:5)	$1.31*10^{-11}$
7	Green	2 (6:0), (2:0)	0.04	Orange 11-15	1 (19:0)	$8.6*10^{-10}$

RESULTS

We used the control group as a reference point to determine the standard clustering behavior among *N. reclivata* individuals. Using the first 32 trials (each observation was considered a trial), we calculated the average number of individuals ± the standard deviation in each cluster. On average, between 3.1 and 9.0 of snails out of every group of 15 formed clusters. In other words, between 20.7% and 60.0% of snails joined a cluster. This is consistent with a random behavior in a binomial system; i.e., there is a 50:50 chance of clustering or not.

In the experimental groups, we expected to see clustering fractions proportional to the amount of individuals of certain colors. For example, with 10 purple individuals and 5 orange individuals, we would expect 2/3 (67%) of clustering individuals to be purple and 1/3 (33%) to be orange if the snails were behaving randomly. Any behaviors that exceeded or fell below these percentages at a significant level indicate departures from random behavior. For experimental groups, we determined the probability (*P*-values) that observed clusterings could have happened by chance using binomial statistics

Snails tended to cluster more significantly when they were in the minority group. In phase 2 of Batch 1, clusters contained an excess amount of orange individuals, in 4 out of 7 regions, on average (Table 2). In

Table 3. Batch 1 experimental Phases 2-7 where green snails (*Neritina reclivata*) accounted for 1/3 of the population. Columns 3 and 6 show the number of instances in which statistically significant clusters formed, and the total number of snails of colors 1 and 2 that were part of each cluster group in the following format: number of significant clusters (number of majority color: number of minority color). The *P*-values in Columns 4 and 7 indicate the likelihood of these results happening by chance.

Phase	Color 1 (10 individuals)	Color 1 excess	*P*-value 1	Color 2 (5 individuals)	Color 2 excess	*P*-value 2
2	Orange	2 (10:0), (2:0)	$7.71*10^{-3}$	Green 1-5	3 (17:5), (5:0), (5:5)	$1.51*10^{-8}$
3	Purple	1 (18:0)	$6.77*10^{-4}$	Green 1-5	5 (10:5), (10:8), (6:3), (2:2), (2:2)	$5.80*10^{-7}$
4	Orange	2 (9:1), (4:0)	0.02	Green 6-10	3 (11:16), (7:6), (5:5)	$1.10*10^{-3}$
5	Purple	0	1	Green 6-10	2 (3:4), (3:5)	0.02
6	Orange	2 (19:0)	$2.00*10^{-4}$	Green 11-15	2 (36:5), (2:0)	$7.31*10^{-14}$
7	Purple	1 (24:2)	$2.15*10^{-3}$	Green 11-15	2 (20:2), (2:0)	$3.27*10^{-9}$

Table 4. Batch 1 experimental Phases 2-7 where purple snails (*Neritina reclivata*) accounted for 1/3 of the population. Columns 3 and 6 show the number of instances in which statistically significant clusters formed, and the total number of snails of colors 1 and 2 that were part of each cluster group in the following format: number of significant clusters (number of majority color: number of minority color). The *P*-values in Columns 4 and 7 indicate the likelihood of these results happening by chance.

Phase	Color 1 (10 individuals)	Color 1 excess	*P*-value 1	Color 2 (5 individuals)	Color 2 excess	*P*-value 2
2	Green	3 (42:0), (5:0), (4:0)	$1.05*10^{-9}$	Purple 1-5	2 (13:0), (2:0)	$6.97*10^{-8}$
3	Orange	2 (17:0), (6:0)	$8.91*10^{-5}$	Purple 1-5	2 (12:6), (10:1)	$3.81*10^{-7}$
4	Green	3 (17:4), (14:2), (13:0)	$1.76*10^{-5}$	Purple 6-10	2 (6:6), (2:1)	0.02
5	Orange	4 (76:5), (2:0), (2:0), (2:0)	$1.62*10^{-3}$	Purple 6-10	2 (19:7), (7:1)	$8.08*10^{-8}$
6	Green	3 (10:2), (2:0), (2:0)	0.03	Purple 11-15	0	1
7	Orange	2 (27:0), (8:0)	$6.87*10^{-7}$	Purple 11-15	1 (29:0)	$1.46*10^{-14}$

Table 5. Batch 1 experimental Phases 2-7 where orange snails (*Neritina reclivata*) accounted for 1/3 of the population. Columns 3 and 6 show the number of instances in which statistically significant clusters formed, and the total number of snails of colors 1 and 2 that were part of each cluster group in the following format: number of significant clusters (number of majority color: number of minority color). The *P*-values in Columns 4 and 7 indicate the likelihood of these results happening by chance.

