

**PROCEEDINGS OF THE 12<sup>TH</sup> SYMPOSIUM  
ON THE NATURAL HISTORY OF  
LOWER TENNESSEE AND CUMBERLAND RIVER VALLEYS**

**HELD AT BRANDON SPRING GROUP CAMP  
LAND BETWEEN THE LAKES  
MARCH 30 AND 31, 2007**

Sponsored by:

The Center of Excellence for Field Biology  
Austin Peay State University, Clarksville, Tennessee

and

The Center for Reservoir Research  
Murray State University, Murray, Kentucky

and

U.S. Department of Agriculture, Forest Service  
Land Between The Lakes National Recreation Area  
Golden Pond, Kentucky

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EDITED BY:

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## PREFACE

The 12<sup>th</sup> Symposium on the Natural History of Lower Tennessee and Cumberland River Valleys was convened at Brandon Spring Group Camp at 1:30 p.m. on Friday, March 30, 2007. Dr. Steven W. Hamilton, Interim Director of The Center of Excellence for Field Biology, Austin Peay State University welcomed the assembly on behalf of the Center. Dr. Susan Calovini, Interim Dean of the College of Science and Mathematics, at Austin Peay State University followed with welcoming comments on behalf of the college. Dr. David S. White, Director of the Hancock Biological Station and the Center for Reservoir Research, Murray State University, greeted the group on behalf of those entities. Representing U.S. Forest Service's Land Between The Lakes National Recreation Area, Environmental Stewardship Department Manager Judy Hallisey welcomed the group to LBL.

Following the welcoming comments, Dr. Betsie B. Rothermel, The Center of Excellence for Field Biology, Austin Peay State University, moderated the invited paper session, which was themed "Habitat Fragmentation: Ecological Implications for Management." The first invited speaker was Dr. Paul Porneluzi, Associate Professor of Biology, Central Methodist University. His presentation was entitled "Testing the Effects of Forestry on Songbirds via the Missouri Ozark Forest Ecosystem Project." Following a brief break, Dr. Thomas O. Crist, Professor, Department of Zoology, Miami University presented an invited talk entitled "From Habitat Fragmentation to Spatial Heterogeneity: New Approaches to Understanding Biodiversity Change in Human-Altered Landscapes." The third invited speaker, Dr. R. Edward DeWalt, Associate Research Scientist, Illinois Natural History Survey, presented "Habitat Fragmentation and Extirpation and Range Loss of Stoneflies of Illinois."

The Saturday morning contributed papers were presented in two concurrent sessions. Session I, Botany, was moderated by Dr. Edward W. Chester, Department of Biology, Austin Peay State University and Session II, Aquatic Biology and Zoology, was moderated by Dr. Andrew N. Barrass, The Center of Excellence for Field Biology, Austin Peay State University. The Botany session was comprised of thirteen papers, four of which are published in these proceedings as full manuscripts. Abstracts of the remaining eleven papers are included herein. The thirteen papers presented in the Aquatic Biology and Zoology session are published here as abstracts, except for one which has a full manuscript.

These proceedings of the 12<sup>th</sup> symposium follow the format of previous proceedings published by the Center of Excellence for Field Biology. Papers and abstracts were reviewed by the staff of The Center for style, structure, content and scientific merit. In addition, invited papers were reviewed by external reviewers. We thank the authors for their diligence in submitting manuscripts and abstracts and hope that our efforts have resulted in a quality presentation of their research.

## ACKNOWLEDGMENTS

The editors thank Jean Langley, secretary of the Center, for her assistance in preparation of these proceedings. Additional thanks go to Ms. Langley for her effort in organizing and managing the two-day symposium. We appreciate the efforts of the many Center for Field Biology undergraduate and graduate research assistants for their help in preparing, assembling, operating and disassembling the symposium. We also thank the staff of Brandon Spring Group Camp for the help and hospitality.

## SYMPOSIUM REGISTRANTS

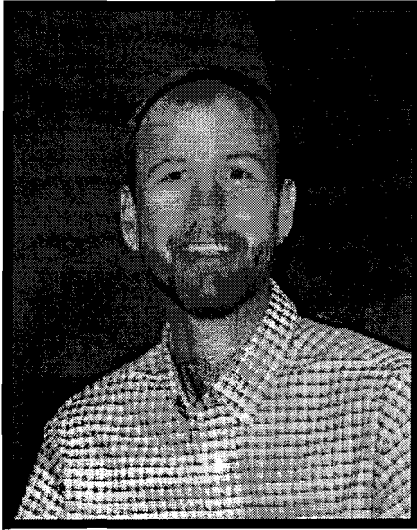
Following, in alphabetical order, is a list of those individuals who registered at the 2007 symposium. Institutional affiliation (when available), city (of the person's institution or home), and state are also given.

Andrew N. Barrass – Austin Peay State University, Clarksville, TN; Carol Baskin – University of Kentucky, Lexington, KY; Jerry M. Baskin – University of Kentucky, Lexington, KY; Charles N. Boehms – Austin Peay State University, Clarksville, TN; Zachary A. Brian – Murray State University, Murray, KY; Brittany Card – Belmont University, Nashville, TN; Emilie Carroll – Vanderbilt University, Nashville, TN; Edward W. Chester – Austin Peay State University, Clarksville, TN; Todd Crabtree – TDEC, Nashville, TN; Thomas O. Crist – Miami University, Oxford, OH; Hal De Selm – University of Tennessee, Knoxville, TN; R. Edward DeWalt – Illinois Natural History Survey, Champaign, IL; Peter Dubinin – Austin Peay State University, Clarksville, TN; Julia Earl – Murray State University, Murray, KY; Dwayne Estes – University of Tennessee, Knoxville, TN; Kevin Fitch – TDEC, Nashville, TN; James Fralish – Southern Illinois University, Carbondale, IL; Judy Hallisey – USDA Forest Service LBL NRA, Golden Pond, KY; Steven W. Hamilton – Austin Peay State University, Clarksville, TN; Iin Handayani – Murray State University, Murray, KY; Kate He – Murray State University, Murray, KY; Susan Hendricks – Murray State University, Murray, KY; Chris Henson – University of Memphis, Memphis, TN; Don Hubbs – TWRA, Nashville, TN; Ben Iobst – Vanderbilt University, Nashville, TN; Jeffrey A. Jackson – Eastern Kentucky University, Richmond, KY; Gehan Jayasuriya – University of Kentucky, Lexington, KY; Sarah Jo Jenkins – Austin Peay State University, Clarksville, TN; Eric Johansen – Austin Peay State University, Clarksville, TN; Mike Kennedy – University of Memphis, Memphis, TN; Josh Koontz – University of Memphis, Memphis, TN; Amy Krzton-Presson – Murray State University, Murray, KY; Morgan Kurz – Austin Peay State University, Clarksville, TN; Jean Langley – Austin Peay State University, Clarksville, TN; DeLacy LeBlanc – Austin Peay State University, Clarksville, TN; David Lincicome – TDEC, Nashville, TN; Laurina Lyle – University of the South, Sewanee, TN; Andy Madison – Union University, Jackson, TN; Josh Maloney – Austin Peay State University, Clarksville, TN; Silas Mathes – TDEC, Nashville, TN; Seth McCormick – Austin Peay State University, Clarksville, TN; Jim McCoy – USDA Forest Service, Golden Pond, KY; Roger McCoy – TDEC, Nashville, TN; Johnathan McQuaide – Southern Illinois University, Carbondale, IL; Jamie Miller – Austin Peay State University, Clarksville, TN; Shelly Morris – The Nature Conservancy, Lexington, KY; Steve Murphree – Belmont University, Nashville, TN; Jim Neblett – Belmont University, Nashville, TN; Nathan Parker – Austin Peay State University, Clarksville, TN; Thomas D. Payne – Hopkinsville, KY; Neil Pederson – Eastern Kentucky University, Richmond, KY; Dana Porneluzi – University of Missouri, Columbia, MO; Paul Porneluzi – Central Methodist University, Fayette, MO; Xiaoxia Qu – University of Kentucky, Lexington, KY; James B. Ramsey – Murray State University, Murray, KY; Josh Ream – Austin Peay State University, Clarksville, TN; Katie Richardson – USDA Forest Service, Golden Pond, KY; Stephen Richter – Eastern Kentucky University, Richmond, KY; Lacey Robertson – Austin Peay State University, Clarksville, TN; Ginger Robinson – Austin Peay State University, Clarksville, TN; Michelle Rogers – Austin Peay State University, Clarksville, TN; Betsie B. Rothermel – Austin Peay State University, Clarksville, TN; Joe Schiller – Austin Peay State University, Clarksville, TN; A. Floyd Scott – Austin Peay State University, Clarksville, TN; Courtney Snapp – Murray State University, Murray, KY; Karl Sorensen – Austin Peay State University, Clarksville, KY; Brooke Traynham – Vanderbilt University, Nashville, TN; Christopher Van Pelt – Austin Peay State University, Clarksville, TN; Brenda H. Webb – Florence, AL; David Webb – TVA, Florence, AL; Carrie Whalen – Austin Peay State University, Clarksville, TN; David White – Murray State University, Murray, KY; Robin Zhang – Murray State University, Murray, KY.

## SYMPOSIUM SPEAKERS

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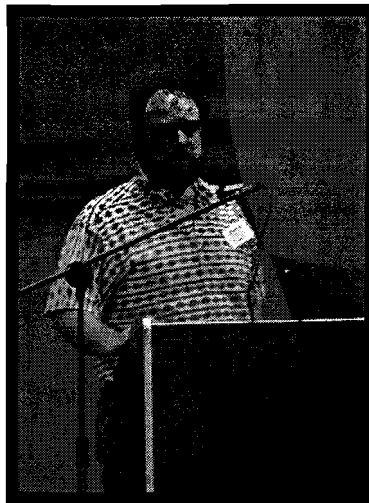
### Invited Speakers



Paul Porneluzi  
Central Methodist University



Thomas O. Crist  
Miami University (Ohio)



R. Edward DeWalt  
Illinois Natural History Survey

## Contributed Papers



**Session I: Botany** – (from left) Kate He, Dwayne Estes, Gehan Jayasuriya, Josh Koontz, Carol Baskin, Edward W. Chester (moderator), Kevin C. Fitch, Laurina I. Lyle, Jerry M. Baskin, James S. Fralish, Xiao-Xia Qu, Hal De Selm



**Session II: Aquatic Biology and Zoology** – (from left) Nathan L. Parker, Benjamin J. Beas, Brooke Traynham, Jamie J. Miller, Joshua L. Maloney, Julia Earl, Courtney Snapp, Ben Iobst, Emilie Carroll, James B. Ramsey, DeLacy LeBlanc, Sarah Jo Jenkins, Andrew N. Barrass (moderator)

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**INVITED PAPERS**

**HABITAT FRAGMENTATION: ECOLOGICAL  
IMPLICATIONS FOR MANAGEMENT**

**Friday, March 30, 2007**

Moderated by:

*Betsie B. Rothemel*

**The Center of Excellence for Field Biology  
Austin Peay State University**





# TESTING THE EFFECTS OF FORESTRY ON SONGBIRDS VIA THE MISSOURI OZARK FOREST ECOSYSTEM PROJECT

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Department of Biology, Central Methodist University, Fayette, Missouri 65248

**ABSTRACT.** Fully documenting ecological implications of management decisions often requires large-scale, long-term study. This may be especially true of a managed forest ecosystem with a regeneration time of 100 years or more. In the late 1980's, the Missouri Department of Conservation began planning the Missouri Ozark Forest Ecosystem Project (MOFEP) in an effort to assess the ecological implications of their management actions. The outcome was a controlled experiment on nine large (average = 400 ha) study sites. The sites were randomly assigned to one of three management treatments; no harvest; even-aged management; and uneven-aged management. Investigators studied a variety of taxa (e.g., mammals, birds, fungi, leaf litter invertebrates) and abiotic conditions during a three to five year pre-treatment period for comparison with responses following the application of the experimental treatments in 1996. In this paper, I summarize some of the findings of the forest bird community response to the management options. I also discuss the connection between forest fragmentation and forest management. In particular, I consider how predicted increases in fragmentation of the Ozark region may alter the effects of forest management in the future.

## INTRODUCTION

Understanding the ecological implications of management decisions often requires large-scale, long-term studies. Landscape-scale studies may be especially important for highly mobile organisms such as migratory birds. Fully assessing management actions in forest ecosystems with a regeneration time of over 100 years requires long-term studies. Additionally, controlled, manipulative experiments with replication are needed to produce strong inferences from such studies. The Missouri Ozark Forest Ecosystem Project (MOFEP) is an attempt to meet these requirements.

MOFEP is a >100-year, manipulative experiment designed to test the effects of forest management on a suite of biotic and abiotic components in Missouri oak-hickory forests (Brookshire & Shifley 1997; Shifley & Kabrick 2002). Each of the nine MOFEP study sites was randomly assigned to even-aged treatment, uneven-aged treatment, or no harvest (i.e., no trees cut), resulting in a randomized complete block design. Investigators studied ecosystem components for three to five years prior to the application of the experimental treatments in 1996, and initiated collection of post-treatment data in 1997. Findings have been reported in numerous publications (see Shifley & Kabrick 2002 and Kabrick et al. 2004 for summaries).

I have been specifically involved in MOFEP as a member of the team of investigators studying the forest-bird component of the experiment. In this paper, I summarize some of our findings on the forest bird community response to forest management options. In Gram et al. (2003) we reported the short-term effects of forest management on focal bird species' density and reproductive success by evaluating 5 years of pretreatment data and 3 years of post-treatment data (1991 – 1999). In this paper, I will evaluate how changes observed in the first three post-treatment years have continued or changed during the next 4 years (2000 – 2003). I also discuss the connection between forest fragmentation and forest management. In particular, I consider how predicted increases in fragmentation of the Ozark region may alter the effects of forest management in the future.

## METHODS

### Study Area

The MOFEP study area is located in the Ozark hills of south-central Missouri (91° 01' to 91°13' W and 37° 00' to 37° 12'N, Fig. 1). The nine study sites averaged 400 ha in size and were located in Carter, Reynolds, and Shannon counties. The region is 84% forested and the canopy is dominated by white oak

(*Quercus alba*), post oak (*Q. stellata*), black oak (*Q. velutina*), scarlet oak (*Q. coccinea*), short leaf pine (*Pinus echinata*) and mockernut hickory (*Carya tomentosa*). Additional details on forest composition and history are published in Brookshire and Shifley (1997) and Shifley and Brookshire (2000). Most overstory trees were 50 to 70 years old and sites were largely free from manipulation for at least 40 years before the start of MOFEP in 1990. Fire, logging, agriculture, and regional and global changes have affected the MOFEP sites over the past 1000 years (Guyette & Larsen 2000).

## Experimental Design

Treatments were designed to mimic three forest management options commonly administered by the Missouri Department of Conservation. The three treatments were no-harvest, even-aged harvest and uneven-aged harvest management. Each of the nine MOFEP study sites was randomly assigned to one of the treatments in a randomized complete block design (Fig. 1). Investigators studied a variety of ecosystem components (e.g., mammals, birds, fungi, herpetofauna, herbaceous and woody vegetation, microclimate, herbaceous insects, leaf litter invertebrates, soils, mast production) during a three to five year pre-treatment period for comparison with responses following the application of the experimental treatments in 1996. Treatments will be re-applied every 15 years.

In no-harvest management, no trees are harvested for the duration of the study. These sites will be maintained as relatively large (average = 400 ha) blocks of forest with similar history and changes will occur on the sites as a result of processes such as tree mortality, disease, wind, and fire.

Similar yields of timber were harvested from sites with the even-aged and the uneven-aged treatments (Kabrick et al. 2002). In both even-aged and uneven-aged sites, a contiguous patch of approximately 10% of each site was permanently designated as a reserve and left uncut. The harvests were conducted using different management practices in the two treatments.

In the even-aged treatment, approximately 10–15% of the total forest area was clearcut. Clearcuts were 3–13 ha in size, resulting in seven to nine clearcut stands per even-aged site (Fig. 1; Brookshire & Shifley 1997). Forest thinning was conducted on other stands within these sites to increase growing space for residual trees. Thus, in even-aged sites, foresters harvested 15–34% of the forest area, and large blocks of cut or thinned forest were interspersed in a matrix of uncut forest. The even-aged treatment will be applied on a 15-year rotation to a different set of stands.

In the uneven-aged treatment, foresters used small-group and single-tree selection cuts. For uneven-aged sites, harvesting occurred in 41–69% of each site outside the permanent reserve stands, and many small areas of cut or thinned forest were scattered throughout uncut forest (Fig. 1; Kabrick et al. 2002). The uneven-aged treatment will also be applied on a 15-year rotation.

## Data Collection

We determined bird species density using spot-mapping, a survey technique that spatially maps bird territories (Anonymous 1970). We divided each study site into seven adjacent 45-ha, spot-mapping plots and surveyed each plot 10 times from mid-May through the end of June each year. Trained field assistants spent 3–4 hours each morning, beginning at dawn, spot-mapping one entire plot. Field assistants surveyed plots in rotation to avoid temporal biases. We recorded all bird locations during each visit on enlarged topographic maps of the plot (map scale 1:3330 mm). To identify territories, we created yearly composite maps for each species per site. We defined a territory as a cluster of at least three detections from three different census dates. We counted partial territories as fractions when a site boundary intersected a territory. We calculated species density by dividing the number of territories per study site by site area. Species density per site is a response variable that depicts a larger spatial scale than density within a specific microhabitat such as a clearcut or selection-cut area. Spot-mapping was conducted over the entire area of each site from 1991 through 2000 but was scaled back to four of seven subplots from 2001 through 2003.

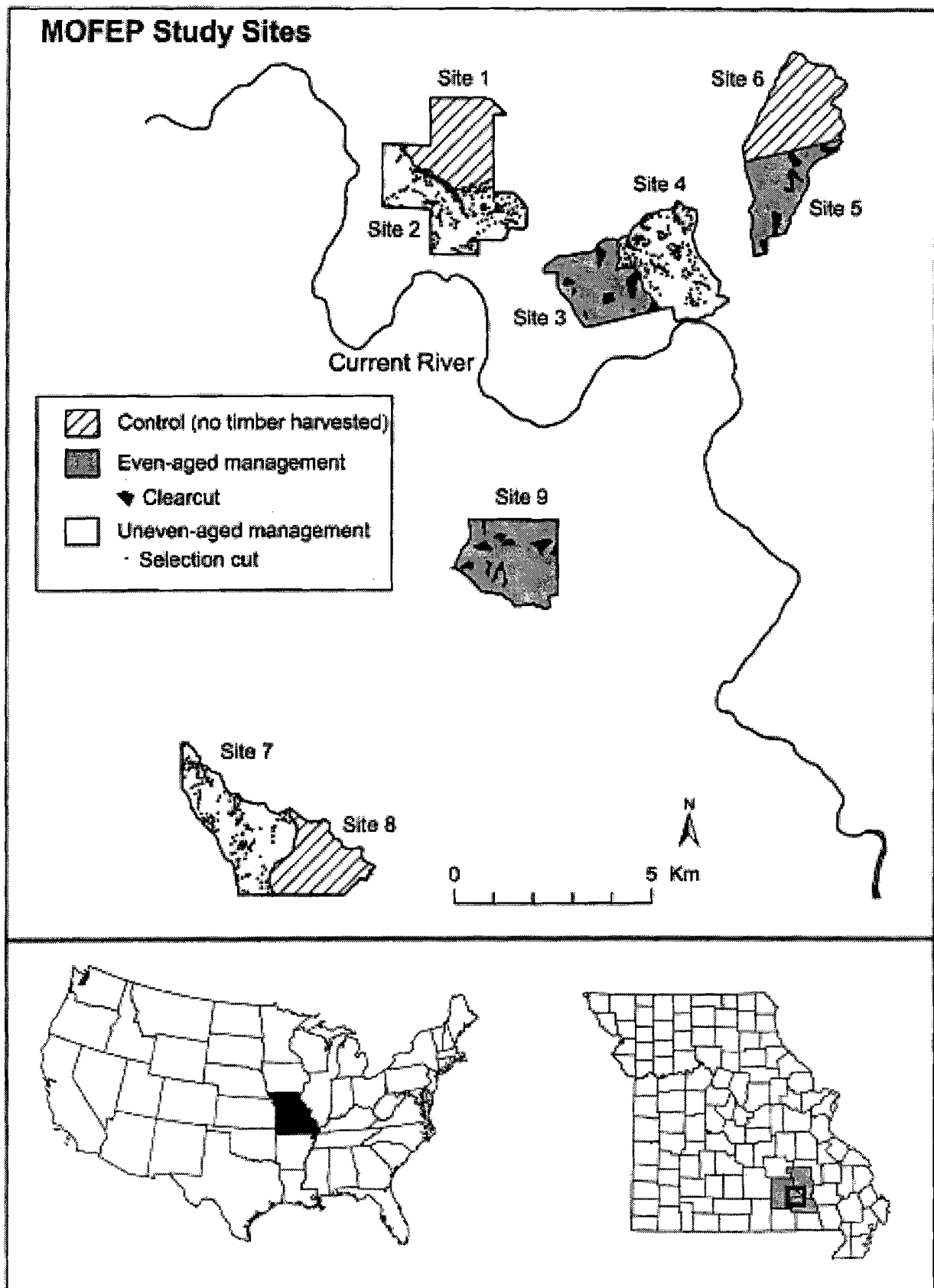


Figure 1. Map of the study sites in the Missouri Ozark Forest Ecosystem Project. From Gram et al. (2003).

We located and monitored nests while spot-mapping and through deliberate searching from mid-May through July. We recorded nest locations on topographic maps of the site and marked nest locations in the field with flagging to facilitate monitoring (Ralph et al. 1993). Most nests were on the ground, in shrubs, or in the subcanopy; we were unable to find or monitor most canopy nests. We checked nests every 3–5 days until nest fate could be determined. We noted predation and parasitism events. Nest searching was conducted by 21–27 field assistants from 1991 through 1999 but was scaled back to 15 field assistants from 2000 through 2003.

## Data Analysis

We focused our analyses on five mature forest species (Acadian Flycatcher [*Empidonax virescens*], Kentucky Warbler [*Oporornis formosus*], Ovenbird [*Seiurus aurocapillus*], Worm-eating Warbler [*Helmitheros vermivorus*], and Wood Thrush [*Hylocichla mustelina*]) and six early-succession species (Blue-winged Warbler [*Vermivora pinus*], Hooded Warbler [*Wilsonia citrina*], Indigo Bunting [*Passerina cyanea*], Prairie Warbler [*Dendroica discolor*], White-eyed Vireo [*Vireo griseus*], and Yellow-breasted Chat [*Icteria virens*]). We selected focal species based on abundance, reliability of spot-mapping data, and nest height.

In Gram et al. (2003), we assessed the effect of the treatments on bird density by contrasting the mean pre-treatment density with the post-treatment data. We analyzed year effects in the pre-treatment period with a multivariate repeated-measures analysis of

variance. We performed planned contrasts (Dunnett's test) among treatments to compare the even-aged and uneven-aged sites with the control sites across years. We used a significance level of  $p < 0.10$  because sample size was small in this experiment ( $n = 9$  sites), and we were interested in detecting an effect if one existed (i.e., minimizing Type II error). All analyses were performed with SAS (version 8.01).

To evaluate reproductive success, we calculated daily nest mortality and the probability that a nest survived the entire nesting cycle, or "nesting success," which is defined as daily survival raised to the exponent of the number of days in the nesting cycle for each species and treatment category (Mayfield 1975). As components of nesting success rate, we also calculated rates of predation and brood parasitism. We compared pretreatment daily nest mortality to post-treatment mortality for each species and treatment with a chi-square test based on the test statistic  $T$  described by Johnson (1990).

## RESULTS

### No-harvest Management

The densities of mature forest species were relatively stable in the five pre-treatment years, and year effects were not significant for most species (Wood Thrush,  $F_{4,1} \leq 72.9$ ,  $p = 0.087$ ; all other species,  $F_{4,1} \leq 26.59$ ,  $p \geq 0.144$ ). In the first three years post-treatment, densities of all five mature forest species were reduced by 24–69% (paired  $t = 3.88$ ,  $df = 4$ ,  $p = 0.018$ ) on the no-harvest treatment sites (Gram et al. 2003). Worm-eating Warblers appeared to return to pre-treatment densities by 3 years post-treatment (1999, Fig. 2). Ovenbird and Acadian Flycatcher density reductions continued on the no-harvest sites for at least six years post treatment, through 2002 (Fig 2). Wood Thrush density remained reduced through 2003 and Kentucky Warbler density was too low and variable throughout the study to infer trends (Fig. 2).

Early-succession species were either absent or occurred in low density on the sites prior to forest management treatments and this did not change on the no-harvest sites in the post-treatment period (Gram et al. 2003, Fig. 3). Indigo Bunting territories were scattered across the sites along road edges and food plots during the pre-treatment years and their density on the no-harvest sites in the post-treatment years corresponds to their density on the harvested sites in the post-treatment years (Fig. 3).

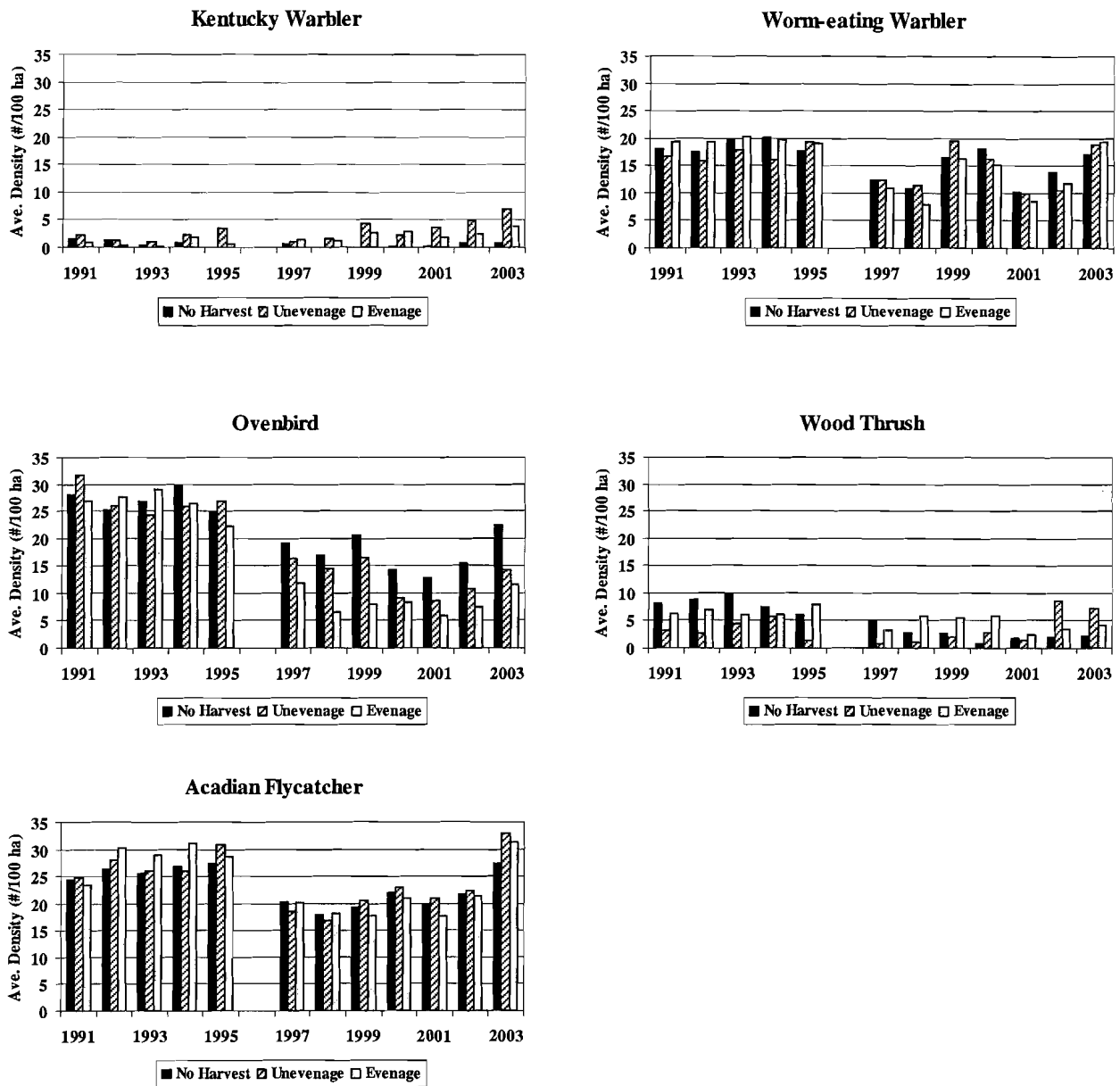


Figure 2. Mean density per 100 ha of mature forest bird species on the four spot map subplots (see Methods) censused on each site from 1991 through 2003.

### Even-aged Management

In the first three years post-treatment, Kentucky Warbler and Wood Thrush density increased on the even-aged treatment sites compared to no-harvest sites (Gram et al. 2003). The increased density on these sites remained relatively stable for these species through seven years post-treatment (Fig. 2). Ovenbird density declined significantly in the first three years on the even-aged treatment sites (Gram et al. 2003) and the reduction continued through year seven post-treatment (Fig. 2). Density of Worm-eating Warblers and Acadian Flycatchers was not significantly different on the even-aged sites compared to the no-harvest sites in either the first three years (Gram et al. 2003) or the next four years (Fig. 2).

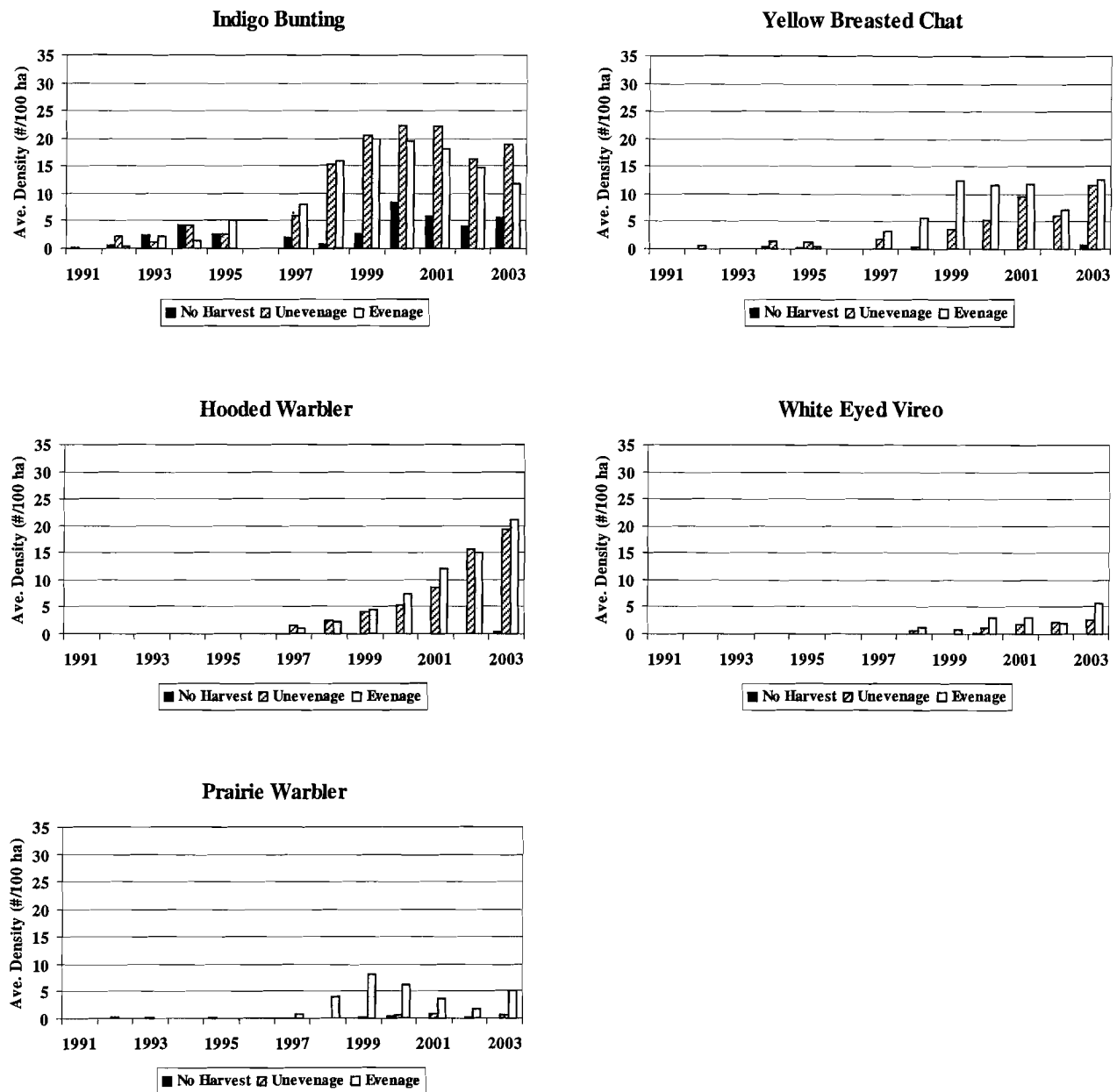


Figure 3. Mean density per 100 ha of early-succession forest bird species on the four spot map subplots (see Methods) censused on each site from 1991 through 2003.

All early-succession species increased in density on the even-aged management sites in the post-treatment period compared to the no-harvest sites (Gram et al. 2003, Fig. 3). The increases were only statistically significant by year three for Indigo Bunting, Yellow-breasted Chat, Prairie Warbler, and White-eyed Vireo (Gram et al. 2003). Hooded Warbler density was too low to achieve significance by year three, but by year seven their density was higher than any other early-succession species (Fig. 3). The densities of most early-succession species leveled off by year three post-treatment, but Hooded Warbler density showed continued increases through year seven (Fig. 3). Blue-winged Warbler density was more variable, but was higher on the even-aged sites relative to the no-harvest sites after treatment (Fig. 3).

## Uneven-aged Management

In Gram et al. (2003) we reported that Worm-eating Warbler density was significantly higher on the uneven-aged sites in year three post-treatment (1999). In the analysis of seven years following treatment, it appeared that 1999 was unusual and that there was no overall positive effect of uneven-aged management on Worm-eating Warbler density (Fig. 2). Only Kentucky Warbler density was significantly higher on uneven-aged sites by year three (Gram et al. 2003), but by year seven a stronger increase in density emerged for Kentucky Warbler and Wood Thrush (Fig. 2). Ovenbird density was consistently lower on the uneven-aged sites compared to the no-harvest sites throughout the post-treatment period, but the effect was not quite large enough to achieve statistical significance (Gram et al. 2003, Fig. 2). Throughout the period, Acadian Flycatcher density did not change on the uneven-aged sites relative to the no-harvest sites (Gram et al. 2003, Fig. 2).

Indigo Bunting and Yellow-breasted Chat density increased immediately on the uneven-aged sites (Gram et al. 2003). Indigo Bunting density reached a plateau by year three, but Yellow-breasted Chat density continued to increase over the seven-year period (Fig. 3). Hooded Warbler density was too low to achieve significance by year three (Gram et al. 2003), but continued to increase up to year seven in a pattern similar to what was observed on the even-aged sites (Fig. 3). White-eyed Vireo density was low throughout the period, but occurred in greater numbers on the uneven-aged sites by years five through seven post-treatment (Fig. 3). Few Prairie Warblers ever occupied the uneven-aged sites (Fig. 3). Blue-winged Warbler density on the uneven-aged sites in the pre-treatment period was due primarily to their presence on one of the sites. Their density was variable but remained low and did not increase significantly in the post-treatment period on the uneven-aged sites (Fig 3).

## Nest Success

As reported in Gram et al. (2003), we found 1394 nests from 29 different species during the five pre-treatment and three post-treatment years. Of the focal species, we found nests on all sites both before and after treatment for six species (Acadian Flycatcher, Kentucky Warbler, Ovenbird, Worm-eating Warbler, Wood Thrush, and Indigo Bunting). Nesting success based on Mayfield calculations averaged 29% for all six species. Daily mortality rate did not change significantly from pre- to post-treatment for all six species ( $X^2 \leq 6.53$ ,  $df = 5$ ,  $p > 0.25$ ). Brood parasitism rates were generally low, averaging 3.2% (range 0–20%) per site for the six focal species in both pre- and post-treatment years. Nest failure was generally attributed to predation because evidence of starvation and nest abandonment was rare. Relatively low numbers of nests and high variability made detection of statistical significance difficult, but some trends are worth noting. During the post-treatment period, Ovenbird nesting success increased in the controls, whereas nesting success declined in the even-aged and uneven-aged treatments. We found higher Wood Thrush nesting success following harvesting in the even-aged sites, but it remained unchanged in the uneven-aged treatments and controls. Kentucky Warbler and Indigo Bunting nesting success declined in the uneven-aged sites following timber harvest. Fewer nests were observed during the period from 2000 through 2003 when crew size and nest searching effort was reduced by about 40%. However, we detected no changes in rates of nest success or brood parasitism.

## DISCUSSION

Overall, the effects of forest management on songbirds were dynamic and species-specific. Songbird response to forestry did not fall into strict categories. Among species that generally require mature, closed canopy forest, the densities of some species declined, others increased, and others showed no change relative to the no-harvest sites. Indeed, all species density declined on the no-harvest sites after neighboring sites were harvested. The densities of all species that require early-succession forest increased as the harvested stands regenerated. However, the pattern of density varied over time for these species. Changes in density over time also varied by treatment for several species. Most of the effects observed in the first three post-treatment years were further supported by the analysis of the additional four years, though some interesting differences were apparent.



## No-harvest Management

We did not expect to see a decline in the density of songbirds on the no-harvest sites following forestry on neighboring sites. It is possible that habitat disturbance resulting from forestry affected densities of mature forest birds over a distance of at least 1000 m and that the effects lasted up to six years. In Gram et al. (2003) we discuss alternative explanations such as regional population decline, El Niño weather patterns, and periodical cicada outbreaks, but these are even less plausible alternatives for explaining reduced density lasting up to six years. Studies documenting edge effects on density and reproductive success typically find the effect occurring within 50 or 100 m from the edge (King et al. 1996, Porneluzi & Faaborg 1999, Manolis et al. 2002). However, these studies typically do not include pre-treatment periods and do not look for edge effects over long distances. Landscape-scale studies find that density, parasitism, and predation are best predicted by percent forest cover within a 10-km radius (Robinson et al. 1995; Donovan et al. 1997, 2000; Thompson et al. 2000). The internal fragmentation resulting from our forestry treatments appeared to cause long-term density reduction in unharvested sites over a spatial scale of several kilometers.

The Wood Thrush density decline on the no-harvest sites showed a different pattern (Fig. 2) and likely has a different explanation. Wood Thrush populations began declining on the no-harvest sites prior to the harvest treatments and continued after the treatments. This is likely due to advanced forest succession and the reduction of understory vegetation as seen in other regions (Holmes & Sherry 2001).

## Even-aged Management

Worm-eating Warbler and Acadian Flycatcher density did not decline more on even-aged compared to no-harvest sites. Wood Thrush and Kentucky Warbler density increased on the even-aged treatment sites. The increase in density of these species was due to their settlement adjacent to regenerating clearcuts (Wallendorf et al. 2007). Both species require closed canopy forest, but tend to select areas within the forest with greater understory development. Ovenbirds showed a nearly opposite response. The reduction in density on the even-aged sites was because they no longer settled in clearcuts or habitat within 100 m adjacent to the clearcuts (Wallendorf et al. 2007). The observation that these effects remain for at least seven years after forestry seems to support the idea that species are responding individually to changes in vegetation structure.

The density increase on even-aged sites by species requiring early-succession habitat was easily predicted. These species settled within the clearcuts immediately and their populations reached a plateau as the vegetation regenerated. Hooded Warbler populations showed a different trend and increased in density in each of the seven post-treatment years. This species settles territories in the clearcuts and within 100 m adjacent to the clearcuts and their density increased over time in both areas (Wallendorf et al. 2007). In the pre-treatment period of the study, Hooded Warblers were nearly absent from this region. By 2003, their density on the even-aged sites was higher than any other early-succession species and was similar to the density of many mature forest species in the pre-treatment period of the study.

## Uneven-aged Management

Songbird response to uneven-aged management was more variable over time. An analysis of the effects over the seven post-treatment years shows that a suggested increase in Worm-eating Warbler density in year three was not supported. Higher density emerged after year three of the post-treatment period for Wood Thrush, Yellow-breasted Chat, White-eyed Vireo and Hooded Warbler. It may be that the smaller openings created with uneven-aged management lead to slower regeneration of the vegetation. Prairie Warblers appear to require large openings in the forest and few settled on the uneven-aged sites.

## Nest Success

We detected no effects of forest management on nest success or brood parasitism in this study. This is probably because populations of nest predators and Brown-headed Cowbirds (*Molothrus ater*) do not increase with the amount of early-succession, regenerating forest within a landscape. Studies have shown that nest

success and brood parasitism are positively correlated with forest cover within a region (Robinson et al. 1995; Donovan et al. 1997, 2000; Thompson et al. 2000). Populations of predators and Brown-headed Cowbirds probably increase in response to food resources available in non-forest habitat and as long as there is no increase in conversion of forest to agricultural and residential land use, nest success should remain stable. A recent study projects dramatic increases in forest conversion on private lands within the Ozark region over the next 30 years (Stein et al. 2005). Private, non-industrial landowners own 80% of the forest in Missouri (Shifley & Sullivan 2002). These land-use changes are likely to affect nest success on the MOFEP sites in the future.

## Summary and Conclusions

The dynamic, species-specific responses of songbirds to the effects of forestry means that short-term studies, especially those lacking a pre-treatment study period, may yield misleading conclusions (Sallabanks et al. 2000; Thompson et al. 2000). The nature of the songbird response also means that it is not possible to say which forest management option is best for songbirds as a group. The answer depends on the relative conservation priority for each species. Sustainable forestry using a mix of strategies may be needed to maintain viable populations of species requiring early-succession and mature forest. Over time, forest conversion may have a greater effect on nest success than forest management. If the management goal is to maintain “undisturbed” populations of mature forest birds, then blocks of uncut forest much larger than our 400-ha study sites may be necessary.

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# FROM HABITAT FRAGMENTATION TO SPATIAL HETEROGENEITY: NEW APPROACHES TO UNDERSTANDING BIODIVERSITY CHANGE IN HUMAN-ALTERED LANDSCAPES

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**ABSTRACT.** Landscape approaches to the study of biodiversity in habitat fragments highlight the importance of habitat heterogeneity, edge effects, and the surrounding land uses as factors that influence spatial patterns of species diversity. Consideration of the spatial arrangement and heterogeneity of habitats often provides improved explanation and prediction of species diversity over island approaches that traditionally emphasize habitat area and isolation. Both island and landscape approaches often consider only the number of species found within habitats ( $\alpha$  diversity), however, while ignoring the spatial turnover of species composition among habitats ( $\beta$  diversity). Metacommunity theory extends traditional island approaches to the study of habitat fragmentation through a greater emphasis on beta diversity, and incorporates elements of landscape approaches such as habitat quality, spillover between habitats, and dispersal limitation. Using a case study on butterfly diversity and grassland fragments, I illustrate how hierarchically scaled measurements and analyses can provide insights into processes that influence spatial patterns of  $\alpha$  and  $\beta$  diversity in heterogeneous landscapes. At fine scales, variation in habitat quality, as measured by host-plant and flower availability, is important in determining patterns of  $\beta$  diversity among grassland patches. At broader scales, however, spatial isolation provides a better explanation of  $\beta$  diversity among patches. These patterns are consistent with predictions of metacommunity theory but different processes may operate at different spatial scales. The challenge for ecologists and conservation biologists will be to inform metacommunity theory with insights from multi-scaled studies in the field, and to explicitly incorporate spatial heterogeneity into predictions of biodiversity change in human-altered landscapes.

## INTRODUCTION

Understanding and predicting the spatial distribution of biodiversity is an enormous challenge to ecologists, conservation biologists, and managers. Habitat loss and fragmentation, invasive species, and climate change add to the urgency of quantifying patterns of regional species diversity and composition (Chapin et al. 2000, Wilson et al. 2004). Human-altered patterns of biodiversity are now a pervasive aspect of most landscapes, and scientists are beginning to incorporate managed and semi-natural areas along with parks and preserves in their assessments of landscape and regional biodiversity (Wagner et al. 2000, Diekötter et al. in press). The emphasis on natural and managed areas as a spatial mosaic is characteristic of a landscape approach (Turner 2005). Habitat arrangement and heterogeneity used in landscape approaches often provide improved explanation and prediction of species diversity over island approaches that traditionally consider only habitat area and isolation (Fig. 1a, b). Landscape ecology also recognizes the influence of the surrounding matrix on the internal dynamics of patches because the movements of species between the patch and matrix may be common, especially for generalist species that use complementary resources in the surrounding matrix (Sisk et al. 1997, Haynes et al. 2007). Different matrix types therefore interact with variation in patch quality to influence species distributions and diversity (Fig. 1c).

The assessment of biodiversity in fragmented landscapes generally involves recording and analyzing the numbers of species recorded at several different localities ( $\alpha$  diversity). Species richness is then compared among localities, perhaps by different vegetation or land-use types, and environmental variables are often used to predict local species richness. This basic protocol has a long history in ecology and forms the basis of hundreds of diversity studies (Veech et al. 2002). Less commonly, investigations of habitat loss and fragmentation consider the spatial turnover in species composition ( $\beta$  diversity) among localities. Different species are present in different locations because of habitat heterogeneity, local species interactions, or limited dispersal among suitable habitats (Fig. 1b, c) (Crist and Veech 2006). Species complementarity is often used in the literature on biodiversity surveys (Colwell and Coddington 1994), and is one of many possible metrics of  $\beta$  diversity (Magurran 2004).

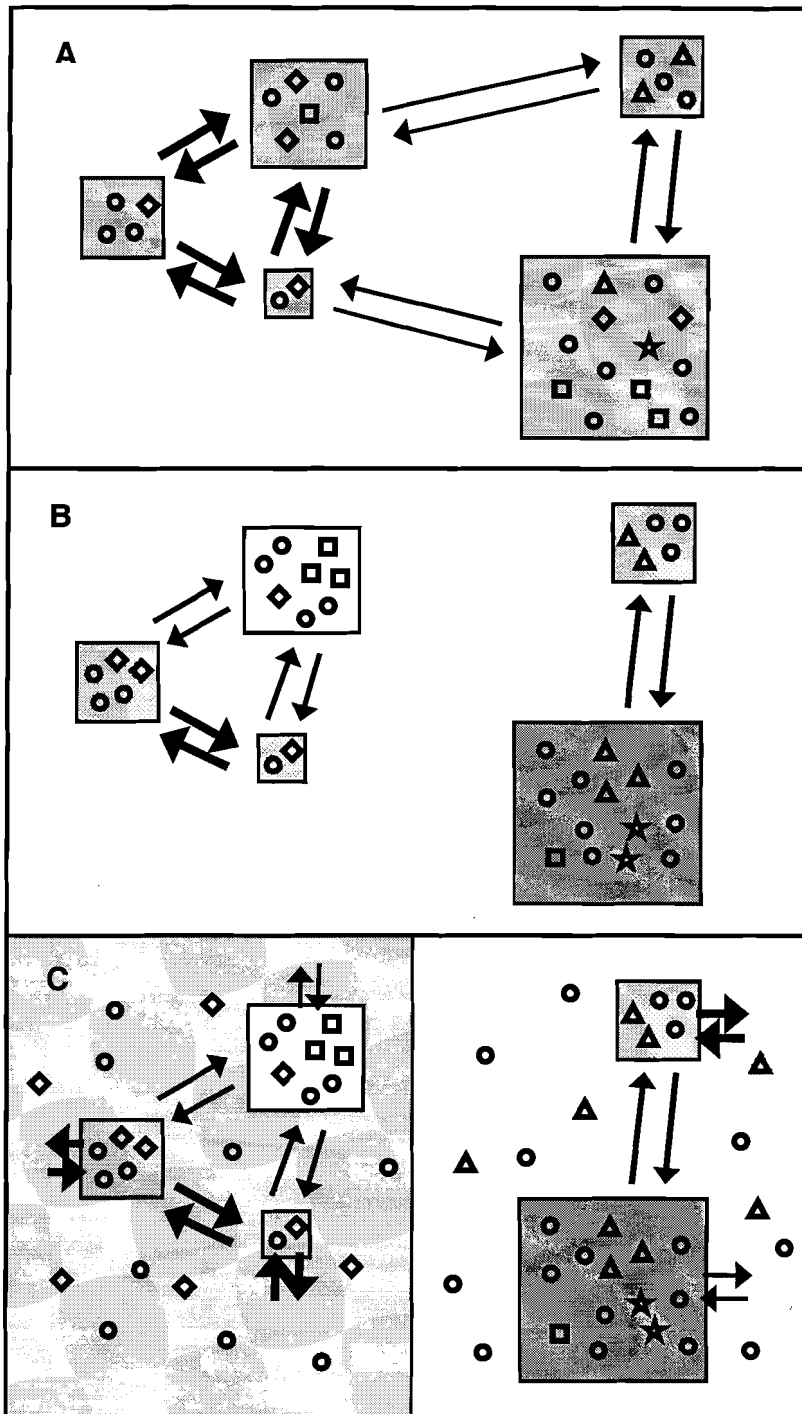


Figure 1. Schematic representation of (A) traditional island view of habitat fragmentation; (B) the incorporation of habitat heterogeneity, species aggregation within patches, and dispersal limitation; and (C) the addition of matrix effects emphasized in landscape ecology. Symbol shapes represent different species, and the numbers of each shape indicate their relative abundances. Arrows show dispersal pathways, and thicker arrows indicate higher dispersal rates. Shading of habitat and matrix types (B and C) represents variation in habitat quality to different species, which leads to species sorting and higher  $\beta$  diversity. The surrounding matrix varies in land use or semi-natural areas (C), and affects species composition within habitat fragments.

The recent extension of single-species metapopulations – an island approach that emphasizes habitat area and isolation – to multispecies metacommunities has been accompanied by a greater recognition of habitat heterogeneity and  $\beta$  diversity among local communities. This is because niche differentiation is a prominent and long-standing explanation for the coexistence of species within habitats or the differences in species occurrences among local communities (Leibold et al. 2004). Thus, niche differentiation or species sorting should limit local  $\alpha$  diversity but lead to high  $\beta$  diversity among habitats. Mass effects refer to dispersal and spillover between habitats, and may act together with species sorting to determine patterns of  $\alpha$  and  $\beta$  diversity. The patch-dynamics perspective views a metacommunity as a collection of single-species metapopulations, with each species having its characteristic extinction rate that varies with habitat area, and a dispersal rate that varies with patch isolation. Therefore, in contrast to species sorting and mass effects, patch dynamics generally ignore variation in habitat quality and instead focus on species-specific colonization and extinction due to stochastic extinction and dispersal limitation (Leibold et al. 2004). Neutral theory (Hubbell 2001) takes this a step further and asserts that ecologically equivalent species should have similar fitness in local communities and similar dispersal rates among communities. Random variations in population size (ecological drift) lead to species dominance and extinction within local communities (Hubbell 2001, Leibold et al. 2004). These processes, together with limited dispersal between local communities, result in local communities with dissimilar species composition and therefore high levels of  $\beta$  diversity in the regional community. These differing concepts of metacommunities may operate simultaneously, but their relative importance likely varies with spatial scale. For example, species sorting and mass effects might predominate at local scales while dispersal limitation and colonization-extinction dynamics should be more important at regional scales (Cotennie 2005).

All of these concepts and approaches provide slightly different explanations for the species-area relationship. Island biogeography theory (MacArthur and Wilson 1967) is a classical patch-dynamics explanation to species-area relationships based on the effects of habitat area and isolation on extinction and colonization rates, respectively. Neutral theory arrives at similar predictions but community size is of central importance, although numbers of individuals are assumed to relate logarithmically to area (Hubbell 2001). Species sorting and mass effects invoke greater habitat heterogeneity in large habitats than in smaller ones, thereby allowing more species to occur in larger habitats. Thus, as with predictions of  $\alpha$  and  $\beta$  diversity, alternative metacommunity concepts do not uniquely explain species-area relationships, but they posit different underlying processes. Here again, we might expect the relative importance of these processes to differ with spatial scale. For example, shifts in the slopes of species-area relationships presumably reflect changes in the processes that are operating at different spatial scales (Crawley and Harral 2001).

### **Additive Partitions of $\alpha$ , $\beta$ , and $\gamma$ Diversity**

The concepts of  $\alpha$ ,  $\beta$ , and  $\gamma$  diversity date back to Whittaker (1960), who compared the local species richness within a community or sample ( $\alpha$ ) to the regional species richness ( $\gamma$ ). He defined  $\beta$  diversity as  $\beta = \gamma / \alpha$ . The relationship among local and regional diversity was therefore viewed by Whittaker as multiplicative,  $\alpha \times \beta = \gamma$ . Because  $\alpha$  and  $\gamma$  are in units of species richness,  $\beta$  is expressed in dimensionless units of community turnover. Since Whittaker's multiplicative partition, there is a long history of dimensionless indices of  $\beta$  diversity (Veech et al. 2002, Magurran 2004). Today, the most common dimensionless metrics of  $\beta$  diversity are pairwise dissimilarity measures used in ordination (McCune and Grace 2002).