Phase	Color 1 (10 individuals)	Color 1 excess	*P*-value 1	Color 2 (5 individuals)	Color 2 excess	*P*-value 2
2	Purple	1 (3:0)	0.30	Orange 1-5	1 (3:1)	0.10
3	Green	3 (19:0), (4:0), (6:0)	$7.82*10^{-6}$	Orange1-5	1 (6:8)	0.16
4	Purple	2 (9:1), (2:0)	0.04	Orange 6-10	3 (13:12), (4:2), (5:6)	$3.45*10^{-4}$
5	Green	0	1	Orange 6-10	3 (11:5), (8:2), (2:2)	$2.9*10^{-6}$
6	Purple	2 (11:0), (10:0)	$2.00*10^{-4}$	Orange 11-15	1 (9:10)	0.08
7	Green	2 (6:0), (2:0)	0.04	Orange 11-15	1 (4:2)	0.08

Table 6. Batch 1 experimental Phases 2-7 where green snails (*Neritina reclivata*) accounted for 1/3 of the population. Columns 3 and 6 show the number of instances in which statistically significant clusters formed, and the total number of snails of colors 1 and 2 that were part of each cluster group in the following format: number of significant clusters (number of majority color: number of minority color). The *P*-values in Columns 4 and 7 indicate the likelihood of these results happening by chance.

Phase	Color 1 (10 individuals)	Color 1 excess	*P*-value 1	Color 2 (5 individuals)	Color 2 excess	*P*-value 2
2	Orange	1 (16:5)	0.13	Green 1-5	3 (17:23), (2:2), (2:2)	$5.37*10^{-3}$
3	Purple	2 (9:3), (5:1)	0.06	Green 1-5	1 (13:2)	$2.93*10^{-5}$
4	Orange	1 (20:5)	0.07	Green 6-10	2 (9:14), (3:0)	$5.26*10^{-3}$
5	Purple	0	1	Green 6-10	3 (10:14), (7:10), (4:4)	$2.99*10^{-3}$
6	Orange	2 (20:2), (2:0)	$3.43*10^{-3}$	Green 11-15	3 (10:9), (8:2), (2:0)	$1.38*10^{-5}$
7	Purple	0	1	Green 11-15	2 (9:1), (2:0)	$3.76*10^{-5}$

Batch 1, the most significant trends are associated with green individuals. Although each experiment showed excess numbers of individuals clustering, green individuals formed clusters most often. For example, out of the multiple trials during phases 2 and 4, in which green individuals were the minority in the experimental tanks, 3 out of 7 areas had a statistically significant excess of green snails. Additionally, phase 3 showed a statistically significant excess of green snails in 5 out of 7 regions (Table 3). With the *P*-value being extremely low in these cases (5.80×10^{-7}), the probability that these cluster patterns formed by chance is highly unlikely. Similarly, in phases 2-5 of Batch 1 when purple individuals were the minority, 2 out of 7 regions contained an excess amount of purple snails (Table 4).

Batch 2 snails showed similar clustering behaviors to those of Batch 1 snails. In Phases 4 and 5 where orange were the minority, 3 out of 7 areas had a significant excess of orange snails (Table 5). When green snails were the minority in Batch 2, 3 out of 7 areas contained excess green individuals (Table 6). In Phase 5 (10 orange and 5 purple), 3 out of 7 regions had excess purple individuals in them, and 0 out of 7 had excess orange individuals (Table 7).

Random behavior was only observed in snails that were part of the majority, with the exception of purple individuals in phase 6 of Batch 1 (Table 4). For example, Phases 2, 4, and 5 in Batch 1 all showed no clustering among the majority colored snails (Table 3); the same can be seen in results from Batch 2 in Phases 5 and 7 where green individuals were the minority (Table 6)

DISCUSSION

We found a significant relationship between the amount of like-colored individuals and the formations of clusters, which supports possible individual recognition in the olive snail *N. reclivata*. Overall, there were 120 total areas with significant clustering, 50 (42%) majority areas and 70 (58%) minority areas. Thirty-seven (74%) of the 50 majority areas only contained majority snails (homogeneous clustering) compared to 19 (27%) of the 70 minority areas.

These results show that individuals of the same color tend to form clusters with one another, especially when they were out-

Table 7. Batch 1 experimental Phases 2-7 where purple snails (*Neritina reclivata*) accounted for 1/3 of the population. Columns 3 and 6 show the number of instances in which statistically significant clusters formed, and the total number of snails of colors 1 and 2 that were part of each cluster group in the following format: number of significant clusters (number of majority color: number of minority color). The *P*-values in Columns 4 and 7 indicate the likelihood of these results happening by chance.