The additive partition of diversity is nearly as old as Whittaker's multiplicative partition, but was used infrequently until Lande's (1996) paper, which provided an analytical framework for additive partitioning using Whittaker's terminology (Veech et al. 2002). Lande's (1996) additive partition was  $\alpha + \beta = \gamma$ , so that  $\beta$  is in units of species richness rather than a dimensionless metric. Operationally,  $\alpha$  is defined as the average number of species recorded in the sample units, whether they be a quadrat, trap, or a habitat patch (Crist and Veech 2006). Then,  $\gamma$  is the total number of species recorded in all sample units, and  $\beta = \gamma - \alpha$ . The  $\beta$  component of richness is the average number of species that are absent from a randomly chosen sample unit (Veech et al. 2002, Crist and Veech 2006).

Wagner et al. (2000) extended Lande's additive partition to multiple sampling scales, and Crist et al. (2003) provided hypothesis tests and randomization procedures for multi-scaled sampling designs. More recently, Crist and Veech (2006) extended the application of additive partitioning to rarefaction curves, patch-occupancy measures, and species-area relationships. Here I focus on additive diversity partitions of hierarchical sampling designs and species-area relationships using an example from a field study of butterfly diversity in prairie remnants.

### A CASE STUDY: BUTTERFLIES IN PRAIRIE REMNANTS

Butterfly communities were studied in tallgrass prairie remnants at the Edge-of-Appalachia (EOA) Preserve in Adams Co., Ohio. Over 100 prairie remnants occur at the EOA Preserve on dolomitic limestone outcrops, which differ from the surrounding acidic sandstone. Prairies are small, ranging in size from 0.1-2.5 ha, and occur in clusters of 3-10 patches that are isolated by large areas of oak-pine and mixed mesophytic forests (Strittholt and Boerner 1995). Butterfly sampling was conducted in six clusters and 26 patches, with 3-9 patches sampled within each cluster (Fig. 2). The average distance between patches within clusters was 0.26 km, whereas the average between patches among clusters was 2.93 km (Crist and Veech 2006). Thus, prairie patches and clusters form two distinct scales of sampling (Fig. 2). Butterflies were recorded along Pollard transects (Pollard and Yates 1993) during five surveys conducted in 2004.

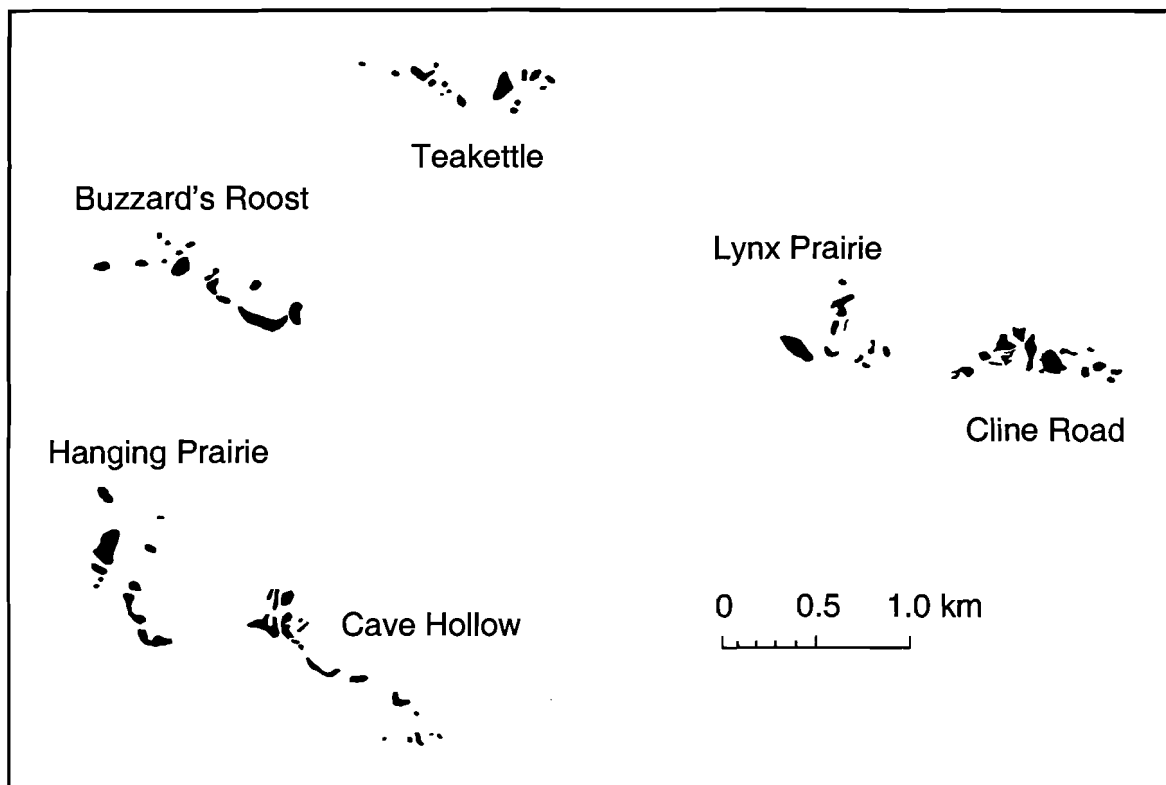


Figure 2. Map of prairie remnants at the Edge-of-Appalachia Preserve in Adams Co., Ohio. Prairies occur in clusters on limestone outcrops, and clusters of prairies vary in isolation by the intervening forest matrix. Six of the largest clusters are shown, and butterfly and plant sampling was conducted in 3-9 patches within each of the six clusters for a total of 26 patches.

A total of  $\gamma = 49$  species of butterflies were recorded during the study. Species-accumulation curves indicated that sampling detected virtually all of the species (Crist and Veech 2006). The average number of species recorded per patch was  $\alpha_{\text{patch}} = 16.7$ , so the total  $\beta$  diversity was  $\beta_{\text{total}} = 49 - 16.7 = 32.3$  species. Some of this  $\beta$  diversity, however, is due to the differences in species composition among clusters. To assess this, we first calculate the average number of species recorded in the six clusters, which is  $\alpha_{\text{cluster}} = 31.7$  species, and  $\beta_{\text{cluster}} = 49 - 31.7 = 17.3$  species. Next, we decompose the diversity components hierarchically (Wagner et al. 2000, Crist et al. 2003), so that  $\alpha_{\text{cluster}} = \alpha_{\text{patch}} + \beta_{\text{patch}}$ , and  $\gamma = \alpha_{\text{cluster}} + \beta_{\text{cluster}}$ . Then, by substitution,  $\alpha_{\text{patch}} + \beta_{\text{patch}} + \beta_{\text{cluster}} = \gamma$ . Using this relationship, we find that  $\beta_{\text{patch}} = 15.0$ .

The hierarchical partition of the butterfly species richness shows that the  $\alpha$  and  $\beta$ -components of diversity each contribute to a third of the total  $\gamma$  in the 26 prairie patches (Fig. 3a). Randomization tests on these components using program PARTITION (Veech and Crist 2006) showed that the  $\alpha_{\text{patch}}$  is lower (-),  $\beta_{\text{patch}}$  does not differ (ns), and  $\beta_{\text{cluster}}$  is greater than (+) expected by chance (Fig. 3a) based on sample-based randomization of the data (Crist et al. 2003). This suggests that habitat quality and intraspecific aggregation of individuals in preferred patches limit local butterfly diversity, resulting in a lower than expected  $\alpha_{\text{patch}}$ . A similar level of  $\beta_{\text{patch}}$  to that expected under the null hypothesis suggests that butterflies move frequently among patches within a cluster and that diversity is not significantly differentiated among patches within clusters. In contrast, a higher than expected  $\beta_{\text{cluster}}$  indicates that limited butterfly dispersal may occur among clusters of patches, or that patches in different clusters vary in habitat characteristics. An important component of habitat for butterflies is the availability of their host plants. A diversity partition of the  $\gamma = 79$  species of putative host plants for these butterflies showed a slightly different pattern than for the butterflies (Fig. 3a). The  $\alpha_{\text{patch}}$  is lower than expected as with the butterflies, but both  $\beta_{\text{patch}}$  and  $\beta_{\text{cluster}}$  are greater than expected under the null hypothesis (Fig. 3a). The difference in statistical significance of the  $\beta_{\text{patch}}$  for butterflies and host plants, as well as the disproportionately large  $\beta_{\text{cluster}}$  for host plants, provides further support for the dispersal limitation hypothesis since plant dispersal distances are predicted to be shorter than those for butterflies.

The influence of patch area on butterfly diversity can also be examined using the standard species-area relationship and the application of additive diversity partitions. A regression of butterfly species richness on the  $\log_{10}$  of patch area shows a statistically significant relationship ( $F=14.25$ ,  $df=1,24$ ,  $P=0.0009$ ) but the  $r^2=0.37$  indicates a substantial amount of unexplained variability (Fig. 3b). More variation is explained ( $r^2=0.51$ ) if a composite variable of host-plant composition (the first principal component of host-plant species abundances) is added to patch area in a multiple regression (not shown). This standard analysis suggests that area and host-plant composition are important to butterfly species richness, but it does not consider  $\beta$  diversity.

Additive partitions can be applied to the species-area relationship by calculating the difference between the average species richness ( $\alpha$ ) of all habitats and the species richness of the largest habitat predicted from the species-area regression (Fig. 3b; Crist and Veech 2006). This provides an estimate the  $\beta$  diversity due to differences in habitat area, termed  $\beta_{\text{area}}$ . The  $\beta_{\text{area}}$  component stems from the addition of new species in larger patches that are not found in smaller ones, and therefore has the range  $0 \leq \beta_{\text{area}} \leq \beta_{\text{total}}$ , where  $\beta_{\text{total}}$  is the total  $\beta$  diversity observed among habitats. If the species that are present in smaller habitats form perfectly nested subsets of those found in larger ones, then  $\beta_{\text{area}} = \beta_{\text{total}}$  (Crist and Veech 2006). If, however, species are both added and lost with changes in patch size, a process which we term species replacement, then  $\beta_{\text{area}} \ll \beta_{\text{total}}$ . The portion of the  $\beta$  diversity due to species replacement can be defined as  $\beta_{\text{replace}} = \beta_{\text{total}} - \beta_{\text{area}}$ , and it follows that the additive partition of the species-area relationship is  $\alpha + \beta_{\text{area}} + \beta_{\text{replace}} = \gamma$  (Crist and Veech 2006). For the butterfly data at EOA Preserve, the  $\beta_{\text{area}}$  component explains only 15 % of the  $\beta_{\text{total}}$ , whereas 85% is due to  $\beta_{\text{replace}}$  (Fig 3b). Clearly, factors such as dispersal limitation or habitat heterogeneity have a greater influence than habitat area on the  $\beta$  diversity of butterflies in these prairie remnants.



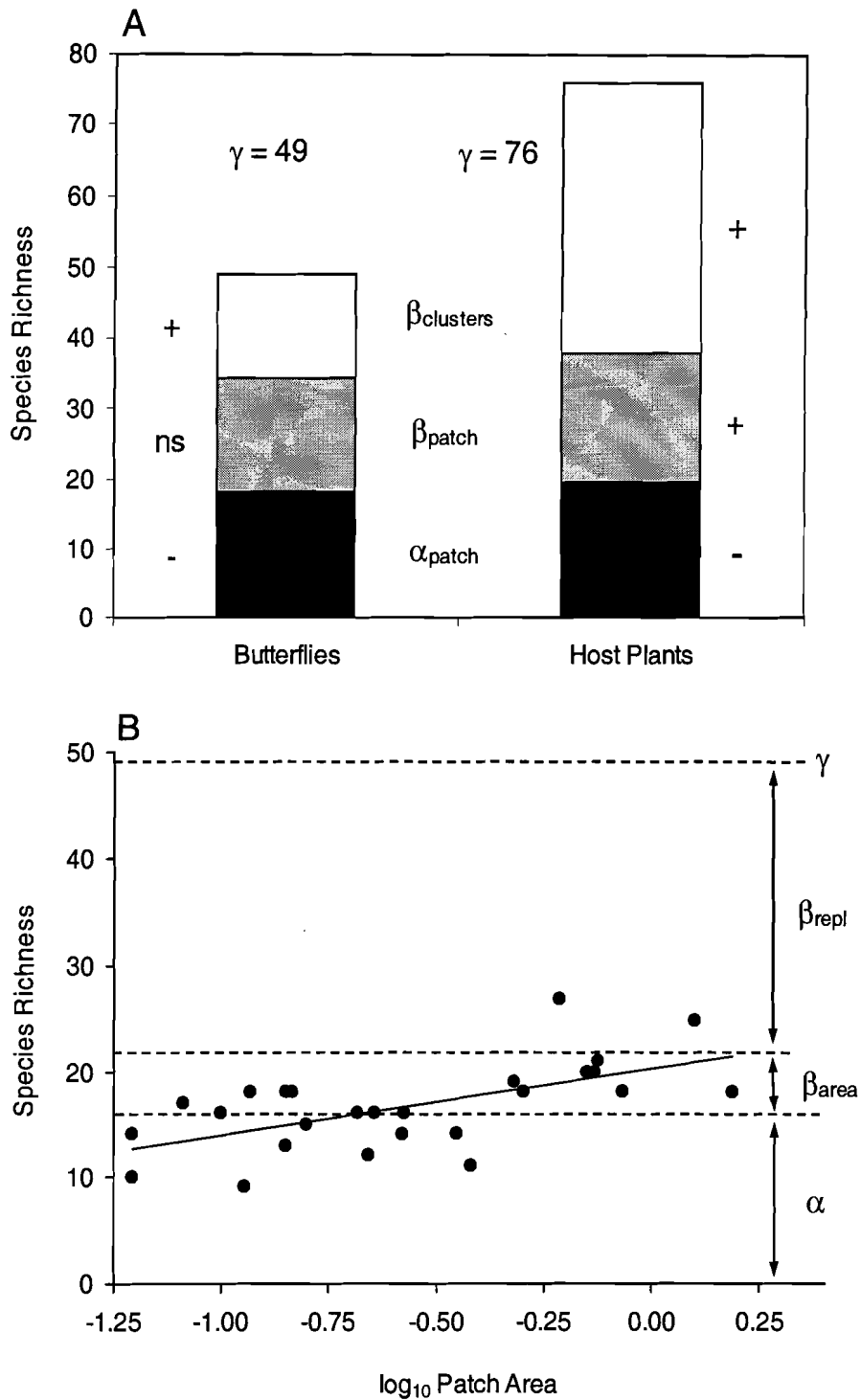


Figure 3. (A) Additive partitions of butterfly species diversity and their putative host plants. The partition is  $\alpha_{patch} + \beta_{patch} + \beta_{cluster} = \gamma$ , where  $\alpha_{patch}$  is the average species richness within patches,  $\beta_{patch}$  is the average species richness found among patches,  $\beta_{cluster}$  is the average species richness found among clusters, and  $\gamma$  is the total species richness. Symbols indicate the statistical significance ( $P < 0.05$ ) of each diversity component as less than (-), greater than (+), or not significantly different (ns) from those expected by chance. (B) Additive partition of the species-area relationship,  $\alpha + \beta_{area} + \beta_{repl} = \gamma$ , where  $\alpha$  is the average species richness of butterflies within patches,  $\beta_{area}$  is the  $\beta$  diversity due to differences in patch area, and  $\beta_{repl}$  is the  $\beta$  diversity due to other factors (species replacement) that influence species composition.

To identify the relative importance of these processes in structuring  $\beta$  diversity, I turn to ordination methods since they provide a way to partition multiple contributions to  $\beta$ -diversity albeit in dimensionless units. First, I conducted an ordination of butterfly relative abundances in the 26 patches using redundancy analysis (program CANOCO; ter Braak and Šmilauer 2002) with  $\log_{10}$  habitat area, flower density, and host-plant species composition (principal component axes 1 and 2) as environmental variables. Next I conducted a separate ordination using spatial variables derived from x-y coordinate positions of the 26 patches as predictor variables of butterfly species composition (see Cotennie 2005 and Crist et al. 2006 for methods). The combined ordination of environmental and spatial variables then provides an overall partition of the relative importance of habitat characteristics versus patch aggregation or isolation. The three environmental variables – patch area, host-plant composition, and flower density – explained 25% of the variation in butterfly species composition among the 26 patches (Fig. 4). Spatial variables explained 31% of the variation in butterfly composition. Together, environmental and spatial factors explained 51%, with 5% due to environmental variation that was also spatially dependent (E + S; Fig. 4). Thus, although both habitat area and quality are important to the  $\beta$  diversity of butterflies, the spatial configuration of prairie patches actually had a greater effect on the total  $\beta$  diversity explained by the ordination. These conclusions are qualitatively consistent with those from additive partitioning: some of  $\beta$  diversity in butterflies could be attributed to patch area and host plants, but a significantly large  $\beta_{\text{cluster}}$  component likely reflects spatial patterns of isolation and dispersal limitation among more widely separated clusters.

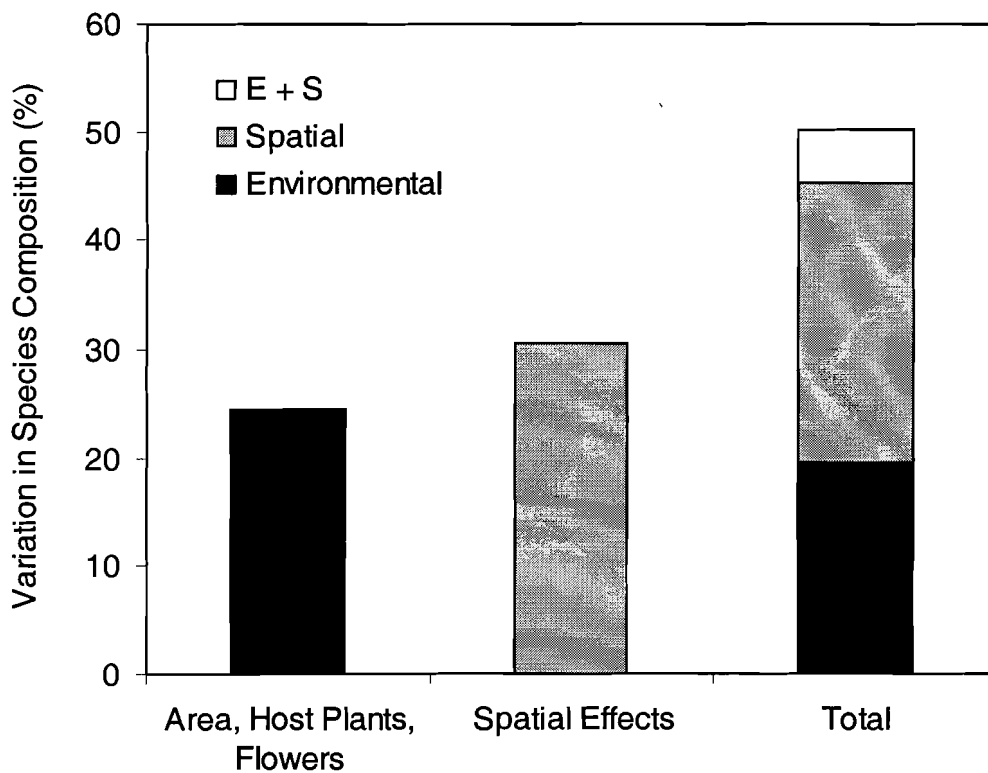


Figure 4. The percent of the variation in butterfly species composition among 26 prairie patches explained by environmental and spatial factors in separate and combined (total) multivariate ordinations using redundancy analysis. The three environmental variables included  $\log_{10}$  patch area, species composition of host plants, and flower density. Spatial variables were derived from x-y coordinates of prairie patches. In the combined ordination of environmental and spatial variables, some of the variation in species composition is due to spatially correlated environmental variation (E + S).

## IMPLICATIONS FOR HABITAT FRAGMENTATION AND BIODIVERSITY

The study of biodiversity in habitat fragments is much more than variation in the numbers of species that occur in different-sized fragments. Most surveys and studies of biodiversity focus on  $\alpha$  diversity within habitats, even though  $\beta$  diversity is critical to understanding the spatial distribution of species diversity at regional scales that are most relevant to conservation and management. Additive partitions of diversity highlight the importance of  $\beta$  diversity because it is expressed in units of species richness that are intuitive and understandable to scientists, managers, and even the broader public. Hierarchical partitions of diversity also facilitate comparisons of diversity components at different sampling scales or locations, which can then be used to identify the range of habitats or localities that contribute most to regional biodiversity (Crist et al. 2003).

The effects of habitat loss and fragmentation in human-altered landscapes have complex effects on the spatial distribution of species diversity. Habitat loss leads to smaller habitats with lower  $\alpha$  diversity, and increased isolation and chance effects of colonization-extinction in small fragments lead to greater  $\beta$  diversity among habitats. At the regional scale, however,  $\gamma$  diversity is decreased by an overall reduction in the area and heterogeneity of natural habitats, and by the non-random conversion of lowland and arable parts of the landscape to urban and agricultural land uses. The case study of butterflies at EOA Preserve was in naturally fragmented prairie remnants within a forested matrix, which has a heterogeneous structure and supports a different assemblage of woodland butterflies. The same is also true of natural habitat fragments surrounded by land use, but species assemblages in human-dominated landscapes tend to be dominated by cosmopolitan or invasive species that may influence patterns of species diversity within isolated habitat fragments (Fig. 1c). Even so, different types of land use and semi-natural areas have important influences on patterns of  $\alpha$  and  $\beta$  diversity in human-altered landscapes (Wagner et al. 2000, Diekötter et al. in press).

For several decades, island theories of biodiversity and species-area relationships have guided the conservation and management of biodiversity. Now, landscape ecology has come of age (Fortin and Agrawal 2005) and its emphasis on scale and spatially explicit heterogeneity brings several quantitative tools for ecologists and managers (Turner 2005). Meanwhile, the development of metacommunity theory, though historically rooted in island approaches, has become pluralistic with alternative views on the roles of habitat area, heterogeneity, and dispersal in determining local and regional diversity (Leibold et al. 2004). The challenge for conservation biologists and managers will be to inform the development of metacommunity theory and landscape ecology with insights from multi-scaled studies in the field, and to explicitly incorporate spatial heterogeneity into predictions of biodiversity change in human-altered landscapes.

## ACKNOWLEDGEMENTS

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# EXTINCTION, EXTIRPATION, AND RANGE LOSS OF STONEFLIES (INSECTA: PLECOPTERA) IN ILLINOIS

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**ABSTRACT.** Illinois is the poster child for fragmentation of aquatic habitats. Today, Illinois is dominated by agricultural lands (76.3%), with approximately 90% land cover devoted to row-crop agriculture in some counties. Conversion to agriculture began in the mid-19<sup>th</sup> Century and was facilitated by channelization of streams and tilling of fields to increase drainage. This work was largely accomplished by the 1920s. The Illinois Natural History Survey (INHS), in existence since 1858, had an early objective to document species occurring in the state. Stoneflies (Plecoptera) are aquatic insects that have been intensively studied at the INHS during the 20<sup>th</sup> Century and provide a relatively complete record that allows for analysis of changes wrought by fragmentation of aquatic resources. Using 5,694 historical and contemporary stonefly specimen records, changes in the assemblage during the 20<sup>th</sup> Century have been assessed. Initially, three hyperdiverse regions existed, including the Grand Prairie Natural Division, which now is approximately 80% row-crop agriculture. Statewide, 28.6% of 77 species have become extinct (two endemics) or been extirpated a rate higher than for mussels or fishes in Illinois. Although all regions have lost stonefly species, the greatest losses were in the Grand Prairie and from large rivers and occurred between 1940 and 1960. Although improvement in stream quality has occurred due to regulations imposed by the Clean Water Act, there is no evidence of sensitive stonefly species moving back into areas of Illinois where they were lost. Potential recolonization routes remain blocked by degraded habitat and poor water quality. Humans will have to act to improve water and habitat quality and connect corridors of dispersal, if stoneflies and other sensitive aquatic insects are to return to Illinois.

## INTRODUCTION

### Imperilment of Aquatic Systems and Invertebrates

Freshwater aquatic systems are highly imperiled across the North American continent. According to Ricciardi and Rasmussen (1999), freshwater ecosystems have had four to five times the number of extinctions in North America than are known for terrestrial systems. Further, they predicted that future extinction rates will increase dramatically. It is important to note that their data exclude the vast majority of invertebrates (except mussels, snails, and crayfishes), but should be generally indicative, if not an underestimate, of the losses that aquatic invertebrates have suffered and will undergo in the future. This is an important consideration because aquatic invertebrates are ubiquitous, diverse, and major converters of organic matter into tissues that feed vertebrates in aquatic habitats.

Strayer (2006) discusses challenges for protection of the nearly 90,000 species of freshwater invertebrates worldwide. Given the sheer diversity and the paucity of knowledge about each species, a species-by-species approach, like that of the US Fish and Wildlife Service (USFWS) for vertebrates and plants, is not feasible for the protection of all but a few invertebrate species. He suggests that protection of entire watersheds with the overarching goal of protecting fresh water supplies and recreation potential as being the best approach for preserving aquatic species. Whatever the solution, we are currently in the midst of a crisis of species extinction and range reduction, so solutions must be found and instituted rapidly. Supporting this imperative is Strayer's (2006) own estimate of up to 10,000 species of aquatic invertebrates extinguished already, most of which we know nothing about.

Insects provide the greatest number of species and biomass in most freshwater aquatic systems. Despite the importance of their diversity and biomass, aquatic insects have received relatively little protection. The International Union for Conservation of Nature and Natural Resources Red List (IUCN 2004) of insects contains 181 (137 are terrestrial) USA species among 11 orders (DeWalt et al. 2005). Approximately 25% of these species are aquatic, the majority of which are Odonata (dragonflies and damselflies). Unfortunately, only five taxa are distributed in Ephemeroptera (mayflies, one species), Plecoptera (stoneflies, one species),

and Trichoptera (caddisflies, 3 species) (a.k.a. EPT taxa), arguably the most environmentally sensitive aquatic insect orders (Hilsenhoff 1987, Lenat 1993). Similarly, the USFWS recognizes 204 species of invertebrates as endangered or threatened, most of these being mussels, snails, and crustaceans (Fig. 1). Only five are aquatic insects and none are EPT taxa (USFWS 2007). This disproportionately low recognition of the imperilment of aquatic insects is certainly not indicative of the true state of affairs.

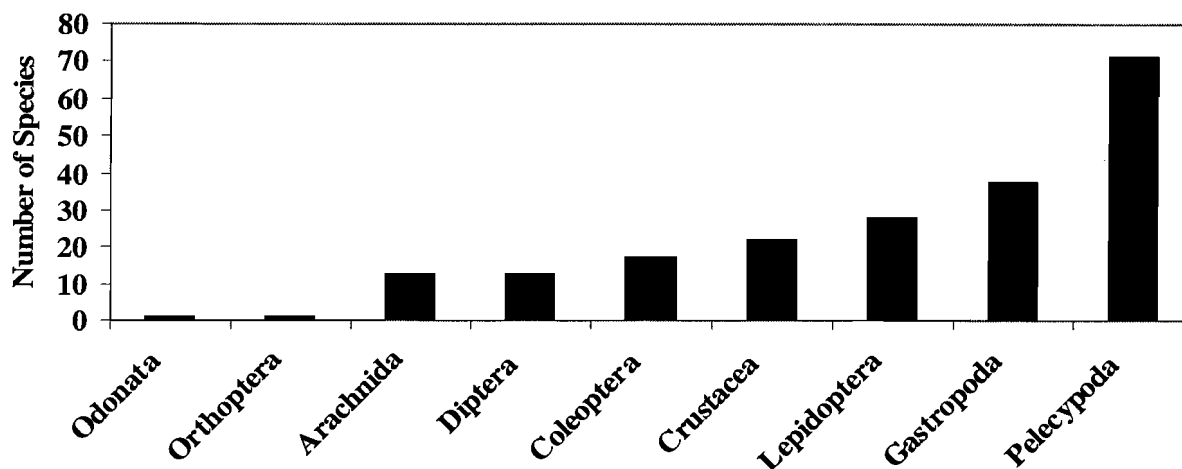


Figure 1. Invertebrate species richness for major invertebrate groupings listed as endangered and threatened by the U.S. Fish and Wildlife Service as of March, 2007 (USFWS 2007).

Whether an insect species is recognized as imperiled is dependent upon many factors, including the availability and age of distribution data, the activity of systematists on the species, the species' charismatic nature, and the amount of public attention it receives. Amateur enthusiasts and a greater public recognition of dragonflies have contributed to the inclusion of Odonata on the Red List. The relatively few USFWS listings for aquatic insects has much to do with the taxonomic difficulties of working with insects. Most aquatic biologists encounter only larvae, which are often unidentifiable because they have not been associated with adults. Additionally, a trend toward the use of lower taxonomic resolution (family and genus level) in the field of aquatic biomonitoring has taken place, leaving much potentially valuable distribution and habitat use information undocumented for aquatic species. Additionally, there is little political will to add insects to the USFWS list because of the sheer number of potential species involved. The public also perceives insects as dirty and disease-ridden, leaving little support for their conservation.

Master et al. (2000) shed some light on the imperilment of aquatic species in the USA. They compiled states' natural heritage data through 1996 and found that among 14 groups of freshwater taxa, mussels, crayfish, and stoneflies were the top three most imperiled (cumulatively all the extinct, critically imperiled, imperiled, and vulnerable categories) taxa at 69, 51, and 43% of species. They ranked Odonata the 13<sup>th</sup> most imperiled. Their efforts are the best to date, but even these data are too coarse to reveal the real story.

### **Illinois as a Poster Child for Habitat Fragmentation**

Habitat degradation is the single largest factor leading to imperilment of species in the United States (Master et al. 2000). Few other landscapes in North America have been disrupted as much as that of Illinois. Estimates of presettlement (early 1800s) land cover show that Illinois was indeed a prairie state with 54.7% of its land surface being tallgrass prairie (Suloway et al. 2002, Cordle & Szafoni 2005) (Table 1). Most of the remainder was forest of various types (savanna, bottomland, upland). Today, the entire prairie and much of the forest have been converted to crop production and cattle grazing (Illinois Department of Natural Resources et al. 2003, Luman et al. 2004).

Table 1. Illinois land cover by class name for presettlement (early 1800's) and 1999-2000 data.

<b>Class Name</b>	<b>Presettlement Area (km<sup>2</sup>)</b>	<b>1999-2000 Area (km<sup>2</sup>)</b>
Agriculture	0	94,517
Grassland	0	19,636
Prairie	79,768	0
Forest/Forested Wetland	61,917	21,357
Urban	444	6,626
Wetland	420	1,163
Water	3,150	2,447
Other	243	196
<b>TOTAL</b>	<b>145,942</b>	<b>145,942</b>

Illinois' relatively flat topography resulted from multiple glacial advances (Wiggers 1997). Flat till plains, the result of the most recent Wisconsinan advance and retreat, left much of the northern half of the state without drainage, allowing extensive, seasonally wet prairies to form. By the 1830s, settlers from the eastern states and abroad began to conquer the prairie for agriculture. Farmers began "improving" drainage almost immediately. The state legislature signed into law the Farm Drainage Act of 1878 to provide a legal and taxation framework for drainage improvements. This fostered the formation of local drainage districts with the right to levee taxes on landowners in the district, which paid for drainage improvements. This law stands today, without substantial modification. By 1960, some counties had the majority of their land modified for drainage, especially in the Grand Prairie (Fig. 2) (Larimore & Bayley 1996). Drainage engineers cut off river bends, constructed levees, and added streams where none had existed before. Mattingly et al. (1993) estimated that statewide, 25% of all stream miles have been modified by channelization, levee construction, and/or a tile drainage network, a value that jumps to over 70% in the Grand Prairie.

These activities and those of rapid urbanization, especially in the greater Chicago metropolitan area, have caused dramatic habitat fragmentation. Because drainage improvements were instituted so early and were concentrated in headwaters of flat areas, we have almost no knowledge of the fauna or function of prairie headwater streams in Illinois. Larger streams in this landscape are often of better quality, supporting a higher aquatic insect species richness and species of greater sensitivity (Sangunett 2005). They often have a treed riparian zone, a sinuous course, pools of varying depth, and a diversity of substrates and current speeds. Unfortunately, municipalities often use these rivers and streams to carry away treated, and occasionally untreated, waste water. The most telling example of this is the building of the Chicago Sanitary and Ship Canal, which carried millions of gallons of untreated sewage in the Illinois River beginning in 1900 (Starrett 1971). This alone eliminated any high-quality, large river habitat in the interior of the state and formed a significant barrier to recolonization of degraded areas throughout central Illinois. Other barriers in the state include the proverbial corn and soybean "desert," miles of contiguous cropland whose streams are channelized and riparian vegetation is limited to 1-3 m of exotic, cool-season grasses. Although agricultural practices are the major culprit, approximately 7,000,000 people live in the six-county metropolitan Chicago area, with built infrastructure occupying 75-80% of the landscape



# Natural Divisions of Illinois

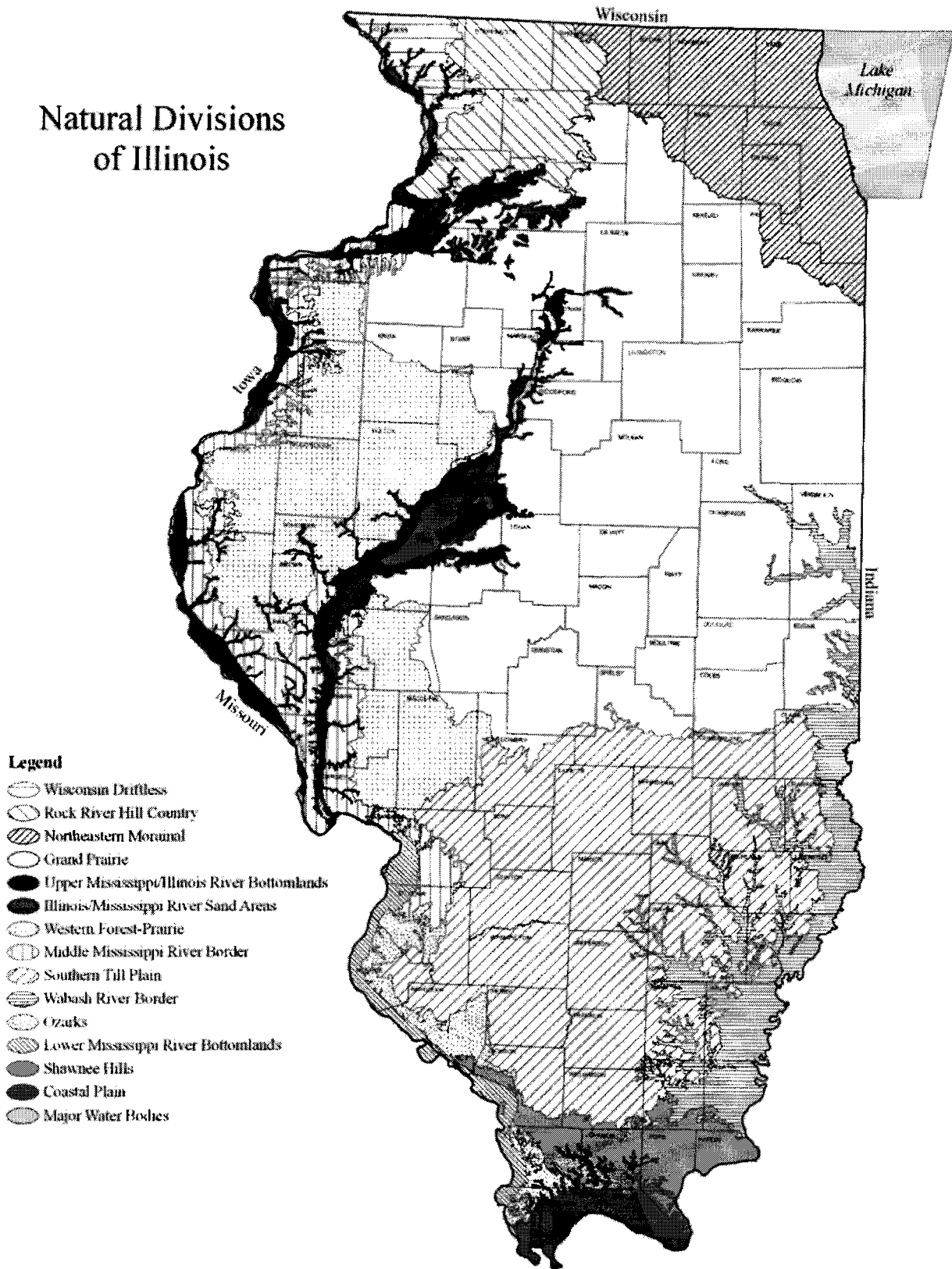


Figure 2. Natural divisions of Illinois.

The forging of a productive agricultural landscape has built a vibrant economy, but it has wrought some severely negative consequences for the diversity of native aquatic animals. The hydrologic changes and the removal of riparian trees have caused reduced groundwater flow in summer and greater variation in stream water temperatures (Wiley et al. 1990). It is surmised that a combination of hydraulic, hydrologic, and temperature effects is partly responsible for the extinctions, local extirpations, range reductions, and community turnover for mussels, fish, and aquatic insects throughout Illinois (Burr 1991, Cummings 1991, DeWalt et al. 2002, Favret & DeWalt 2002). Burr (1991) documented the extirpation of 12 of 187 native fishes, while 31 extant species now have a protective status in Illinois (IESPB 2005). Mussels, which rely on fish as hosts for their larval stages, have also fared poorly with 16 of 77 species extirpated and 24 having protective status (Cummings 1991).

### **Stoneflies as Indicators of Current and Future Losses of Aquatic Insects**

The Plecoptera (stoneflies) is a small order of aquatic insects consisting of just over 2,000 species worldwide. In the Nearctic realm, there are 658 species in nine families (PLSA 2007). Stoneflies include the most sensitive of aquatic species and as such are useful for monitoring of water quality and as a surrogate for determining changes in other aquatic insect species.

Plecoptera have been the object of systematic and faunistic study at the INHS throughout the 20<sup>th</sup> Century. This is in large credit to Theodore H. Frison, best known for his work on winter-emerging stoneflies (Frison 1929) and his statewide monograph (Frison 1935). INHS policy states that specimens accumulated by scientists for research are to be deposited in its various formal collections as a permanent record. Frison's work forms the basis of a unique historical record for stoneflies. Other entomologists, including Herbert H. Ross, William Ricker, and Donald W. Webb have added taxa, updated nomenclature, and revised families and genera (Ricker & Ross 1968, Ross & Ricker 1971, Harris & Webb 1995, Webb 2002). Recent work by R. Edward DeWalt (DeWalt 2002, DeWalt et al. 1998, 1999, 2001, 2002, 2005 and Favret & DeWalt 2002) has described new species, allowed for re-evaluation of museum specimens, and demonstrated stonefly species losses and range reductions. National Science Foundation funds have been instrumental in digitizing the label and identification labels from all 23,000 records of stoneflies at the INHS. Because of past collecting and the digitization project, the INHS Plecoptera collection is an extremely data-rich and valuable resource that can be used to infer changes in the stonefly fauna of Illinois and to ascertain the imperilment of stonefly species in the state. It should also infer changes in the aquatic insect fauna as a whole within Illinois and in areas of similar glacial and cultural heritage. While collections data are usually qualitative in nature, appropriate data aggregation can yield inference on assemblage and species changes when viewed using broad geographical and temporal scales (Shaffer et al. 1998, Favret & DeWalt 2002).

The objectives of this study were to evaluate a rich historical and contemporary Illinois stonefly record to answer several questions including:

- 1) How many extirpations of stoneflies have occurred during the 20<sup>th</sup> Century and how do rates of extirpation compare with other well known aquatic groups?
- 2) Were changes related to family or generic designation?
- 3) Do changes have a temporal component?
- 4) Were some regions more affected than others?
- 5) Do species traits explain losses?

### **METHODS**

Because much of the literature reporting species for Illinois was old and published prior to recent revisions, most literature records were deemed unreliable to determine the historic stonefly assemblage. Instead, we used the 5,694 Illinois stonefly specimen records in our collection and records from a few specimens seen by DeWalt from Agriculture Canada's Canadian National Collection, to answer questions about changes in Illinois' stonefly fauna. Localities for these records were georeferenced and associated with

14 Illinois natural divisions (Fig. 2), areas of relatively homogeneous plant communities and soil types (Schwegman et al. 1973). To determine extirpations, records were scanned for those species known from the historical record, but absent from the contemporary one. Generally, the division between these two time periods was 1950 (chosen by scanning the data for breaks in species presence), but six species have been lost afterwards. Essentially, we have as comparison all species ever present versus those that remain. Species found since 1950 were treated as having always been present in Illinois. Cummings (1991) and Cummings and Mayer (1992) and Burr (1991) were consulted to compare extirpation rates within Illinois for mussels and fishes, respectively.

To determine if certain families and genera had disproportionate losses, counts were made of the number of species per family ever reported for Illinois and for those remaining in contemporary time. One family, the Perlidae, was found to have experienced the greatest losses of species. Consequently, species richness was tallied for historic versus contemporary times for each of the seven perlid genera known from the state.

Perlid records were again used to ascertain the timing of losses. Unique perlid collection records were tallied by decade in the 20<sup>th</sup> Century along with the proportion of records devoted to each of six genera where data were sufficient. These values were graphed by decade throughout the 20<sup>th</sup> Century. Because one genus changed from being infrequently collected to being the most frequently collected genus (*Perlesta*), we believe sampling was adequate to find genera that were reported as lost (e.g. *Acroneuria*). Regional changes were determined by tallying species richness for historic and contemporary stoneflies found in each of the 14 natural divisions of Illinois for both time periods.

Important species traits included the presence/absence of egg or nymphal diapause and voltinism (life cycle length). These were gathered for each species from Stewart and Stark (2002), or were surmised from the authors' field experience.

Imperilment status was set using criteria for the NatureServe (2005) categories: S1=Critically Imperiled, S2=Imperiled, S3=Vulnerable, S4=Apparently Secure, S5=Secure, SH=Apparently Extirpated, and SX=Extirpated. Those species not present in the record after 1950 were given SX status, while those remaining in 1950 but not seen since were given SH status. Functionally, both groups are extirpated from the state. Definitions for these categories depend mostly upon the number of recent unique locations for well-sampled taxa. All data used in this study can be found at the on-line version of the INHS insect collection database ([http://ctap.inhs.uiuc.edu/insect/search\\_inhs.asp](http://ctap.inhs.uiuc.edu/insect/search_inhs.asp)).

## RESULTS

Seventy-seven species of stoneflies in eight families are known from Illinois (see DeWalt et al. 2005 for current species list). Comparisons of historic and contemporary assemblages presented here are based on 41,015 specimens and 1,120 unique positive records (Fig. 3.). The latter demonstrate that collection effort was actually greater in contemporary times than in historic ones, helping to ease fears that the contemporary fauna have been under sampled. Recent collection efforts found one extant population of *Leuctra alta* James, which in DeWalt et al. (2005) was listed as SX, extinct. It is now upgraded to S1 status.

Extant populations of only 55 of the original 77 species of stoneflies are supported in Illinois (Fig. 4). These losses included the extinction of two endemics, the Chloroperlidae *Alloperla roberti* (Surdick) and the Perlodidae *Isoperla conspicua* (Frison), both lost from the northwest of Illinois near Rock Island. Extirpations/extinctions occurred in all families except the Pteronarcyidae.

When compared to mussels and fishes, stoneflies have the highest percentage of extirpated/extinct taxa, making them the most imperiled group of aquatic organisms known in Illinois (Fig. 5). Illinois has lost 28.6% of its stoneflies, whereas mussels, with an equivalent number of species, have lost 20.8%. Fishes are a distant third at 6.4% of 187 species being lost.

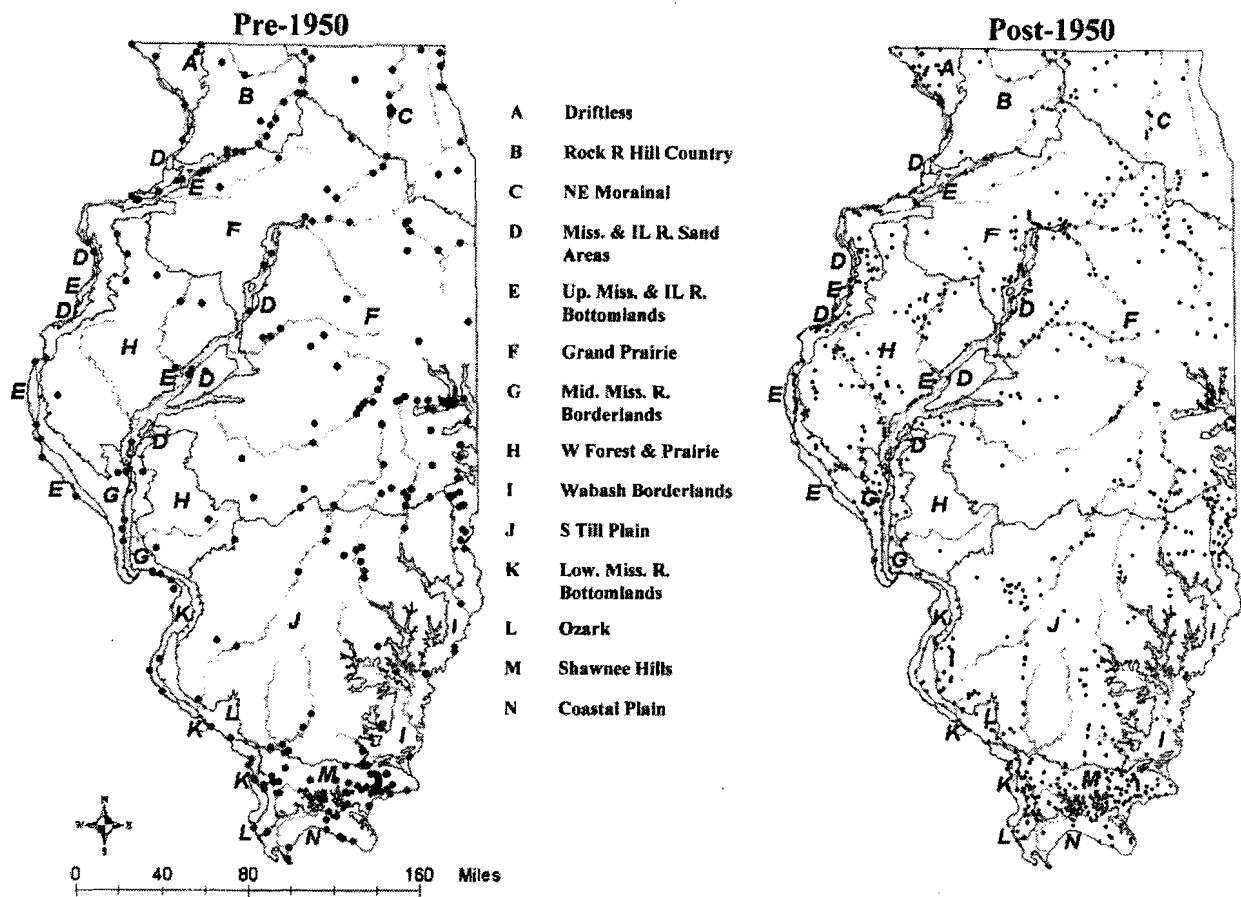


Figure 3. Unique localities for Illinois historic and contemporary stonefly collections.

**How many extirpations of stoneflies have occurred during the 20<sup>th</sup> Century and how do rates of extirpation compare with other well-known aquatic groups?**

**Were changes related to family or generic designation?**

Most of the extirpated species belong to the family Perlidae (Fig. 4). This included the extirpation of 10 species within five of seven genera (Fig. 6). It is highly probable that three genera of perlids have been eliminated from Illinois. One of these genera, *Agnentina*, was widespread across eastern Illinois, from its southern tip to the border with Wisconsin. Two nymphs were collected from the Pecatonica River at the Wisconsin border in 1976, but were too young to be reliably identified to species. This large river receives much cattle pasture drainage and tremendous amounts of silt and probably does not support *Agnentina* any longer. We have listed both species as extirpated at this point. Repeated trips to this area have yielded no specimens. The genera *Acroneuria*, *Paragnetina*, and *Neoperla* have lost two, two, and four species, respectively. *Acroneuria* and *Neoperla* were once relatively widespread and abundant. *Paragnetina media* (Walker) was known from relatively few specimens, and *P. kansensis* (Banks) was found in larger rivers of three natural divisions. The state apparently no longer supports the largest perlid species, *Attaneuria ruralis* (Hagen). The genera *Perlesta* and *Perlinella* have lost no species, for reasons that we will discuss in relation to species traits.

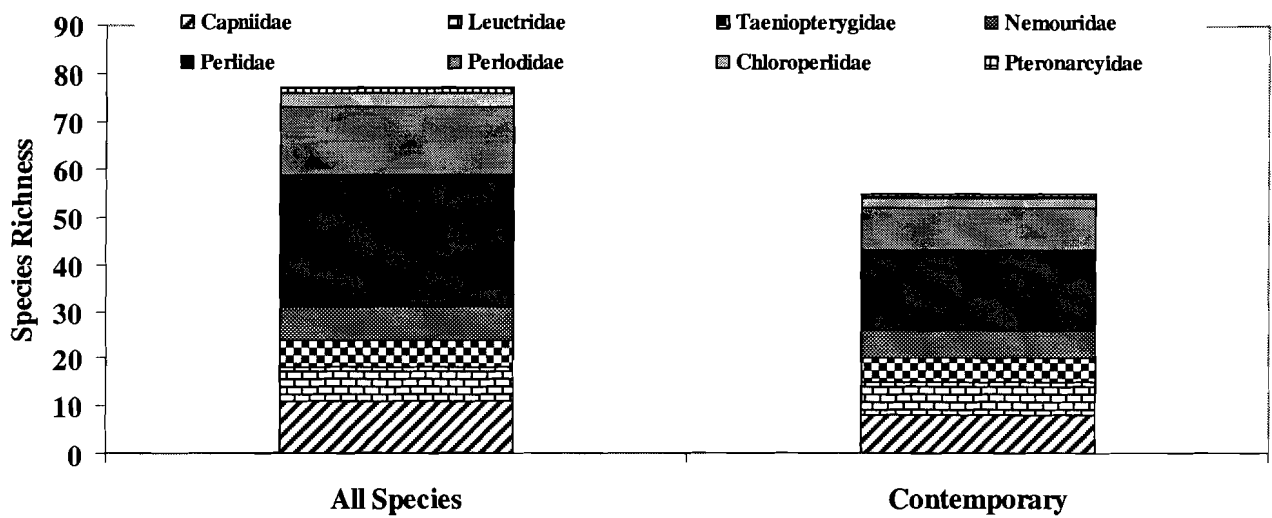


Figure 4. Comparison of Illinois historic and contemporary stonefly species richness by family.

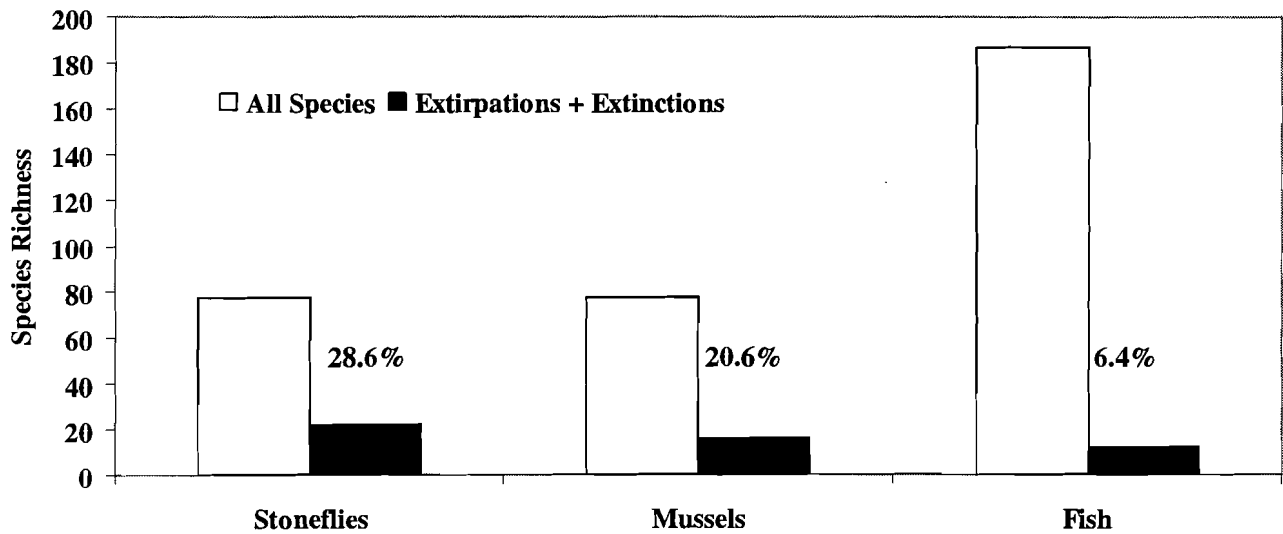


Figure 5. Comparison of extinctions/extirpations for stoneflies, mussels (Cummings 1991), and fishes (Burr 1991).