Phase	Color 1 (10 individuals)	Color 1 excess	*P*-value 1	Color 2 (5 individuals)	Color 2 excess	*P*-value 2
2	Green	2 (33:14), (7:1)	0.02	Purple 1-5	2 (6:4), (3:4)	0.01
3	Orange	2 (8:2), (2:0)	0.09	Purple 1-5	2 (7:1), (4:0)	$3.01*10^{-5}$
4	Green	2 (20:9), (2:0)	0.07	Purple 6-10	1 (13:9)	0.01
5	Orange	0	1	Purple 6-10	3 (18:6), (8:12), (3:1)	$4.46*10^{-7}$
6	Green	0	1	Purple 11-15	2 (12:5), (6:6)	$1.71*10^{-4}$
7	Orange	2 (4:0), (4:0)	0.04	Purple 11-15	1 (16:0)	$2.32*10^{-8}$

numbered by unfamiliar individuals: i.e., 70 minority clustering areas vs. 50 majority clustering areas. This is not to say that snails will not form clusters with novel individuals, but clusters that contained both colors of snails tended to have a larger amount of the minority color present. Given the fraction of the majority color compared to the minority color in any given experimental phase, these behaviors are significantly different than what is expected from random behavior.

Future studies should consider alternative placement of the experimental snails in new territories and examine the movement of individual snails once they are placed in those new territories. In all, 1341 individuals formed clusters: 584 green, 413 orange, and 344 purple. It would be interesting to examine the role of visual mechanisms involved in the clustering behavior of these snails. It may be possible that green individuals were more attracted to each other because the color green is a sign stimulus for the main food source of these snails, algae. Another possibility may be the differences in luster and clarity of the green, orange, and purple paints. Introduction to new environments may be something to consider. Although we were careful to create uniform environments for each group, there may have been cues (olfactory or otherwise) that we were unable to control. According to Prokopy and Roitberg (2001), the payoff to the individual for aggregating with or leaving groups of conspecifics depends on (a) the response of conspecifics to such actions and (b) the physiological and ecological context within which such decisions are made.

Aggregating in clusters has many mutual advantages such as increased feeding efficiencies (Focardi et al., 1985). In the sea slug genus *Aplysia*, clustering promotes reproduction (Kupfermann and Carew, 1974), and the jellyfish, *Linuche unguiculata*, significantly increases its reproductive success by social swarming (Larson, 1992). Clustering can also provide a particularly strong defense against predators, if a snail can secure an internal position within a cluster (Chase et al., 1980). In addition, forming clusters prevents desiccation by decreasing the total surface-to-volume ratio and thus reducing net evaporation (Chase et al., 1980). Moisture is conserved in this manner in aggregations of *Clypeomorus* sea snails (Moulton, 1962). Fraenkel (1968) found a direct correlation between heat resistance of intertidal mollusks and their position in the tidal zone. During observational periods, we occasionally noticed some individual snails completely above the surface of the water; if grouping is related to heat resistance or moisture conservation, in might be interesting to examine body size in relation to cluster formation in *N. reclivata*.

In the terrestrial snail *Achatina fulica*, degree of aggregation is related to the snails' ages, genetic relationships, and time of day (Chase et al., 1980). Clustering was greater when the sample population consisted of snails that hatched from one clutch of eggs compared to when they hatched from two clutches. Recently hatched snails aggregated less than older animals, and aggregation was greater during the night. The proximate basis for clustering is thought to be olfactory. Since snails often distribute themselves nonrandomly, it is reasonable to conclude that aggregation is a social behavior, although the adaptive significance does not seem to be the same in heterospecifics (Chase et al., 1980).

Recognition in invertebrates is not uncommon; there are numerous species of invertebrates that can recognize predators and learn to avoid them. For example, the sweat bee *Lasioglossum umbripenne* exhibits evasive behaviors to their ant predators, *Ectatomima ruidum*, mainly based on visual pattern recognition and ant movement (Wcislo and Schatz, 2003). Bee behavior differed based on whether an ant near the nest entrance was dead or alive (Wcislo and Schatz, 2003). Bluebell tunicate larvae (*Clavelina moluccensis*) siblings clump with other siblings that are already settled while non-siblings settle randomly (Davis and Campbell, 1996), thus exhibiting a form of kin recognition. Although we demonstrated individual recognition through clustering, we do not know whether our snails were related or not. Therefore, kin recognition in *N. reclivata* should be considered in future studies.

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