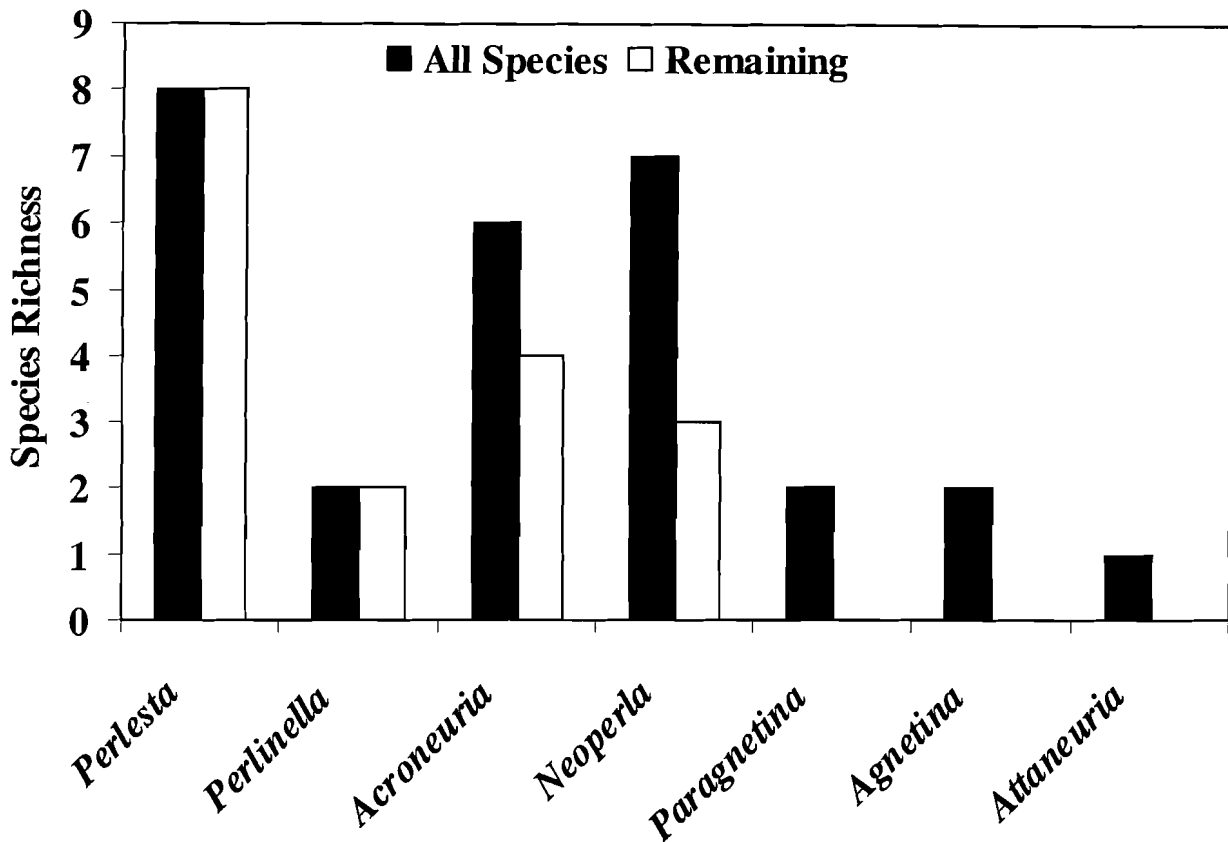


Figure 6. Extinctions/extirpations for seven Perlidae stonefly genera known from Illinois.

**Do changes have a temporal component?**

The absolute number of perlid records varied to a large extent over the course of the 20<sup>th</sup> Century (Fig. 7a). The decades of the 1920s and 1930s saw over 900 records added to the collection, with numbers dropping off dramatically into the 1940s and remaining low through the 1980s. A tremendous increase in records took place in the decade of the 1990s, the result of the efforts of D. W. Webb, M. A. Harris, and R. E. DeWalt. This information provides a glimpse into the amount of effort expended by entomologists through the century. The percentage of records by decade provides a much better interpretation of the relative abundance of genera across the landscape of Illinois (Fig. 7b). It appears that collections of the most widely distributed perlid genus, *Acroneuria*, were relatively common in the first half of the 20<sup>th</sup> Century, contributing on average 56.5% of collections through the 1940s (Fig. 7a). Unfortunately, they became scarce in the second half of the century when they contributed only 6.5% of collections. Conversely, *Perlesta* made up 18.5% of collections prior to 1950, but a whopping 78.0% of collections in the second half of the century. The other genera do not contribute greatly to supporting this time signature for loss, because their numbers were always relatively low.

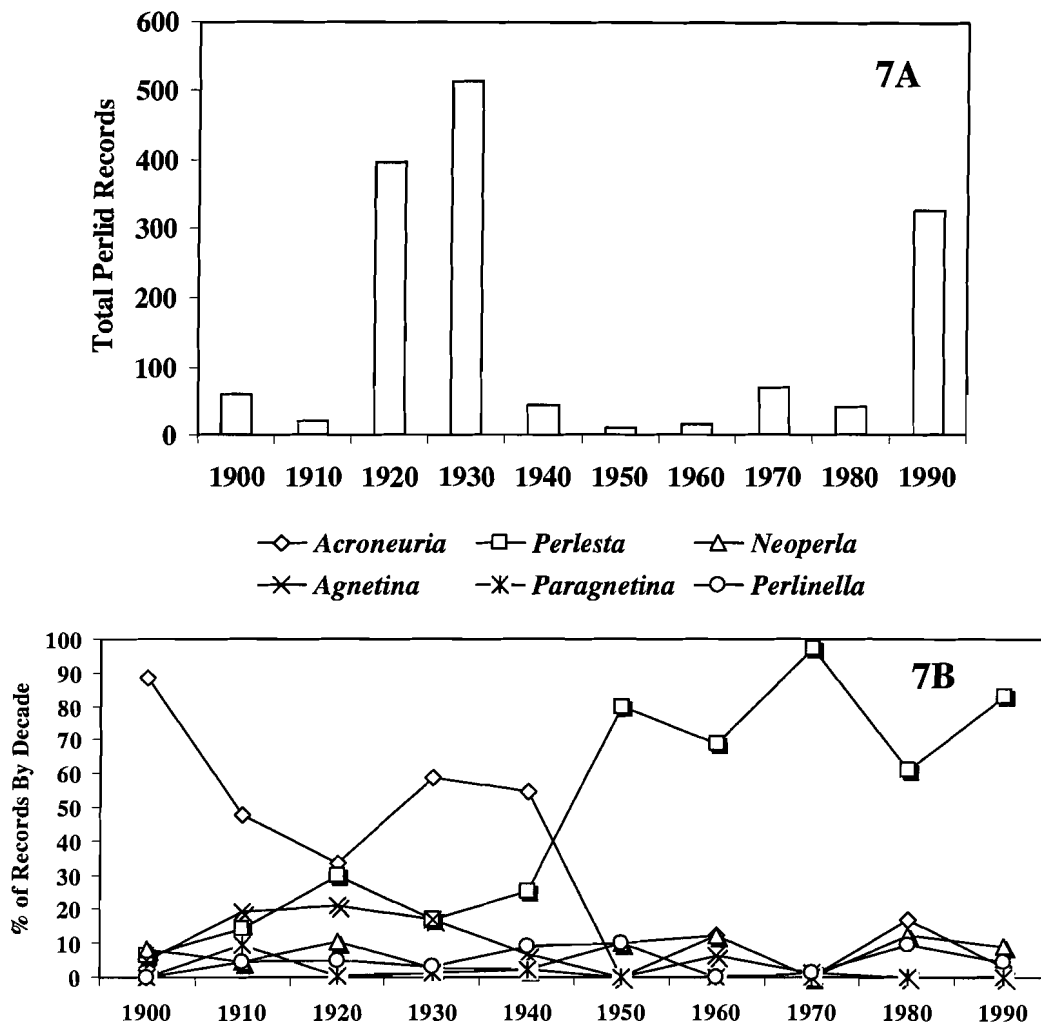


Figure 7. A. Absolute number of Illinois Perlidae specimen stonefly records by decade from the INHS insect collection. B. Unique Illinois specimen records for Perlidae genera as a function of the total number of Perlidae records within a decade.

**Were some regions more affected than others?**

Of the 14 Illinois natural divisions, three supported a hyperdiverse stonefly fauna (Fig. 8). These include the uplifted Shawnee Hills, the high gradient Wabash Border, and the once tallgrass Grand Prairie (Fig. 2), with 49, 46, and 39 species respectively. All other areas demonstrated mediocre species richness historically, because they were large river habitats, droughty, or rather small in overall area. Contemporarily, all divisions lost species; even the Shawnee Hills lost 24% of its known fauna. Particularly large losses were found in the Grand Prairie, where 49% of its entire species can no longer be found. Large rivers also lost a large percentage of their fauna. These divisions included the Upper Mississippi and Illinois River Bottomland, the Coastal Plain (Ohio and lower Mississippi floodplains), and the Illinois and Mississippi River Sands Area. The faunal assemblages have changed so much in some cases that historic and contemporary assemblages did not cluster together, even clustered at opposite ends of the dendrogram, during a Bray-Curtiss cluster analysis of presence/absence data (DeWalt et al. 2005).

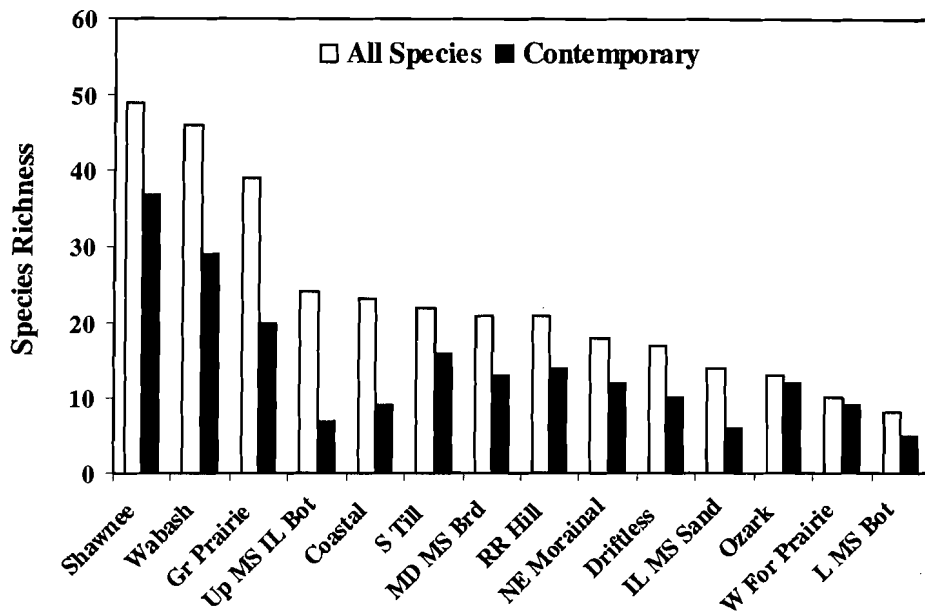


Figure 8. Historic and contemporary stonefly species richness in 14 natural divisions of Illinois.

### Do species traits explain losses?

Historically, the stonefly fauna of Illinois was attuned to drought, given that 58.4% of all species had either an egg or nymphal diapause (Fig. 9). This diapause permitted species to avoid dry stream beds or warm, stagnant waters in summer. Those species with direct egg hatch and one or two year life cycles, exposing the nymphs to poor water quality or intermittency for 11 or 23 months, made up the rest of the fauna. These species trait complexes all lost species as a function of the original total; however, the percentage of species having diapause increased to 69.1% of the current fauna. Hence, the fauna of Illinois has become even more tolerant of drought and poor water quality.

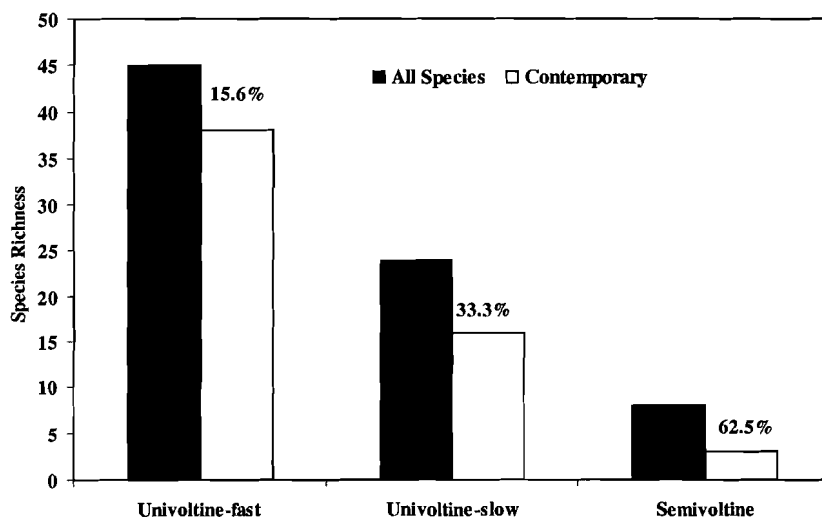


Figure 9. Distribution of life history species trait complex for all species known and contemporary stonefly assemblages in Illinois. Percentages indicate losses from historical state.



## DISCUSSION

Stoneflies in Illinois are highly imperiled. DeWalt et al. (2005) provided imperilment status for all 77 species, finding that a large proportion of the fauna had been either extinguished (two endemics) or extirpated (20 species). Many of these losses occurred in the 1940s and 1950s, with some species presumably being lost as late as the mid-1970s. This news is discouraging, but the fact that another 34 species (44.2%) are rated as S1 and S2, critically imperiled and imperiled, is the real story (Table 2). Many of these species are known from one or two populations in small nature preserves, a fact that puts them at great risk for extirpation from the state.

It appears that glaciated regions of Illinois, comprising about two-thirds of the state, sustained the greatest losses. Two of these areas, the Grand Prairie and the Wabash Border, were hyperdiverse for stoneflies and presumably other aquatic insects. It is here where the greatest losses of large perlid stoneflies have taken place. Streams such as the Salt Fork of the Vermilion River and the Embarras River in east-central Illinois spanned these two divisions, and supported similar fauna including four *Neoperla*, three *Acroneuria*, and one at least one *Agnatina* species, all of which are lost.

Table 2. Distribution of NatureServe categories for 77 species of Illinois stoneflies by number of species and percentage of total reported species.

S1 Critically Imperiled	S2 Imperiled	S3 Vulnerable	S4 Apparently Secure	S5 Secure	SH Probably Extirpated	SX Extirpated or Extinct	Total
19	15	4	2	15	4	18	77
24.7	19.5	5.2	2.6	19.5	5.2	23.4	

Other divisions that have lost a large share of their stonefly fauna have large rivers as a dominant feature. The Ohio, Mississippi, Wabash, and Illinois rivers supported the perlids *Attaneuria ruralis*, three species of *Acroneuria*, a *Neoperla*, and *A. kansensis*. Other large-river taxa such as the perloidid *Isogenoides varians* (Walsh), the Capniidae *Nemocapnia carolina* (Banks), and the Taeniopterygidae *Taeniopteryx parvula* (Banks) have been lost, and it is feared that they no longer occur in the greater Midwest region.

It is true that stoneflies still exist in nearly every flowing water body across the state. However, in many cases they are those that have egg diapause and shortened nymphal growth periods. Species in the perlid genus *Perlesta* emerge in June, requiring one or more weeks to mate and mature eggs, and then deposit eggs back in the stream. Their eggs diapause in the sediments until late March when they hatch and undergo rapid growth. Hence, the nymphs are exposed to environmental conditions for only three months. It is possibly because of this species trait complex that the genus has increased as a proportion of perlid records per decade (Fig. 7B) during the 20<sup>th</sup> Century.

The Shawnee Hills natural division of Illinois still maintains 76% of its original fauna, including some large, long-lived perlids. Much of the area is too rugged to grow row crops and a large portion is protected by the Shawnee National Park. The Kankakee River in the northeastern corner of the Grand Prairie supports populations of *A. abnormis*, although losses have indeed occurred for other perlids once known from there. Much of its drainage is in Indiana, where sandy soils promote high groundwater recharge that keeps water temperatures cool. Additionally, there are no large population centers on the river until it gets into Illinois, so organic enrichment from sewage treatment plants is minimal. The Sugar River in the Rock River Hill Country natural division is a highly prized, moderately large, sand-bottomed river. Here, *A. abnormis* can be found in abundance, along with another large stonefly in the Pteronarcyidae, *Pteronarcys pictetii* (Hagen). Some segments of the Mississippi River still hold *Acroneuria* (1 or 2 species) and *Neoperla* (1 species), but this is a far cry from its original fauna.

The advent of the Clean Water Act of 1972 saw a legal mandate to improve river quality. Since that time, much improvement has taken place, mostly in the treatment of domestic sewage. However, not enough has been done to improve habitat quality in the region, with many waterways being channelized and heavily enriched by inorganic nutrients.

Still, some restoration is taking place through re-meandering and planting of treed riparian zones. Perhaps some of these streams will support sensitive perliids if the species could only get there. These recovering streams are akin to islands in a sea of inhospitable habitat and separated by significant barriers of poor habitat and water quality. The distances that must be covered to return any of the six Illinois *Acroneuria* species to historic localities is enormous (Table 3). Corridors of dispersal are no longer contiguous. Many species would have to disperse from Indiana, but the Wabash River and the West Fork of the White River have very poor water quality. If any of these species are to recolonize Illinois, they must be aided by humans.

Table 3. *Acroneuria* species, Illinois historic location, nearest extant location, distance to recolonize, and average distance to recolonize.

Species	Illinois Historic Location	Nearest Extant Location	Distance to Recolonize (km)	Mean Distance (km)
<i>A. abnormis</i> (Newman)	Peoria	Kankakee, IL	153	150
	Dixon	Shirland, IL	71	
	Golconda	Alton, IL	225	
<i>A. filicis</i> Frison	Oakwood	Bloomington, IN	150	224
	Oakwood	Eddyville, IN	298	
<i>A. frisoni</i> Stark & Brown	Champaign	Eddyville, IL	291	254
	Champaign	Bloomington, IN	182	
	Wilmington	Hamilton, IN	288	
<i>A. evoluta</i> Klapalek	Champaign	Alton, IL	212	181
	Effingham	Alton, IL	142	
	New Athens	Alton, IL	69	
	Keithsburg	Alton, IL	253	
	Metropolis	Alton, IL	231	
<i>A. internata</i> (Walker)	Momence	Bristol, IN	166	242
	Oakwood	Bristol, IN	243	
	Charleston	Bristol, IN	318	
<i>A. perplexa</i> Frison	Petersburg	Bixby, MO	283	252
	Petersburg	Shoals, IN	303	
	Shawneetown	Bixby, MO	259	
	Shawneetown	Shoals, IN	161	

## CONCLUSION

This is one of those cautionary tales that should be heeded lest similar losses occur elsewhere. Stonefly communities tell us a lot about the quality of our drinking, irrigation, and recreation waters. Their losses also suggest that other groups of aquatic insects are being lost and their communities homogenized by tolerant species. The Clean Water Act helped to reduce point sources of water pollution with tangible benefits. However, habitat quality was not well addressed and neither was non-point source pollution, sources of degradation that must be addressed if we are to avoid the disastrous consequences for aquatic life predicted by Ricciardi and Rasmussen (1999).

This fate could befall large areas of Tennessee and Kentucky. Today there are large forest areas in the Cumberland Plateau that are being cleared for timber (Evans 2005). Coal extraction is widespread and growing and the resultant valley filling and acid mine drainage is having devastating effects on streams and the communities that depend upon them. Still, cities throughout the country are growing larger all the time, if not in actual population, then in the infrastructure footprint they occupy. Water usage is increasing dramatically, causing conflicts between the needs of society and that of wildlife.

Fragmentation of landscape features will ensure that populations of imperiled species become smaller and at greater risk for extinction. The 34 species of Illinois stoneflies (and countless other aquatic insects of unknown status) listed by DeWalt et al. (2005) as imperiled may not be around to open the next century if we do not act. Pushing politicians to sponsor legislation and to appropriate funds for improving water quality, acquiring public land, and monitoring streams is necessary. Selling the idea to them by focusing on safe and reliable water sources for consumers, businesses, and recreation is the key since we cannot depend upon the USFWS to list more invertebrate species for protection (Strayer 2006). Supporting non-profit organizations that specialize in protecting rivers is also important. It is these organizations that often take the data accumulated by government agencies and use them to hold developers and politicians accountable for keeping waters usable by all. Individuals can do a lot to reduce everyday water use. This reduces the amount of water pulled from rivers, reservoirs, and groundwater sources, reducing treatment costs and leaving water for aquatic insects.

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**CONTRIBUTED PAPERS**

**SESSION 1: BOTANY**

**Saturday, March 31, 2007**

**Moderated by:**

*Edward W. Chester*  
**Department of Biology**  
**Austin Peay State University**



# SOME VASCULAR PLANT RECORDS FOR LAND BETWEEN THE LAKES NATIONAL RECREATION AREA, KENTUCKY AND TENNESSEE

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**ABSTRACT.** The vascular flora of Land Between The Lakes National Recreation Area has been studied extensively since 1964. Published checklists were in 1971 (listing 799 taxa), 1993 (1310), and 2003 (1334). A literature report in 2006 added four taxa. Field work and annotations by experts have resulted in the addition of 14 taxa with the county records indicated as: L = Lyon County, KY; T = Trigg County, KY, and S = Stewart County, TN. Taxa include *Acer floridanum* (L,T), *A. nigrum* (T), *Carya aquatica* (T), *Crataegus coccinea* (T), *Hydrangea cinerea* (L,T,S), *Hydrocotyle ranunculoides* (S), *Lonicera morrowii* (T), *L. xylosteum* (L), *Murdannia keisak* (S,T), *Prunus mexicana* (T), *Rubus allegheniensis* (S), *Schoenoplectus purshianus* (T), *Valerianella umbilicata* (S), and *Viburnum prunifolium* (S). The addition of these 11 native and three introduced taxa (*Lonicera morrowii*, *L. xylosteum* and *Murdannia keisak* are introduced) increases the known LBL vascular flora to 1352 taxa (1033 native and 319 introduced). Field work continues and additional records are expected as the area changes from a mostly agrarian landscape to that of a publicly-owned recreation area.

## INTRODUCTION

Land Between The Lakes (LBL) is a 69,000-ha National Recreation Area encompassing parts of Stewart County, Tennessee, and Lyon and Trigg Counties, Kentucky. The area was established for public use in 1964 and was under stewardship of the Tennessee Valley Authority from inception until 1999; the United States Department of Agriculture, Forest Service, assumed management then and continues in that capacity. The area is mostly dissected upland, surrounded on three sides by water (impounded Tennessee River westward, impounded Cumberland River eastward, a man-made canal northward), and more than 80% forested. A thorough discussion of the area, its history, physical characteristics, management, and research therein may be found in Chester and Fralish (2002).

The vascular flora of LBL has been studied extensively since 1964, resulting in three checklists. Ellis, Wofford, and Chester (1971) prepared the initial list of 799 taxa. A second checklist (Chester 1993) listed 1310 taxa, and a third (Chester 2003) listed 1334 taxa. The lists were based on extensive field work by the authors, herbarium studies in all regional and some national herbaria, numerous theses by masters level students and undergraduate research projects at Austin Peay State University, site studies, reports for state and federal agencies, and others. A complete account and bibliography of botanical studies in LBL may be found in Chester (2002, 2003).

Thompson and Poindexter (2006) prepared a floristic list of the Elk and Bison Prairie, a 265-ha large-herbivore enclosure in the Trigg County portion of LBL. Of the 497 taxa encountered, three were listed as new for LBL, i.e. *Carex gravida*, *Uvularia sessilifolia*, and *Vulpia myuros*. Vouchers are housed at Berea College with a duplicate set at Austin Peay State University. While filing these specimens, another LBL record, *Asclepias viridiflora*, was encountered. These four taxa increased the known LBL vascular flora to 1338.

## METHODS

Since the 2003 checklist, more than 30 collecting trips have been made by the author to various sites in LBL. Vouchers are in the Austin Peay State University Herbarium; numerous duplicates have been forwarded to Eastern Kentucky University and The University of Tennessee-Knoxville. Collections of Kentucky woody taxa were annotated by Dr. Ross Clark (Eastern Kentucky University) as part of his on-going research on the woody plants of Kentucky.



## RESULTS AND DISCUSSION

### Additions to the LBL Vascular Flora

The 14 additions to the LBL vascular flora are given alphabetically, each with the following standard sequence of information: binomial and authority, synonymy if needed, vernacular (family in caps) – county of collection (in bold): habitat from herbarium label, date of collection, collector and collection number (in italics), herbarium or herbaria with vouchers (accepted abbreviations for these herbaria are APSC, EKY, TENN), annotation if present. The collection information is followed by a statement concerning the distribution of the taxon in Kentucky and Tennessee. Unless noted otherwise, distribution information was taken from Jones (2005), Wofford and Chester (2002), and USDA,NRCS (2007). Abbreviations of physiographic provinces are ME (Mississippi Embayment), ILP (Interior Low Plateaus), and AP (Appalachian Plateaus).

*Acer floridanum* (Chapman) Pax [*A. barbatum* Michx.], Southern Sugar Maple (ACERACEAE) - **Lyon County**: woodlands around Sardis Cemetery, 30 June 1975, *E.W. Chester 2992* (APSC). **Trigg County**: Low and slope forests at junction of Laura Furnace and Bethlehem Cemetery Roads, 14 July 1975, *E.W. Chester 3042* (APSC). Identifications by Dr. R. Clark of specimens previously reported as *A. saccharum* Marsh. Previous Kentucky reports were from Fulton and Hickman Counties adjacent to the Mississippi River. These collections thus represent a significant range extension eastward in Kentucky from the ME onto the ILP. Tennessee records are scant from middle and western sections.

*Acer nigrum* Michx., Black Maple (ACERACEAE) - **Trigg County**: creek margin, Barnes Hollow, 7 July 1987, *E.W. Chester 87-448* (APSC). Identification by Dr. R. Clark of a specimen previously reported as *A. saccharum*. A range extension westward from Logan County; the species is widespread in Tennessee.

*Carya aquatica* (Michx.f.) Nutt., Water Hickory (JUGLANDACEAE) - **Trigg County**: Barnett Bay, Tennessee River, edge of water, 28 July 1986, *E.W. Chester 86-667* (APSC). Identification by Dr. R. Clark of a specimen previously reported as *C. illinoensis* (Wang.) K.Koch. Listed as Threatened in Kentucky and otherwise known from seven ME and western ILP Counties (KSNPC 2007); it is widespread in western Tennessee.

*Crataegus coccinea* L., Fireberry Hawthorn (ROSACEAE) - **Trigg County**: low woods, Redd Hollow at head of bay from Tennessee River, 9 July 1986, *E.W. Chester 86-513* (APSC). Identification by Dr. R. Clark of a specimen previously reported as *C. phaenopyrum* L. *Crataegus coccinea* is found mostly in the AP of Kentucky and although not listed in the state (KSNPC 2007), it is considered to be rare (Jones 2005); it is unknown from Tennessee.

*Hydrangea cinerea* Small, Ashy Hydrangea (SAXIFRAGACEAE) - **Stewart County**: Rayburn Creek woods just south of LBL Road 389 and west of the Trace, 16 June 1988, *D. Grasty and T. Wyatt, s.n.* (APSC). **Lyon County**: on dam at Duncan Lake, 14 June 1985, *E.W. Chester 85-300* (APSC). **Trigg County**: slopes across from Mountain Laurel stand, Redd Hollow, 9 July 1986, *E.W. Chester 86-525* (APSC). Identification by Dr. R. Clark of specimens previously reported as *Hydrangea arborescens* Raf. *Hydrangea cinerea* is well-known and scattered across Tennessee but the Kentucky distribution is unclear. Jones (2005) noted that it is rare and limited to the AP; however, USDA,NRCS (2007) mapped it from several counties, all west of the AP. *Hydrangea arborescens* is apparently infrequent in LBL and known only from Lyon County.

*Hydrocotyle ranunculoides* L.f. (APIACEAE), Floating Marsh Pennywort - **Stewart County**: terminus of LBL Road 387, marshy area by Cumberland River, 18 October 2005, *E.W. Chester 14688* (APSC, TENN). A significant range extension from the ME for this species, which is otherwise known from Reelfoot Lake (Lake and Obion Counties) in Tennessee and Graves and Crittenden Counties in Kentucky, where it is listed as Endangered (KSNPC 2007).

*Lonicera morrowii* A. Gray, Morrow's Honeysuckle (CAPRIFOLIACEAE) - **Trigg County**: LBL Road 134 south of Energy Lake, shrubs around an old home site, 19 July 1988, *E.W. Chester 88-165* (APSC), verified by Dr. R. Clark. An introduced and potentially invasive bush honeysuckle, heretofore known from scattered locations in the two states.

*Lonicera xylosteum* L., Dwarf Honeysuckle (CAPRIFOLIACEAE) - **Lyon County**: East side of HW 49, vicinity of Newby Cemetery Road, 28 April 2005, *E.W. Chester 14686* (APSC), identification by Dr. R. Clark of a specimen previously identified as *L. x bella* Zabel, another introduced and potentially invasive bush honeysuckle. *Lonicera xylosteum* is unknown from Tennessee and of uncertain distribution in Kentucky (unknown according to USDA, NRCS 2007; rare according to Jones 2005).

*Murdannia keisak* (Hassak.) Hand.-Maz., Marsh Dayflower [*Aneilema keisak* Hassk.] (COMMELINACEAE) - **Stewart County**: Clay Bay, Tennessee River (Kentucky Reservoir), dewatered zone along Clay Creek at head of Clay Bay, 18 October 2006, *E.W. Chester 14709* (APSC, TENN). **Trigg County**: marshy shoreline of the Tennessee River (Kentucky Reservoir) just south of Highway 68 at Fenton, 3 October 2006, *E.W. Chester 14702* (APSC, EKY, TENN). A first report for the ILP of Kentucky; the few previous reports have been from the AP. The Tennessee distribution is mostly eastern with a few records from along the Tennessee River, including a recent record from Humphreys County (Gunn and Chester 2003). This invasive introduction is apparently expanding its range northward in Tennessee and Kentucky along the Tennessee River.

*Prunus mexicana* S. Watson, Mexican Plum (ROSACEAE) - **Trigg County**: 1.5 miles north of U.S. 68 along Shanklin Creek, 15 June 1965, *W.H. Ellis 96* (APSC). Identification by Dr. R. Clark of a specimen previously reported as *P. americana* Marsh. A native plum scattered across Kentucky and Middle and West Tennessee.

*Rubus allegheniensis* Porter ex Bailey, Allegheny Blackberry (ROSACEAE) - **Stewart County**: roadside by Rayburn Creek woodlands, 30 June 1988, *T. Wyatt & D. Grasty, s.n.* (APSC). Identification by Dr. R. Clark of a specimen previously reported as *R. argutus* Link. Scattered in both states but rare west of the Tennessee River.

*Schoenoplectus purshianus* (Fern.) Strong, Pursh's Bulrush (CYPERACEAE) - **Trigg County**: old pond on west side of North-South Trail, 0.5 mile south of Laura Furnace Creek Road, 10 October 2006, *E.W. Chester 14706* (APSC). An infrequently-encountered species in both states and heretofore unknown from the western ILP.

*Valerianella umbilicata* (Sull.) Wood., Navel Cornsalad (VALERIANACEAE) - **Stewart County**: weedy bottomland field by Cumberland River east of Bards Dam, 30 May 2006, *E.W. Chester 14692* (APSC). Essentially a species of limestone areas in Middle Tennessee; the Kentucky distribution is unclear (Jones 2005).

*Viburnum prunifolium* L., Common Blackhaw (CAPRIFOLIACEAE) - **Stewart County**: dry roadside embankment west of Tenn. Highway 49, 1 October 1980, *J. Stack 995* (APSC). Identification by Dr. R. Clark of a specimen previously reported as *V. rufidulum* Raf. Infrequent but scattered across both states.

## Synopsis of the Known LBL Vascular Flora

The currently known LBL vascular flora may be summarized as follows.

**Table 1. Floristic Summary of the Land Between The Lakes Vascular Flora.**

Taxa Group	Families	Genera	Native Taxa	Introduced Taxa	Total
Ferns/Allies	14	22	31	0	31
Gymnosperms	3	5	4	6	10
Monocots	20	129	275	74	349
Dicots	107	453	722	239	961
<b>TOTALS</b>	<b>144</b>	<b>609</b>	<b>1033</b>	<b>319</b>	<b>1352</b>

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# HORTICULTURE, A KEY SOURCE OF INTRODUCING EXOTIC SPECIES INTO NATIVE COMMUNITIES

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**ABSTRACT.** Studies have shown that invasive species can have negative effects on natural ecosystems including changing their structure and function and causing loss of biodiversity. Currently, there is still a lack of specific information on exotic and invasive plants in the state of Kentucky, especially concerning origin of invasives and the mechanisms of species introduction. This project was designed to gather information on plant species found in local nurseries in western Kentucky and to test the following hypotheses: there is no relationship between species taxonomic affinity and native origin; and there is no origin preference by people when they purchase gardening plants from local nurseries. By identifying and recording all species found in the local nurseries, we discovered a significant relationship between taxonomic affinity and the origin of plant species. Further, we found that exotic plant species, especially of eastern Asian origin, are preferred by gardeners in general. Therefore, it is suggested that taxonomic affinity and native origin of plant species could be used as an effective indicator in identifying the pool of potentially invasive species in the future. Our results are consistent with other research findings that nurseries have been one of the major sources of introducing exotic plants to natural communities. This project could provide a solid basis for further research on agricultural, recreational, aquacultural, and conservational effects of exotic plants in this area. Most importantly, this project could help increase society's awareness of biological invasion and the significance of native ecosystem conservation.

## INTRODUCTION

Exotic plant species are also called alien plants, non-indigenous plants, and introduced plants in the literature. According to Pysek et al. (2004) exotic plants are defined as plant species in a given area whose presence there, is due to intentional or unintentional human involvement. Some of the non-native species are capable of independent growth and sustain self-replacing populations for at least ten years without direct human intervention, and then they are categorized as naturalized plants. Among the naturalized plant species, about 10% or less could become invasive in the introduced habitats (Williamson 1996). Here 'invasive' means that plants produce reproductive offspring, often in very large numbers, and thus have the potential to spread over a large area (Pysek et al., 2004).

The impact of invasive plants has been observed in major natural ecosystems (Baskin 2002). Typically, plant invasion can change the niches of native species, alter the structure and function of ecosystems, and disrupt the evolutionary processes (D'Antonio and Vitousek 1992, Williamson 1996, Mack et al. 2000). According to Pimentel et al. (2000), it is estimated that in the United States alone more than 137 billion dollars are spent annually on combating biological invasion. Thus, the study of invasive species and their impact on the native ecosystems has emerged as a crucial area of biological research.

In the state of Kentucky, plant invasion has become one of the critical issues for conservation management. About 90 invasive plant species have been listed by the Kentucky Exotic Pest Plant Council (KEPPC) (Southeast Exotic Pest Plant Council 2000). However, there is lack of a systematic research on exotic and invasive plants in the state, especially concerning the origin of these species and their mode of introduction. This project was designed to gather information of plant species found in local nurseries in western Kentucky by achieving the following objectives: (1) identifying species origin; (2) studying species taxonomic affinity, i.e., which family they belong to; and (3) determining if a relationship exists between species taxonomic affinities and their native origin.

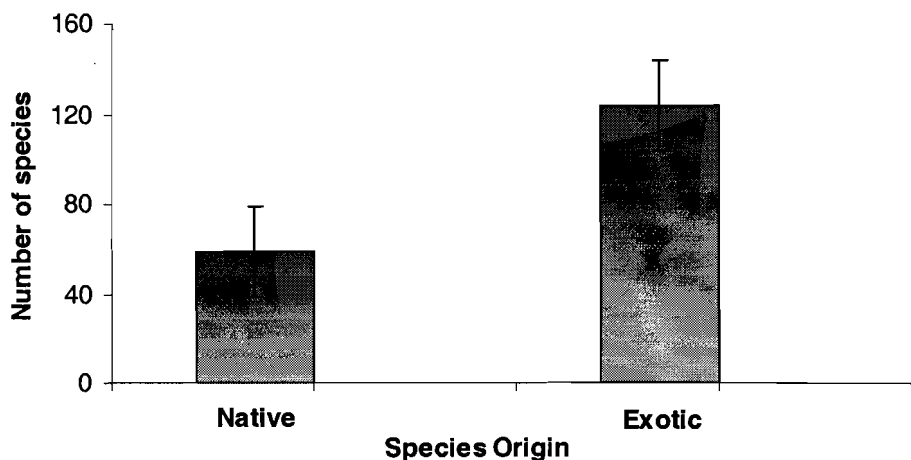
We decided to choose local nurseries as our main sources of data collection because it has been well recognized that a substantial amount of plant species, especially woody plants have been intentionally introduced to new locations through nurseries and botanical gardens (Reichard and White 2001). Furthermore, local nursery data allow us to study the anthropogenic dimension involved in this study by determining people's first preference for native species or exotic. Our null hypotheses were two: there is no relationship between species taxonomic affinity and their origin; and there is no origin preference by people when they purchase gardening plants from local nurseries.

## METHODS

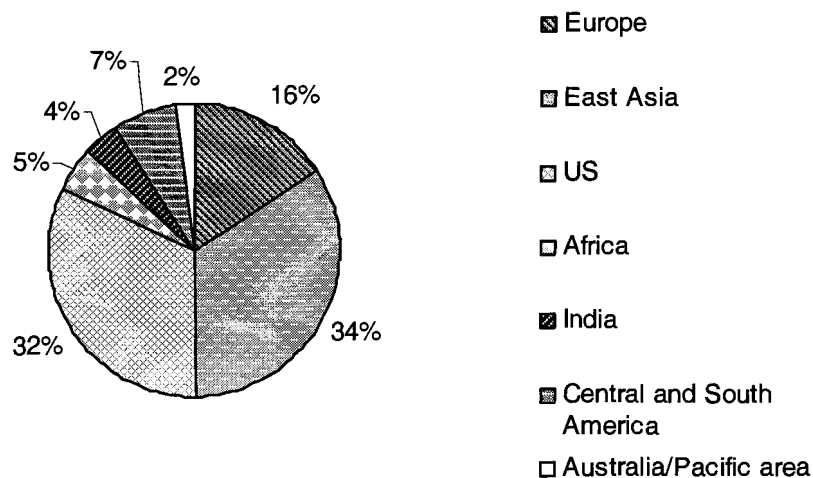
To test our hypotheses, we collected plant data from four local nurseries around the city of Murray in western Kentucky. These nurseries included the nursery of Wal-Mart, Lowe's, Rolling Hills, and the Wyatt Farms. Each plant species found in the nurseries was recorded and identified to the species level. Taxonomic affinity was also identified at family level for each plant. Native origin, the independent (factor) variable, was determined for all exotic species. Total number of plants per family, the dependent (response) variable, was also counted and recorded. StatView software was used to perform chi-square analyses to determine if the null hypotheses were supported or otherwise.

## RESULTS

The total number of native species proved to be much lower than the number of exotic species. There were fifty-nine (32%) native plants while there were one hundred and twenty-four (68%) exotic species (Fig. 1). Information of species native origin is shown in Fig. 2. The native origins were identified according to seven main geographical areas, which included Europe, eastern Asia, Africa, the United States, India, Central and South America, and the Australia/Pacific area. Most of the plants, about 34%, came from eastern Asia and the least number of plants came from the Australia/Pacific area.



**Figure 1.** Total number of exotic and native plant species found at four Murray nurseries.



**Figure 2.** Information of native origin of plant species found at four local nurseries.

The results indicated that the aster family (Asteraceae) had the most number of native plants with a total of nine species as shown in Table 1. The cypress family (Cupressaceae) had the highest number of exotic plant species with 11 as shown in Table 2. The results of chi-square analyses revealed that there is a significant relationship between taxonomic affinity and the origin of plant species ( $p < 0.0001$ ). Further, by taking the frequency with which plants are found in nurseries to be a proxy for estimating people's preference for species origin, the results indicate that exotic plant species are preferred by gardeners in general ( $\chi^2 = 23.08 \geq \chi^2_{\alpha=0.05, df=1} = 3.841$ ).

## DISCUSSION

The results of our research show there were more than twice as many exotic than native plants found in the local nurseries primarily due to the people's preferences on garden and ornamental plants. Our result is consistent with other research findings that nurseries have been one of the major sources of introducing exotic plants to natural communities (Reichard and White 2001). Among the exotic species found in Kentucky, a few have made negative impacts on the native ecosystems by endangering and replacing native species and have resulted in a loss of biodiversity. Typical invasive plants found in the local area include Japanese honeysuckle (*Lonicera japonica*), Chinese privet (*Liqustrum sinense*), oriental bittersweet (*Celastrus orbiculata*), multiflora rose (*Rosa multiflora*), and tree of heaven (*Ailanthus altissima*). Unfortunately, some of these species are still sold in the local nurseries. Therefore, it is important to increase society's awareness of biological invasion and its negative impact on native ecosystems. It is equally critical to have informed and educated nursery staff and gardeners, so that invasive exotic species will not be introduced and purchased at the nurseries in the first place.

Our study also pointed out that a significant relationship between taxonomic affinity and the origin of plant species does exist. Certain families contain more exotic species than others, thus, taxonomic affinity could be used as an effective indicator in identifying and predicting potentially invasive species in the future. Information on the native origin of species can serve the same purpose as well.

**Table 1. Top eight families with most native species.**

<b>Family Name</b>	<b>Number of species</b>
Asteraceae	9
Cupressaceae	8
Hydrangeaceae	7
Pinaceae	6
Rosaceae	4
Ericaceae	4
Juncaceae	3
Cactaceae	2

**Table 2. Top eight families with most exotic species.**

<b>Family Name</b>	<b>Number of species</b>
Cupressaceae	11
Araceae	9
Aquifoliaceae	8
Lythraceae	7
Lamiaceae	7
Asteraceae	7
Brassicaceae	7
Rosaceae	6

Although this research was limited in its scope, it should provide a model for further research on agricultural, ecological, aquacultural, conservational, and commercial effects of exotic plants in this area. Identifying potentially harmful species presents a major challenge for scientists and is an essential step in preventing invasion from exotic plants. Further research is needed to determine if any of these species could present future danger to local ecosystems. Additional statistical analyses could also be performed to determine the probability that any of the exotic species will become problematic in the future. At the same time, increasing society's awareness of biological invasion should be treated as one of the most important elements in the management and conservation of our native ecosystems.

#### **ACKNOWLEDGEMENTS**

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# FLORA OF SEVERAL OAK AND EASTERN REDCEDAR – OAK FOREST STANDS FROM THE VALLEY AND RIDGE PROVINCE OF TENNESSEE

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**ABSTRACT.** A study of the flora of 22 oak and eastern redcedar-oak forest stands in the Valley and Ridge Province of Tennessee has been made. Stands were on several bedrock types including dolomite, limestone and shale and on various aspects. Topographic positions included bottom, low flat, ravine, open slope, ridge and bluff with cliffs. Total taxa were 570; 6.5 percent were introduced. Floristically rich families and floristic element proportions were similar to those of other local floras in this area. Twelve taxa on the Tennessee List of Rare Plants were found. The variety of sites allowed a fairly high number of mesophytic taxa to persist here. The stands were sequenced from wet to xeric using site information. The median numbers of occurrences among forbs, grasses and oaks varied in the array and declined in abundance at the extremes. Ferns, sedges and rushes were most abundant at the wet end of the array.

## INTRODUCTION

The importance of oak forests to civilizations in the temperate regions is well known (Logan 2005) and to the eastern United States Deciduous Forest biota (McShea and Healy 2002) with its biotic diversity (Stein et al. 2000). The importance of oak forests in the Tennessee Valley and Ridge Province is emphasized by definitions and descriptions of forests here. Shantz and Zon (1924) mapped the areas as within the chestnut-chestnut oak-yellow poplar type, and it was later mapped at a large scale with extensive hardwood (mostly oak) forests (Tennessee Valley Authority 1941). Braun (1950) described it as part of the oak-chestnut forest region, and K uchler (1964) mapped this area as within the Appalachian oak forest—the same name was used by Stephenson et al. (1993). Local studies have confirmed regional interpretations. Hardaway (1962), Hedge (1979) and De Selm (in progress) have sampled, or sampled and described, many oak stands. Martin (1971, 1978, 1989), and Martin and De Selm (1976) described numerous oak forest types. Martin (1971), in particular, described 33 oak dominated vegetation types distributed among seven dominant oak taxa. The prevalence of oak vegetation in the forests of the Valley and Ridge near the time of European-American settlement is indicated by land survey records: Fifth District (Knox County and northward) (De Selm 1995), northern Sevier County (De Selm and Rose 1995), Campbell County (De Selm 1997), Hawkins County (De Selm 1999), Blount and Roane counties (De Selm 2001), Hamilton County (De Selm 2005) and several other East Tennessee counties (De Selm 2006).

This study was stimulated by the writer's experience in many Valley oak forest stands since 1984 (De Selm in progress). It was apparent that the sample flora obtained from an hour's examination was but a fraction of the stand flora. In this study, selected stands were examined at intervals throughout a growing season to obtain a fuller proportion of each stand's flora

## THE STUDY AREA

The Valley and Ridge Physiographic Province extends from central Alabama north to the Hudson River valley (Fenneman 1938). The Tennessee section of the Valley is underlain by Paleozoic bedrocks of sandstone, dolomite, limestone and shale with many named units which have been extensively folded and faulted. The erosion which followed has formed a parallel valley and ridge topography which extends to the northeast and southwest. Elevations range from about 800-1500 feet (Rodgers 1953, Hardeman 1966). Sample sites are from the dolomitic bedrock Knox Group including the Newalla Formation with limestone and dolomite, and, on gentle topography the Chickamauga limestone and Conasauga shale (Rodgers 1953,

Hardeman 1966). The Chickamauga, Newalla and certain other parts of the Knox have weathered to stoney, clayey, and shallow Rockland or Rockland-Talbott soil series of the order Alfisol, subgroup Hapludalf. Most of the Knox has weathered to deep, clayey, cherty Fullerton or Clarksville series, order Ultisol, subgroup Typic Paleudults. The Conasauga has weathered here to flattish, winter-wet, lower slope sites with the Dowelltown series, order Alfisol subgroup Vertic Ochraqualf. On a Tennessee River terrace in a Chickamauga valley, the alluvial deposit has developed the Guthrie series, order Ultisol, subgroup Typic Fragiaquilt (USDA Soil Conservation Service Soil Survey Staff 1975 and several county soil surveys).

The climate of the study area is temperate, with well distributed (monthly total) precipitation (mainly rain) of 44-48 inches (Dickson 1960, 1931-1960 data) or 45-51 inches (De Selm and Schmidt 2001, 1961-1990 data). Summer droughts, usually of short duration are common. Mean January minimum temperatures are near 30°F and mean July maximum temperatures are near 88°F (Dickson 1960). Parts of the two bottoms and sites, Guthrie and Dowelltown series were covered by shallow surface water during May, 2005. The Rockland and Rockland-Talbott shallow soil sites experience one or more short moderate droughts most years.

The flora and vegetation of the study area has been evolving from the Cretaceous through the Tertiary and Holocene Periods (Graham 1999). Land connections and plant migrations have occurred between North America and Europe and Asia thus greatly enriching the flora. Cool Pleistocene climatic periods and southward invasion of northern spruce and pine may have restricted the growth of upland vegetation north of the 34 degrees parallel (Graham 1999, Delcourt et al. 1987). Warm Interglacials and the warm, dry Holocene Hypsithermal period and Medieval Warm Period resulted in some species ranges to expand and others to contract. Modern species distributions (as Chester et al. 1993, 1997, Wofford 1989, De Selm et al. 1997, Gleason and Cronquist 1991) and fossil evidence (Delcourt et al. 1983, Delcourt 1980, Delcourt and Delcourt 1987) suggest, and in some cases indicate, movement of species or genera. Such movement also may enrich the flora.

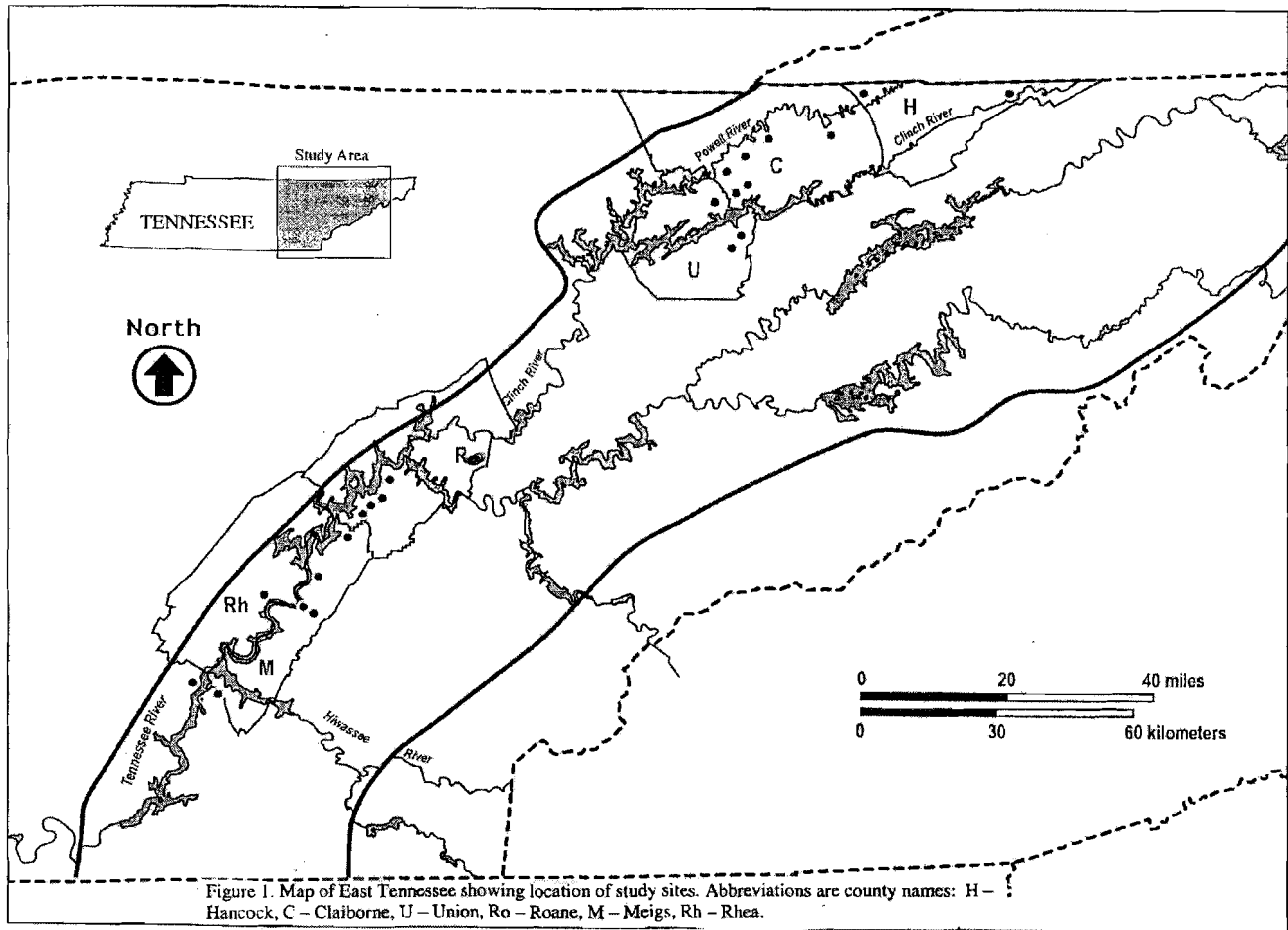
The vascular flora of the Southern Appalachians is well known and is compiled into summary lists as White (1982), and manuals (Wofford 1989, Wofford and Chester 2002). Studies of local Valley and Ridge floras include those of Hawkins County (Wolfe 1956), the barrens (De Selm et al. 1969, De Selm 1993), a section of the Clinch River border (Bullington 1997), and the Oak Ridge National Laboratory land (Mann et al. 1985). The actual total flora of the Tennessee Valley is unknown but its considerable size is suggested by the Oak Ridge area flora of 842 taxa and the 1058 species of Blount County flora (University of Tennessee Herbarium 2000).

Early in the Holocene, North America and then Tennessee was invaded by low populations of Native Americans. As their populations grew and villages were established, land was intensively used for village, field and burial sites. Uplands were used as a wood source, other plant (as food) sources and hunting. Fire was often used for hunting game (Lewis and Kneberg 1958, Delcourt and Delcourt 1996, Swanton 1946). By the late eighteenth century, European-Americans began to settle the area after wars and treaties with Native Americans. They logged the forest, cultivated row crops in valleys and other land was used for stock grazing. Spring fires were usually set in the forest to increase forage (Folmsbee et al. 1969, Killebrew et al. 1874). As human populations grew, logging became more widespread, and destructive herb collecting by land owners and their neighbors, and by stock and deer, weed invasion, fire control, and foreign insect and disease introduction have all become greater problems affecting forest structure and diversity (Nolt et al. 1997, Nash 1999).

## METHODS AND SAMPLE AREAS

Location and examination of stands first occurred during the period 1984-2004 (Fig. 1). During the approximately one hour sample, stand flora was determined or collected and other stand attributes determined. Stands were selected which had no evidence of recent disturbance, with a closed canopy, and with a variety of tree diameters: 5 inches to the 24-30 inch class. From this group, a set of 18 stands of a variety of oak with eastern redcedar as dominants and site types, were selected for study, March through mid-November, for one

day about every 21 days, 2005, for inventory of the vascular flora. A few stands were found spring 2005, and included because of their particular site, or spring floristic richness. Two stands had been studied during 2003 and 2004 during the same monthly periods. Stands were from six counties and 11 topographic quadrangles and are described in Appendix I.



At each site a transect of about 200 meters was walked during each period of examination. Specimens of unknown vascular taxa were collected. Species names and ranges were determined using standard manuals and with the aid of personnel and facilities at the University of Tennessee Herbarium (TENN) and other literature. Sources included Gleason Cronquist (1991), appropriate volumes of the Flora of North America (Flora of North America Editorial Committee 1993 et seq.), Chester et al. (1993, 1997), Jones (2005), Campbell (2002), Isley (1990), McKinney (1997), and Terrell (1991). Floristic data was compiled by site.

Geologic beds were determined from the maps of Rodgers (1953) and Hardeman (1966); soil series were determined from appropriate county soil surveys; and elevations from 7.5 minute U.S. Geological Survey topographic quadrangle maps.

## RESULTS AND DISCUSSION

From this series of samples, a total of 570 species and infraspecific taxa were determined (Appendix II). Nine taxa were determined only to genus. The most speciose (species-rich) families were the Asteraceae (14.2%), Poaceae (10.9%), Cyperaceae (9.7%), and Fabaceae (6.5%)—such proportions also occur in the State flora (Wofford and Kral 1993). Introduced taxa totaled 6.8%, lower than in the State flora (Wofford and Kral 1993), but nearly double that seen in the mesic forest flora (De Selm 2006). A total of 11.1% of this flora was

weedy (listed in Underwood 1965). The weed flora included both weedy native as well as introduced taxa—their numbers were probably a reflection of past stand disturbances noted above as well as modern deer and hunter traffic. Also, half of the stands had an open (sunlit) border allowing heliophiles in the stands.

The floristic elements are of interest. The widespread intraneous group was 62.2%; the local intraneous Southern Appalachian taxa 3.9%, northern 10.2%, southern 13.7%, and western 1.2%. These numbers differed from the mesic flora (De Selm 2006) in that the northern proportion was lower and southern higher. The warmer microclimate (often south aspect) and the location of half of the stands from the southern half of the Valley—compared to more common north aspects and more northern location of mesic stands (De Selm 2006), may account for these differences.

Woody taxa represented 22.2% (trees 11.0%, shrubs 8.2% and woody vines 3.0%). Among the herbs, native perennial forbs were the largest group at 41.5% and there were 45 native annuals. Herbaceous vine taxa were about as numerous as woody vine taxa.

Graminoids (grasses, sedges and rushes) were 21.6% of the flora. Grass and sedge percents were higher than in the mesic flora (De Selm 2006) perhaps because of warmer site microclimates and inclusion of wetlands in this set. The fern flora, 22 taxa (3.8%), was lower by nearly half of that of the mesic flora but larger than the 2.3 percent of the Valley and Ridge barrens flora mostly from xeric sites (De Selm 1993). Floras with somewhat similar proportions are found in the data of Oxendine (1971), Hedge (1979), the Oak Ridge flora (Mann et al. 1985) and in Hawkins County (Wolfe 1956).

Presence classes (Oosting 1956, based on his work in the Sierran red fir forests) are similar to Oosting's classes: constant (17-22 stands, 4.4% of the flora), mostly present (13-16 stands, 6.2%), often present (9-12 stands, 8.0%), seldom present (5-8 stands, 10.3%), and rare (1-4 stands, 71.1%). The trend illustrates the lack of homogeneity of the group of stands—an attribute resulting from ridge to wetland stand/site choices.

Twelve taxa were on the Tennessee Rare Plant List (Bailey 2004). They were:

*Arabis patens*, State Endangered  
*Aster oolentangiensis*, State Special concern  
*Berberis canadensis*, State Special concern  
*Carex comosa*, State Endangered  
*Carex echinata*, State Special concern  
*Castanea dentata*, State Threatened  
*Diervilla sessiliflora* var. *rivularis*, State Threatened  
*Juglans cinerea*, State Threatened  
*Lysimachia quadriflora*, State Special concern  
*Dichantheium acuminatum*, subsp. *leucothrix*, State Special concern  
*Rhamnus alnifolia*, State Endangered  
*Ruellia purshiana*, State Special concern

The number of rare taxa is approximately in proportion to the size of the flora (compared with the mesic flora of six rare taxa, De Selm 2006) and 45 rare taxa in the Valley and Ridge barrens flora (De Selm 1993).

A list of Appalachian endemics compiled by De Selm (1984) chiefly from lists by Harper (1947, 1948) and subsequently supplemented by those listed from the Great Smoky Mountains (White 1982) was short—only three endemics. Apparently there are not enough special sites (elevation, bedrock, topography) among the sampled areas for the endemic flora. The endemics were *Dievilla sessiliflora* var. *rivularis*, *Solidago curtisii*, and *Trillium luteum*.

Upon reviewing the list of taxa, it was estimated that around 25% were common in mesic stands and might justifiably be called mesophytes. A similar conclusion was reached upon examining the flora of 20 wetland sites (De Selm this proceedings). Half of the current stand sites were on northeast or northwest facing slopes and three of the northeast and most of the northwest sites were lower side slopes. These are more likely

to be moist sites where mesophytes could survive. However, some of the “mesophytes” may in fact be “wides,” which occur, with varying frequency in oak, mesic, and wetland stands.

Using site characteristics and overstory composition, the stand data was ordered/sequenced from wet to intermediate to dry and numbered 1-22 (see arrangement in Appendix I, site descriptions). Stands 1-4 included two stands dominated by *Quercus phellos* and *Nyssa sylvatica*, a flat site dominated by *Quercus stellata*, and a bluff with oaks and mesic taxa. These stands were 12-30 feet above the Tennessee River. Stands 5-10 were dominated by *Quercus alba* and were located on side slopes 60-629 feet above the nearest major river. The *Quercus velutina* stand (11) and mixed *Quercus* stands and *Q. prinus* stands (12-18) were on side slope and crest positions 76-624 feet above the nearest major stream. Four stands (19-22) considered most xeric occurred on Knox dolomite, the Newalla Formation and the Chickamauga limestone. These stands were dominated by calcareous oaks (*Quercus muhlenbergii*, *Q. shumardii*) taxa and *Juniperus virginiana* and they occurred on steep bluff and cliff positions 30-170 feet above the nearest major stream. Sites 20 and 21 overlooked the Tennessee River, and site 22 the Clinch River.

Using the stand order, elements of the stand floras were examined. In this old, well-adapted flora, the numbers of tree taxa were fairly uniformly high with a decline in taxa in stands 19-22. The shrub and woody vines responded similarly. The herb totals were slightly lower in the stand 1-4 and 12-22—the wet and dry ends of the gradient. The numbers of fern taxa declined in the steep slope stands (19-22). The Cyperaceae numbers were highest in the wet and mesic stands 1-4 and least in the driest stands 19-22. The Juncaceae behaved similarly. Similar responses of species across environmental gradients have been shown by Curtis (1959), Whittaker (1956), Oxendine (1971), Burrows (1990) and in studies paralleled to this one: mesic forests (De Selm 2006) and wetlands (De Selm this proceedings).

## SUMMARY AND CONCLUSIONS

In this one year examination of the flora of 22 chiefly *Quercus* dominated forests, a flora of 570 taxa was determined. Although the stands were chosen on the basis of no recent disturbance, an introduced element of 6.8% and a weed element of 11.1% occurred. Their arrival was at least, in part, the result of past intensive land use including logging, stock grazing, fire, current grazing, deer browse, and various forms of human traffic (i.e. hunters). Geographic floristic element percentages were similar to those found in other local studies—in this study the southern element was somewhat higher than in the flora of several mesic forests probably because more southern stands were sampled here and because of the warm southern aspect of several stands. The rare flora and the Southern Appalachian endemic elements were small. Since the same geologic beds extend for many miles through the Valley and Ridge province resulting in similar soils and topographic features, mixing of the flora has apparently been easy (few rarities) and isolation rare (less endemism). These stands shared many wide taxa (nearly 40%) occurring across geologic and soil moisture boundaries and also perhaps as many as 25% of the flora were mesophytes.

The stand data sets were arrayed in a sequence of wet to intermediate to dry. Sedges and rushes were concentrated in numbers of species and occurrences at the wet end of the gradient. Grass and forb taxa occurrences were fewer at both ends of the array; ferns were fewer at the dry end. Numbers of tree, shrub and woody vine taxa were fewer at the dry end of the array. These distributions suggest that the water factor was in fact an important one operating through lowered soil oxygen levels at the wet end and drought at the other end (Brady and Weil 1999). However, soil fertility may operate across this gradient, although the natural levels of fertility on this group of bedrocks, and in particular the soils of these sites, are unknown. Bottomland and low site soils, because of weathering and accumulation of nutrients from upslope with less loss, are known as more fertile sites (Brady and Weil 1999, Tisdale et al. 1993). At the xeric end of the gradient, the steep slope sites lose soil and nutrients by erosion but shallow soils may allow more root contact with nutrients being made available by weathering in the shallow regolith or the bedrock (Tisdale et al. 1993). The very steep slopes associated with, in particular the xeric sites, also changes light availability both for the canopy layer and understory layers and may also change the temperature regime thus affecting physiological processes

influencing survival and growth (Chabot and Mooney 1985, Kozłowski and Pallardy 1997, Gilliam and Roberts 2003). The effects of changing environmental conditions on plant seed production, survival, and germination are another set of factors to be considered (Baskin and Baskin 1998, Young and Young 1992).

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## Appendix I

### Stand Descriptions

Order follows wet to xeric sequence.

1. Washington Ferry W.M.A., 02-103, 01-104, Rhea County, Rt. 302, 2.2 miles north from Rt. 30, stand 0-0.5 m above summer water level (swl), *Quercus phellos* and *Q. alba* dominants, past grazing and present deer browse probable. Bedrock: Chickamauga limestone, soil: Guthrie series. Related to the willow oak – water oak type 88 of the Society of American Foresters (Eyre 1980).
2. Rt. 304 south of Rt. 68, 02-48, Meigs County, location as named, stand 0-0.5 m above spring water level, *Liquidambar-Quercus phellos-Nyssa sylvatica* dominated. Past stock grazing and present deer browse probable. Bedrock: Conasauga shale, soil: Dowelltown series. This may represent the Society Sweetgum-willow oak type 92 (Eyre 1988).
3. Hornsby Hollow Campground, 02-37, Meigs County, Campground on Rt. 304 2.6 miles south of Meigs County line, dominated by *Quercus stellata* and *Q. falcata*, past grazing and present deer browse probably. Bedrock: Conasauga shale, soil: Litz series. A similar type was seen by Martin (1971). This may represent the *Quercus stellata* Flatwoods Forest Alliance (Weakley et al. 1998).
4. Eave Springs Bluff, 02-55, Meigs County, at terminus of Eave Springs Rd., west from Rt. 304 at Tennessee River/Chickamauga Lake edge, dominated by *Acer saccharum* and mixed *Quercus*. Main forested slope angle 88 percent, talus 5 percent, also with a vertical cliff. Bedrock: Knox dolomite, soil: Rockland. This stand has experienced a recent increase in sugar maple: 90% of them are  $\leq 10$  inches DBH, 46% of the oaks are  $\geq 10$  inches DBH. Modern increases in sugar maple are reported commonly (Bryant et al. 1993).
5. Eave Springs Ravine 05-04, Meigs County, on Eave Springs Rd. 0.2 miles west from Rt. 304, dominants *Quercus alba*—*Q. prinus*. Some past stock grazing possible, modern deer browse probable. Bedrock: Knox dolomite, soil: Fullerton series. Martin (1971) reported two forms of this community on the Knox; the white oak type 53 is reported to be common (Eyre 1980), A *Quercus alba* Montane Forest Alliance is reported by Weakley et al. (1998).
6. Oxford Hollow Rd. 02-272, Claiborne County, on the Oxford Hollow Rd. 1.7 miles east of Goin Rd., *Quercus alba*—mixed *Quercus* dominated. Some past stock grazing and modern deer browse possible. Bedrock: Knox dolomite, soil: Fullerton series. This area contained a seep with *Carex* spp., *Glyceria striata* and *Oxypolis rigidior* and some additional mesophytes.
7. Manis Rd. 05-03 Roane County, on Manis Rd. 1.1 mile east from Rt. 304. *Quercus alba*—*Q. coccinea* dominated. Some past stock grazing and present deer browse probable. Bedrock: Knox dolomite, soil: Fullerton series. The white oak type 53 is noted as common by Eyre (1980) and Martin (1971) described the white oak-scarlet oak variant. Two types of *Quercus alba*—*Q. coccinea* forests are noted in Weakley (1998).
8. Montgomery Hollow Rd., 02-325, Hancock County on Montgomery Hollow Rd. 1.4 miles north from Rob Camp Rd. *Quercus alba*—other *Quercus* dominated. Bedrock: Knox dolomite, soil: Clarksville series. Site is owned by Claude Calvin; it is fenced and pastured.
9. Gordon Hollow Rd. 05-06, Roane County, on Gordon Hollow Rd. 0.6 mile east from Rt. 304, *Quercus alba*—*Q. falcata* dominated. Past stock grazing probable and present deer browse occurring. Bedrock: Knox dolomite, soil: Fullerton series. Martin (1971) reported a white oak-southern red oak variant. Weakley et al. (1998) noted a *Quercus alba*—*Q. falcata*—*Q. stellata*—*Nyssa* Forest.
10. Chestnut Grove Rd. 02-266, Claiborne County, on Chestnut Grove Rd. 0.7 miles south from Keck Rd., *Quercus alba*—*Q. coccinea*—*Q. velutina* dominated. Bedrock: Knox dolomite, soil: Clarksville series. Currently fenced and grazed and current deer browse probable. Martin (1971) and Weakley et al. (1998) note similar types.
11. Cupp Ridge Rd., 02-274, Claiborne County, Cupp Ridge Rd. at Daniel's Hollow Rd., *Quercus velutina*—*Oxydendron arboreum*, *Q. alba* dominated. Past stock grazing and present deer browse probable. Bedrock: Knox dolomite, soil: Fullerton series. This may be the Society's black oak type 110 (Eyre 1980). Martin (1971) described a black oak—scarlet oak community.
12. Grigsby Hollow Rd., 05-02, Roane County, Grigsby Hollow Rd., 0.7 miles from Rt. 304, *Quercus alba*—mixed *Quercus* dominated. Past stock grazing and present deer browse probable. Bedrock: Knox dolomite, soil: Fullerton series.
13. Rt. 33 at old Rt. 33, 05-01, Union County, at the northwest corner of this junction, north of Maynardville, *Quercus alba*—mixed *Quercus* dominated. Past stock grazing and present deer browse probable. Bedrock: Kingsport Formation of the Knox Group, soil: Fullerton series.
14. Rt. 33 at South edge of Claiborne County, 99-212, Union County, 0.5 mile south of Claiborne County line, mixed *Quercus* dominated. Past stock grazing and current deer browse probable. Bedrock: Chickamauga limestone, soil: Rough stony land—Talbot soil material. Two sinkholes are on this site.

15. Wilco Rd. Off Rt. 33, 99-190, Union County, on top of Hinds Ridge, north of Maynardville. Mixed *Quercus* dominated. Past stock grazing and current deer browse probable. Bedrock: Knox dolomite, soil: Clarksville series. Old machinery storage current. R. G. Williams current owner. Bedrock: Knox dolomite, soil: Clarksville series.
16. Winson Rd., 02-262, Claiborne County, at end of Winson Rd. off Goin Rd., off Eason Ridge Rd. west from Rt. 33 near Carr Branch, *Quercus prinus*—mixed *Quercus*—*Oxydendron arboreum* dominated. Currently fenced and grazed. Bedrock: Knox dolomite, soil: Fullerton series. Several variants of *Quercus prinus* forests were reported by Martin (1971); the chestnut oak type 44 is widespread according to Eyre (1980) and Weakley et al. (1998).
17. Woody Hill Rd. 05-05, Roane County, on Woody Hill Rd. 0.5 miles south from Manis Rd., the fork at 1.2 miles from east from Rt. 304. Dominated by *Quercus prinus*—mixed *Quercus*. Past stock grazing and current deer browse probable. Bedrock: Knox dolomite, soil: Fullerton series.
18. Heath Rd., 02-267, Claiborne County, on Heath Rd. east from Bunch Hollow Rd. about one mile west from Ford Chapel. This spur ridgetop is dominated by *Quercus prinus*—*Nyssa sylvatica*. Currently fenced and grazed. Bedrock: Knox dolomite, soil: Clarksville series.
19. Little Valley Rd., 04-12, Claiborne County, on Little Valley Rd. 0.5 miles south from Cedar Fork Rd. at Gibson Hall. Dominants were mixed calcareous *Quercus* (*Q. muhlenbergii* and *Q. shumardii*)—*Juniperus virginiana*. An old fence bordered the stand indicating past stock grazing and present deer browse is probable. Bedrock: Knox dolomite, soil: Fullerton series. Martin reported a yellow oak-eastern redcedar type (Martin 1971). Weakley et al. (1998) listed *Quercus muhlenbergii* (*Acer saccharum*) Forest Alliance to which this stand may be related.
20. Blythe Ferry Bluff, 03-05, Meigs County, a bluff over the Tennessee River just upstream of the former river ferry site. Site dominated by *Juniperus virginiana*—calcareous oaks (*Quercus muhlenbergii*, *Q. shumardii*). The site was formerly part of the Blythe Ferry Goose Management Area, but after 2003, it became part of the Cherokee Removal Park. Trees 10 inches DBH or greater were *Juniperus* 6 stems (14% of *Juniperus*), *Quercus* 4 stems (33% of *Quercus*). Most *Juniperus* were smaller. The cause of the flurry of *Juniperus* reproduction was unknown. Bedrock: Newalla Formation, soil: Rockland.
21. Blythe Ferry Ridge, 03-04, Meigs County, the ridge over the Tennessee River just upstream of the former river ferry site and just upslope of the bluff (site 20). Dominants were *Juniperus virginiana*—calcareous *Quercus* (*Q. shumardii* and *Q. muhlenbergii*)—*Fraxinus americana*. Human history and recognition as known forest types are as in site 20. Reproductive history was similar, trees proportions equal to or over 10 inches DBH were *Juniperus* 5% of *Juniperus*, calcareous *Quercus* 43%, *Carya carolina-septentrionalis* 27%, *Fraxinus americana* none. Most *Juniperus* and *Fraxinus* stems were small. Here again was a flurry of *Juniperus* and *Fraxinus* reproduction the causes of which were uncertain.
22. Line Rd. 04-19, Hancock County, a bluff and cliff on Line Rd. in Dry Valley 0.2 mile north from Big Springs Rd., one mile west from Horton Ford Bridge on the Clinch River. Dominants were *Juniperus virginiana*—calcareous oaks (*Quercus muhlenbergii* and *Q. shumardii*)—*Fraxinus americana*. Past stock grazing, present deer browsing, and within-the-decade *Quercus* logging were probable. Bedrock: Chickamauga limestone, soil: Rock outcrop, Talbott material. *Juniperus* types were well known in past literature (see stands 20 and 21).

## Appendix II

### Oak Forest Flora Site codes follow numbers in Appendix I

- Acalypha graciliens* A. Gray – 17.  
*A. virginica* L. – 17.  
*Acer negundo* L. – 2, 4, 9.  
*A. rubrum* F. Michx. – 1, 2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18.  
*A. saccharum* Marshall – 3, 4, 5, 6, 8, 10, 11, 13, 14, 15, 16, 18, 19, 20, 21.  
*Actaea pachypoda* Elliott – 5, 14, 15.  
*Adiantum pedatum* L. – 4, 5.  
*Aesculus flava* Aiton – 5, 6, 19.  
*Agalinus tenuifolia* (Vahl.) Raf. – 20.  
*Agastache nepetoides* (L.) Kuntz – 11.  
*Ageratina altissima* (L.) R. M. King & H. Rob. (*Eupatorium*) – 3, 4, 5, 6, 8, 10, 15, 16, 19, 22.  
*A. aromatica* (L.) Spach. (*Eupatorium*) – 4, 5, 6, 7, 12, 13, 17.  
*Agrimonia pubescens* Wallr. – 10, 12, 14, 19, 21.  
*A. rostellata* Wallr. – 3, 4, 6, 14.  
*Agrostis gigantea* Roth – 2, 3.  
*A. perennans* (Walter) Tuck. – 6, 8, 12, 17.  
*Allium cernuum* Roth – 1, 20, 21.  
*Ambrosia trifida* L. – 19.  
*Amelanchier arborea* (F. Michx.) Fernald – 3, 6, 7, 8, 10, 11, 17, 18.  
*Ampelopsis cordata* Michx. – 2, 5.  
*Amphicarpaea bracteata* (L.) Fernald – 1, 4, 5, 6, 9, 10, 11, 12, 14, 15, 16, 19.  
*Andropogon gerardii* Vitman – 20, 21.  
*A. gyrans* Ashe – 17.  
*A. ternarius* Michx. – 7.  
*A. virginicus* L. – 3, 7, 8, 12, 14, 15, 17, 20.  
*Anemone quinquefolia* L. – 9.  
*A. virginiana* L. – 3, 4, 5, 6, 8, 9, 10, 11, 12, 13, 16, 18, 19, 20, 21.  
*Anemonella thalictroides* (L.) Spach. – 5, 6, 14, 16, 19, 20, 21.  
*Angelica venenosa* (Greenway) Fernald – 8, 9, 17.  
*Antennaria plantaginifolia* (L.) Richardson – 5, 6, 7, 9, 10, 13, 16, 17, 18.  
*Apios americana* Medic. – 1, 12.  
*Apocynum cannabinum* L. – 3, 8, 10.  
*Aquilegia canadensis* L. – 4, 10, 19.  
*Arabis laevigata* (Muhl.) Poir. – 4, 5, 6, 8, 15, 19, 20, 21.  
*A. patens* Sull. – 4.  
*Aralia spinosa* L. – 15.  
*Arenaria serpyllifolia* L. – 20, 21.  
*Arisaema dracontium* (L.) Schott. – 19.  
*A. triphyllum* (L.) Schott. – 4.  
*Aristida purpureascens* Poir. – 7, 17.  
*Arnoglossum atriplicifolium* (L.) H. Rob. (*Cacalia*) – 6, 9, 19.  
*Aruncus dioicus* (Walter) Fernald – 5.  
*Asarum canadense* L. – 9.  
*Asclepias amplexicaulis* Sm. – 7.  
*A. quadrifolia* Jacq. – 20.  
*A. sp.* – 3, 12, 17.  
*A. syriaca* L. – 22.  
*A. tuberosa* L. – 6, 14.  
*Asimina triloba* (L.) Dunal – 1, 2, 4, 14.  
*Asplenium montanum* Willd. – 4.  
*A. platyneuron* (L.) BSP – 2, 4, 5, 6, 8, 10, 11, 12, 14, 16, 18, 22.  
*A. resiliens* Kunze – 4, 21.  
*Athyrium felix-foemina* (L.) Roth subsp. *asplenioides* (Muhl.) Hulten – 12.  
*Aureolaria laevigata* (Raf.) Raf. – 6, 8, 10, 13.  
*A. virginica* (L.) Pennell – 6.  
*Berberis canadensis* Mill. – 2.  
*Berchemia scandens* (Hill) K. Koch. – 1, 3, 20.  
*Bidens aristosa* (Michx.) Britton – 18.  
*B. bipinnata* L. – 19, 22.  
*B. frondosa* L. – 1.  
*B. sp.* – 2, 8, 12, 19.  
*Bignonia capreolata* L. – 1, 2, 3, 4, 9, 12, 19, 21.  
*Boehmeria cylindrica* (L.) Sw. – 1, 2, 5.  
*Botrichium dissectum* Spreng. – 9, 12.  
*B. virginianum* (L.) Sw. – 3, 4, 5, 9, 10, 11, 12, 16, 18, 19.  
*Brickellia eupatorioides* (L.) Shinners (*Kuhnia*) – 7, 20.  
*Bromus pubescens* Muhl. – 11, 14, 19, 21.  
*B. racemosus* L. – 8, 22.  
*Buglossoides arvensis* (L.) I. M. Johnston (*Lithospermum*) – 1, 3, 8, 9, 21.  
*Calamintha nepeta* (L.) Savi (*Satureja*) – 20, 21.  
*Camassia scilloides* (Raf.) Cory – 2, 19.  
*Campanulastrum americanum* (L.) Small (*Campanula*) – 19.  
*Campanula divaricata* Michx. – 12.  
*Campsis radicans* (L.) Seem. ex Bureau – 1, 2, 3, 4, 5, 11, 14, 19, 22.  
*Cardamine hirsuta* L. – 4.  
*Carex aureolensis* Steudel – 2.  
*C. blanda* Dewey – 1, 2, 3, 5, 6, 11, 13, 14, 18.  
*C. caroliniana* Schweinitz – 4.  
*C. cephalophora* Muhl. ex Willd. – 3, 6, 11.  
*C. communis* L. H. Bailey – 8.  
*C. comosa* Boott – 1.  
*C. complanata* Torrey & Hooker – 6.  
*C. crinita* Lam. – 1.  
*C. debilis* Michx. – 1.  
*C. eburnea* Boott – 20, 21.  
*C. echinata* Murray – 22.  
*C. festucacea* Schkuhr. – 1, 7.  
*C. flaccosperma* Dewey – 3.  
*C. frankii* Kunth – 1.  
*C. gracilescens* Steud. – 6.

- C. gracillima* Schwein – 1.  
*C. grvida* L. H. Bailey – 9.  
*C. grayi* J. Carey – 1.  
*C. grisea* Wahlenb. – 14.  
*C. hirsutella* Mack. – 1, 3, 9, 12, 13, 14.  
*C. intumescens* Rudge – 1.  
*C. joorii* L. H. Bailey – 2.  
*C. kraliana* Naczi & Bryson – 4, 6, 10, 14, 19.  
*C. laxiflora* Lam. – 14.  
*C. leptonervia* (Fernald) Fernald – 5.  
*C. meadii* Dewey – 1.  
*C. nigromarginata* Schwein. – 4, 6, 8, 9, 14, 16.  
*C. pensylvanica* Lam. – 10, 11.  
*C. pigra* Naczi – 2, 3, 6, 15.  
*C. planispicata* Naczi – 15.  
*C. retroflexa* Willd. – 3, 19.  
*C. rosea* Schkuhr ex Willd. – 12, 14,  
*C. scoparia* Schkuhr – 1.  
*C. squarrosa* L. – 2.  
*C. styloflexa* Buckley – 13, 14.  
*C. swanii* (Fernald) Mack. – 11, 18.  
*C. tribuloides* Wahlenb. – 1.  
*C. typhina* Michx. – 2.  
*C. umbellata* Schkuhr ex Willd. – 6, 10, 11, 16.  
*C. venusta* Dewey – 17.  
*C. vulpinoidea* Michx. – 1, 2.  
*Carpinus caroliniana* Walter – 1, 2, 4, 5, 6, 12, 14, 16,  
19.  
*Carya carolinae-septentrionalis* (Ashe) Engelm. &  
Graebn. – 20, 22.  
*C. cordiformis* (Wangen.) K. Koch – 1.  
*C. glabra* (Mill.) Sweet – 1, 3, 4, 6, 7, 8, 9, 10, 11, 12,  
13, 15, 16, 17, 18, 19, 22.  
*C. ovata* (Mill.) K. Koch – 3, 5, 8, 11, 13, 15, 16, 17.  
*C. pallida* (Ashe) Engelm. & Graebn. – 11.  
*C. tomentosa* (Poir.) Nutt. – 4, 5, 7, 12, 15, 17, 19.  
*Castanea dentata* (Marshall) Borkh. – 17.  
*Ceanothus americana* L. – 3, 9, 12, 14, 16, 20, 21.  
*Celastrus scandens* L. – 8, 19, 20, 22.  
*Celtis laevigata* Willd. – 2.  
*C. occidentalis* L. – 1, 2, 3, 5, 8, 9, 12, 14, 16, 19, 22.  
*C. tenuifolia* Nutt. – 20, 21, 22.  
*Cephalanthus occidentalis* L. – 2.  
*Cercis canadensis* L. – 3, 4, 5, 8, 10, 11, 12, 13, 14, 15,  
16, 19, 21, 22.  
*Chaerophyllum tainturieri* Hook. – 4, 19, 21.  
*Chamaecrista fasciculata* (Michx.) Greene (*Cassia*) – 4,  
12, 15, 17.  
*C. nictitans* (L.) Moench. (*Cassia*) – 7, 8, 11, 13, 17, 18.  
*Chamaesyce nutans* (Lag.) Small (*Euphorbia*) – 22.  
*Chasmanthium latifolium* (Michx.) H. O. Yates – 9.  
*Cheilanthes lanosa* (Michx.) D. C. Eaton – 22.  
*Chelone glabra* L. – 1, 5.  
*Chimaphila maculata* (L.) Pursh – 3, 4, 5, 6, 7, 8, 10, 11,  
12, 13, 14, 15, 17, 18.  
*Chrysopsis mariana* (L.) Elliott – 6, 7, 8, 17.  
*Cimicifuga racemosa* (L.) Nutt. – 4, 6, 11, 13, 14, 15, 16,  
18.  
*Cinna arundinacea* L. – 1, 2.  
*Circaea lutetiana* (L.) Asch & Magnus subsp.  
*canadensis* (L.) Asch & Magnus – 5, 17.  
*Clematis viorna* L. – 6, 19, 22.  
*C. virginiana* L. – 5, 6, 13, 19, 21, 22.  
*Clitoria mariana* L. – 8, 12.  
*Cocculus carolinus* (L.) DC – 1, 19.  
*Collinsonia verticillata* Baldwin ex Elliott – 5, 12.  
*Conopholis americana* (L.) Wallr. – 9, 13, 14.  
*Coreopsis major* Walter – 5, 6, 7, 8, 10, 11, 12, 13, 14,  
15, 16, 17, 18.  
*C. verticillata* L. – 7, 10, 17.  
*Cornus florida* L. – 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13,  
14, 15, 16, 17, 18, 19, 22.  
*C. foemina* Mill. – 12.  
*Corylus americana* Walter – 1, 5, 6.  
*Crataegus marshallii* Eggl. – 1.  
*C. pruinosa* (H. L. Wendl.) K. Koch – 3.  
*C. sp.* – 14.  
*Croton monanthogynous* Michx. – 20.  
*Cryptotaenia canadensis* (L.) DC – 6, 11, 18, 19.  
*Cunilla origanoides* (L.) Britton – 10.  
*Cuscuta* sp. – 22.  
*Cynoglossum virginianum* L. – 3, 5, 8, 9, 14.  
*Cystopteris bulbifera* (L.) Bernhardt – 12.  
*C. protrusa* (Weath.) Blasdel – 4.  
*Daucus carota* L. – 19, 22.  
*Dennstaedtia punctilobula* (Michx.) T. Moore – 12.  
*Dentaria diphylla* Michx. – 3, 13, 15.  
*Descurania pinnata* (Walter) Britton subsp. *brachycarpa*  
(Richardson) Detling – 20, 21.  
*Desmodium canescens* (L.) DC – 5.  
*D. ciliare* (Muhl. ex Willd.) DC – 7, 10, 13, 17, 20, 21.  
*D. glutinosum* (Muhl. ex Willd.) A. Wood – 4, 14, 22.  
*D. laevigatum* (Nutt.) DC – 8, 12, 17.  
*D. marilandicum* (L.) DC – 7, 8, 10, 17.  
*D. nudiflorum* (L.) DC – 5, 6, 8, 9, 10, 11, 12, 13, 14, 15,  
16, 18.  
*D. obtusum* (Muhl. ex Willd.) DC – 22.  
*D. paniculatum* (L.) DC var. *dillenii* (Darl.) Isley – 2, 3,  
5, 8, 10, 13, 15, 22.  
*D. paniculatum* (L.) DC var. *paniculatum* – 3, 5, 7, 8, 9,  
10, 11, 13, 15, 19, 22.  
*D. pauciflorum* (Nutt.) DC – 1, 5, 10, 14.  
*D. rotundifolium* DC – 8, 13, 18.  
*D. viridiflorum* (L.) DC – 7, 8, 12, 13, 17, 22.  
*Dianthus armeria* L. – 9, 19, 22.  
*Dichantheium aciculare* (Desv. ex Poir) Gould & C. A.  
Clark subsp. *angustifolium* (Elliott) Freeman &  
Lelong – 13.  
*D. acuminatum* (Sw.) Gould & C. A. Clark subsp.  
*acuminatum* – 3, 12, 13, 14.  
*D. acuminatum* (Sw.) Gould & C. A. Clark subsp.  
*fasciculatum* (Torr.) Freckmann & Lelong – 6.  
*D. acuminatum* (Sw.) Gould & C. A. Clark subsp.  
*leucothrix* (Nash) Freckmann & Lelong – 1.  
*D. acuminatum* (Sw.) Gould & C. A. Clark subsp.  
*longiligulatum* (Nash) Freckmann & Lelong – 2.  
*D. boscii* (Poir.) Gould & C. A. Clark – 3, 4, 5, 6, 8, 10,  
11, 12, 13, 14, 15, 18, 19, 22.

- D. commutatum* (Schult.) Gould – 3, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18.  
*D. depauperatum* (Muhl.) Gould – 21.  
*D. dichotomum* (L.) Gould subsp. *dichotomum* – 2, 6, 7, 8, 11, 12, 13, 15, 16, 17, 18.  
*D. dichotomum* (L.) Gould subsp. *microcarpon* (Muhl. ex Elliott) Freckmann & Lelong – 3, 4, 6, 7, 8, 10, 11, 12, 13, 15, 16, 17, 18.  
*D. laxiflorum* (Lam.) Gould – 6, 7, 13, 15.  
*D. linearifolium* (Scribn.) Gould – 17.  
*D. ovale* (Elliott) Gould & C. A. Clark subsp. *villosissimum* (Nash) Freckmann & Lelong – 6, 19.  
*D. polyanthes* (Schult.) Mohlenbr. – 7, 8, 15, 17.  
*Diervilla sessilifolia* Buckley var. *rivularis* (Gattinger) Ahles – 4.  
*Digitaria sanguinalis* (L.) Scop. – 22.  
*Diodia teres* Walter – 21.  
*Dioscorea polystachya* Turez. (*D. batatas*) – 1, 2, 8, 11, 16, 18, 19, 22.  
*D. villosa* L. – 1, 3, 4, 5, 6, 7, 9, 10, 12, 14, 16, 20, 22.  
*Diospyros virginiana* L. – 3, 14, 15, 16, 20, 22.  
*Doellingeria infirma* (Michx.) Nees (*Aster*) – 10.  
*Dulichium arundinaceum* (L.) Britton – 1.  
*Elaeagnus umbellata* Thunb. – 12.  
*Elephantopus carolinianus* Rausch – 9, 19.  
*E. tomentosus* L. – 21.  
*Elymus glabriflorus* (Vasey ex L. H. Dewey) Scribn. & Ball – 18.  
*E. hystrix* L. – 6, 8, 10, 19, 21, 22.  
*E. riparius* Wiegand – 1.  
*E. virginicus* L. – 1, 3, 4, 5, 6, 9, 11, 12, 16, 18, 19, 22.  
*Eragrostis spectabilis* (Pursh) Steud. – 12, 17.  
*Erigeron philadelphicus* L. – 4, 5, 6, 8, 13, 15, 18, 19.  
*E. pulchellus* Michx. – 5, 10.  
*E. strigosus* Muhl. ex Willd. – 3, 6, 7, 8, 10, 11, 16, 18, 20.  
*Erythronium americanum* Ker Gawl – 3.  
*Euonymus americana* L. – 1, 2, 3, 5, 6, 7, 9, 10, 12, 14.  
*E. fortunei* (Turez.) Hand.-Muzz. – 4.  
*Eupatorium hyssopifolium* L. – 7, 12, 15, 17.  
*E. perfoliatum* L. – 2.  
*E. purpureum* L. – 3, 12, 17, 18.  
*E. serotinum* Michx. – 15, 16.  
*E. sessilifolium* L. – 13, 15, 16.  
*Euphorbia corollata* L. – 7, 8, 9, 13, 17, 20, 21.  
*E. dentata* Michx. – 7, 14, 22.  
*E. mercurialina* Michx. – 12.  
*Eurybia divaricata* L. (*Aster*) – 4.  
*Fagus grandifolia* Ehrh. – 1, 2, 3, 4, 6, 8, 10, 12, 13, 14, 16, 18.  
*Festuca pretensis* Huds. – 22.  
*F. subverticillata* (Pers.) E. B. Alexi. – 1, 19, 20, 22.  
*Fleischmannia incarnata* (Walter) R. M. King & H. Rob. (*Eupatorium*) – 22.  
*Fragaria virginiana* Duchesne – 3, 6, 8, 9, 10, 11, 13, 14, 19.  
*Fraxinus americana* L. – 1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12, 13, 14, 15, 19, 20, 21, 22.  
*F. pennsylvanica* Marshall – 2.  
*F. quadrangulata* Michx. – 4, 19.  
*Galactia volubilis* (L.) Britton – 3, 7, 8, 9, 13, 17, 20, 21, 22.  
*Galium aparine* L. – 1, 2, 3, 4, 5, 6, 8, 11, 12, 14, 16, 18, 19, 21, 22.  
*G. circaezans* Michx. – 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21.  
*G. obtusum* Bigelow – 2.  
*G. pilosum* Aiton – 5, 8, 10, 11, 12, 13, 14, 15, 16, 17, 18.  
*G. tinctorium* L. – 1.  
*G. triflorum* Michx. – 1, 3, 4, 5, 6, 7, 8, 12, 15, 18, 19, 22.  
*Gamochaeta purpurea* (L.) Cabrera (*Gnaphalium*) – 8, 16.  
*Gaylussacia baccata* (Wangenh.) K. Koch – 7, 9, 17.  
*Geranium carolinianum* L. – 19, 21.  
*G. maculatum* L. – 1, 5, 9, 10, 12.  
*Geum canadense* Jacq. – 1, 2, 3, 4, 5, 6, 8, 9, 11, 12, 13, 14, 15, 18, 19, 21, 22.  
*G. vernum* (Raf.) Torr. & A. Gray – 11, 19.  
*Glecoma hederacea* L. – 3.  
*Gleditsia triacanthos* L. – 9, 11, 22.  
*Glyceria striata* (Lam.) Hitchc. – 1, 2, 6.  
*Goodyera pubescens* (Willd.) R. Br. – 7, 9, 11, 12, 13.  
*Gratiola neglecta* Torr. – 2.  
*G. virginiana* L. – 2.  
*Hamamelis virginiana* L. – 12.  
*Helianthus angustifolius* L. – 12, 17.  
*H. hirsutus* Raf. – 16.  
*H. microcephalus* Torr. & A. Gray – 5, 6, 7, 11, 13, 15, 16, 18, 20, 21.  
*Hepatica acutiloba* DC – 4.  
*H. americana* (DC) Ker Gawl – 5, 12.  
*Heuchera americana* L. – 5, 6, 8, 12, 21, 22.  
*H. villosa* Michx. – 4, 5, 20.  
*Hexastylis arifolia* (Michx.) Small var. *ruthii* (Ashe) H. L. Bloomq. – 5, 6, 8, 12, 13, 14, 15, 16.  
*Hieracium gronovii* L. – 8, 10, 11, 14, 16.  
*H. venosum* L. – 7, 8, 13, 17.  
*Hordeum pusillum* Nutt. – 22.  
*Houstonia caerulea* L. – 3, 6, 7, 10, 11, 12, 18, 21.  
*H. canadensis* Willd. ex Roem. & Schult. – 11, 14.  
*H. purpurea* L. – 4, 5, 6, 10, 11, 16, 18.  
*Hydrangea arborescens* L. – 5, 12, 16, 20.  
*H. cinerea* Small – 6.  
*Hymenocallis occidentalis* (Le Conte) Kunth. – 1, 9.  
*Hypericum dolabrifforme* Vent. – 20, 21.  
*H. frondosum* Michx. – 20, 21, 22.  
*H. hypericoides* (L.) Crantz – 7, 9, 12.  
*H. mutilum* L. – 6.  
*H. punctatum* Lam. – 3, 4, 5, 7, 8, 9, 10, 11, 12, 15, 16, 17, 18, 19, 22.  
*H. stragulum* P. Adams & N. Robson – 6, 7, 8, 10, 13, 14, 15, 17, 18, 21.  
*Ilex opaca* Aiton – 2, 6, 9.  
*Impatiens capensis* Meerb. – 1, 2, 5, 15.  
*I. pallida* Nutt. – 19, 21, 22.

- Ipomoea pandurata* (L.) G. Mey. – 2, 7, 11, 12, 16, 17, 18, 19, 22.  
*I. purpurea* (L.) Roth – 7.  
*Iris cristata* Aiton – 5, 6, 9, 22.  
*I. pseudacorus* L. – 1.  
*Itea virginica* L. – 1.  
*Jeffersonia diphylla* (L.) Pers. – 19.  
*Juglans cinerea* L. – 21.  
*J. nigra* L. – 1, 4, 5, 6, 7, 8, 9, 10, 11, 13, 14, 15, 16, 18, 19, 21, 22.  
*Juncus coriaceus* Mack. – 2.  
*J. effusus* L. var. *solutus* Fernald & Wiegand – 2.  
*J. interior* Wiegand – 1.  
*J. sp.* – 22.  
*J. tenuis* Willd. – 1, 2, 21.  
*Juniperus virginiana* L. – 1, 2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22.  
*Kalmia latifolia* L. – 5, 17.  
*Krigia biflora* (Walter) S. F. Blake – 5, 6, 7, 8, 10, 11, 13.  
*Lactuca floridana* (L.) Gaertn. – 1, 2, 4, 5, 6, 8, 9, 10, 11, 12, 18, 19, 20, 22.  
*L. serriola* L. – 22.  
*Leersia oryzoides* (L.) Sw. – 1.  
*L. virginica* Willd. – 1, 2, 3, 5, 6, 11, 12, 18.  
*Lespedeza cuneata* (Dun.) G. Don. – 11, 17, 21, 22.  
*L. hirta* (L.) Hernem. – 7, 8, 10, 13, 17.  
*L. intermedia* (S. Watson) Britton – 2, 4, 5, 6, 7, 8, 10, 11, 13, 14, 15, 16, 17, 18, 19, 21.  
*L. procumbens* Michx. – 3, 6, 7, 8, 9, 12, 13, 15, 17, 20, 21.  
*L. repens* (L.) Barton – 7, 8, 9, 13, 17, 20, 21.  
*L. violacea* (L.) Pers. – 8, 11, 19.  
*L. virginica* (L.) Britton – 10, 17.  
*Leucanthemum vulgare* Lam. (*Chrysanthemum*) – 22.  
*Ligustrum sinense* Lour. – 1, 2, 3, 4, 5, 8, 9, 10, 11, 12, 14, 18, 19, 20, 21.  
*Lindera benzoin* (L.) Blume – 1, 4, 6, 9, 12, 16.  
*Linum medium* (Planch.) Britton var. *texanum* (Planch.) Fernald – 7, 8, 10, 11, 12, 13, 16, 17.  
*Liparis liliifolia* (L.) Rich. ex Lindl. – 10.  
*Liquidambar styraciflua* L. – 1, 2, 3, 4, 5, 9, 12, 17, 20.  
*Liriodendron tulipifera* L. – 1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12, 13, 15, 16, 17, 18, 19, 21, 22.  
*Lithospermum canescens* (Michx.) Lehm. – 19, 20, 21.  
*Lobelia cardinalis* L. – 1, 2.  
*L. inflata* L. – 1, 3, 4, 6, 10, 11, 12, 15, 16, 17, 18.  
*L. puberula* Michx. – 5, 12, 17.  
*L. spicata* Lam. – 20, 21.  
*Lonicera fragrantissima* Lind. & Paxton – 21.  
*L. japonica* Thunb. – 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22.  
*L. maackii* (Rupr.) Maxim. – 21.  
*Ludwigia alternifolia* L. – 2.  
*L. palustris* (L.) Elliott – 1.  
*Luzula acuminata* Raf. – 12.  
*L. bulbosa* (A. Wood) Smyth – 5, 6, 12.  
*L. echinata* (Small) F. J. Herm. – 11.  
*Lycopodium digitatum* Dill. – 12.  
*Lycopus virginicus* L. – 1, 2.  
*Lysimachia ciliata* L. – 8, 13.  
*L. lanceolata* Walter – 3.  
*L. quadriflora* Sims. – 12.  
*L. tonsa* (A. Wood) K. Kunth. – 8, 15.  
*Magnolia acuminata* (L.) L. – 14.  
*Mahonia* sp. – 21.  
*Maianthemum racemosum* (L.) Link (*Smilacina*) – 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 14, 15, 16, 18.  
*Manfreda virginica* (L.) Rose (Agave) – 20, 21.  
*Matelea* sp. (*Gonobolus*) – 3, 4, 14.  
*Medicago lupulina* L. – 8, 22.  
*Melica mutica* Walter – 20.  
*Melilotus alba* Medic. – 22.  
*M. officinalis* (L.) Pall. – 14.  
*Menispermum canadense* L. – 1, 3, 4, 22.  
*Microstegium vimineum* (Trin.) A. Camus – 1, 2, 3, 5, 6, 9, 11, 12, 13, 14, 15, 16, 17, 18.  
*Mimulus alatus* Aiton – 2.  
*Mitella diphylla* L. – 6.  
*Monarda fistulosa* L. – 6, 8, 9, 21.  
*Morus rubra* L. – 1, 3, 6, 8, 9, 10, 11, 13, 15, 16, 18, 19, 20, 22.  
*Muhlenbergia schreberi* J. F. Gmel. – 11, 16, 22.  
*M. sobolifera* (Muhl.) Trin. – 6, 19.  
*M. tenuiflora* (Willd.) BSP – 6, 14.  
*Nyssa sylvatica* Marshall – 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 22.  
*Opuntia humifusa* (Raf.) Raf. – 20, 21.  
*Orbexilum onobrychis* (Nutt.) Rydb. (*Psoralea*) – 19.  
*Osmunda cinnamomea* L. – 3, 12.  
*O. regalis* L. – 6.  
*Ostrya virginiana* (Mill.) K. Koch – 4, 12, 14, 20, 21, 22.  
*Oxalis dillenii* Jacq. – 6, 8, 9, 10, 14, 18, 21, 22.  
*O. stricta* L. – 2, 3, 7, 8, 13, 14.  
*O. violacea* L. – 3, 6, 8, 9, 13, 15, 18, 19.  
*Oxydendrum arboreum* (L.) DC – 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18.  
*Oxypolis rigidior* (L.) Raf. – 6.  
*Packera anonyma* (A. Wood) W. H. Weber & A. Love (*Senecio*) – 7, 8, 9, 10, 13, 15, 17, 18.  
*P. aurea* (L.) A. Love & D. Love (*Senecio*) – 20, 21.  
*P. glabella* (Poir.) C. Jeffrey (*Senecio*) – 1.  
*P. obovata* (Muhl.) W. A. Weber & A. Love (*Senecio*) – 4.  
*Panicum anceps* Michx. – 9, 12, 17.  
*P. bicknellii* putative hybrid – 7.  
*P. capillare* L. – 22.  
*P. flexile* (Gatt.) Scribn. – 20.  
*Parthenocissus quinquefolia* (L.) Planch. – 1, 2, 3, 4, 6, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 21, 22.  
*Passiflora lutea* L. – 3, 9, 12, 18.  
*Pellea atropurpurea* (L.) Link – 4, 10, 19, 20, 21.  
*Penstemon canescens* (Britton) Britton – 15.  
*P. laevigatus* (L.) Aiton – 4, 5, 6, 8, 10, 11, 20, 21, 22.  
*P. sp.* – 14, 16.  
*Penthorum sedoides* L. – 2.  
*Phegopteris hexagonoptera* (Michx.) Fee – 5.  
*Philadelphus hirsutus* Nutt. – 4.



- P. pubescens* Loisel. – 21.  
*Phlox divaricata* L. – 8, 14.  
*P. glaberrima* L. – 6.  
*P. pilosa* L. – 9.  
*Phryma leptostachya* L. – 3, 4, 9, 11, 12, 13, 16, 18.  
*Physalis pubescens* L. – 19.  
*P. virginiana* Mill. – 4, 15, 17.  
*Phytolacca americana* L. – 19, 22.  
*Pilea pumila* (L.) A. Gray – 1, 2, 6.  
*Pinus echinata* Mill. – 3, 5, 7, 9, 11, 13, 14, 17.  
*P. strobus* L. – 5, 10, 12.  
*P. virginiana* Mill. – 3, 4, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 20, 21.  
*Pityopsis graminifolia* (Michx.) Nutt. (*Chrysopsis*) – 4, 7, 17.  
*Platanus occidentalis* L. – 4, 5, 6.  
*Pleopeltis polypodioides* (L.) Andrews & Windham subsp. *michauxiana* (Weatherby) Andrews & Windham (*Polypodium*) – 3, 4, 20, 21.  
*Poa annua* L. – 3.  
*P. autumnalis* Muhl. ex Elliott – 8, 21.  
*P. compressa* L. – 5, 8, 10.  
*P. cuspidata* Nutt. – 4, 6, 8, 20, 21.  
*P. pratensis* L. – 2, 10, 14.  
*Podophyllum peltatum* L. – 1, 3, 4, 5, 8, 9, 11, 12, 13, 15, 16, 18.  
*Polygonatum biflorum* (Walter) Elliott – 4, 5, 6, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 20, 21.  
*Polygonum amphibium* L. var. *emersum* Michx. – 1.  
*P. convolvulus* L. – 19, 22.  
*P. hydropiperoides* Michx. – 1.  
*P. pennsylvanicum* (L.) Small – 1.  
*P. scandens* L. – 16.  
*P. virginianum* L. – 1, 4, 5, 15.  
*Polymnia canadensis* L. – 22.  
*Polystichum acrostichoides* (Michx.) Schott – 1, 3, 4, 5, 6, 8, 9, 10, 11, 12, 14, 16, 18.  
*Porteranthus trifoliata* (L.) Britton (*Gillenia*) – 8, 10.  
*Potentilla canadensis* L. – 3, 5, 6, 7, 8, 9, 11, 12, 13, 14, 15, 16, 17, 18, 19.  
*P. recta* L. – 3, 22.  
*P. simplex* Michx. – 3, 12, 16, 18, 21.  
*Prenanthes altissima* L. – 5, 6, 12, 15, 16, 18.  
*P. serpentaria* Pursh – 8, 9, 10.  
*P. sp.* – 13.  
*P. trifoliata* (Cass.) Fernald – 10.  
*Prosartes maculata* (Buckley) A. Gray (*Disporum*) – 16.  
*Prunella vulgaris* L. var. *lanceolata* (Barton) Fernald – 3, 5, 8, 10, 11, 12, 13, 15, 16, 17, 18.  
*Prunus serotina* Ehrh. – 1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 20, 21.  
*Pseudognaphalium obtusifolium* (L.) Hilliard & B. L. Burt. (*Gnaphalium*) – 5, 7, 8, 10, 11, 13, 13, 16, 17, 18.  
*Ptelea trifoliata* (L.) Raf. – 20, 21, 22.  
*Pteridium aquilinum* (L.) Kuhn – 9, 13, 17.  
*Pycnanthemum incanum* (L.) Michx. – 8.  
*P. pycnanthemoides* (Leavenw.) Fernald – 3, 5, 6, 8, 9, 11, 12, 13, 15, 17.  
*Pyrus calleryana* Decne – 10.  
*Quercus alba* L. – 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 17, 18, 21.  
*Q. coccinea* Muenchh. – 5, 6, 7, 8, 10, 11, 13, 15, 16, 17, 18.  
*Q. falcata* Michx. – 1, 3, 6, 7, 8, 9, 10, 11, 12, 13, 14, 17, 21.  
*Q. marilandica* Muenchh. – 7, 21.  
*Q. michauxii* Nutt. – 2.  
*Q. montana* Willd. – 5, 9, 11, 12, 13, 15, 16, 17, 18.  
*Q. muehlenbergii* Engelm. – 3, 4, 6, 13, 19, 20, 22.  
*Q. phellos* L. – 1, 2, 3.  
*Q. rubra* L. – 1, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 14, 18.  
*Q. shumardii* Buckley – 14, 19, 20, 22.  
*Q. stellata* Wangenb. – 3, 7, 11, 13, 14, 17, 19.  
*Q. velutina* Lam. – 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18.  
*Ranunculus abortivus* L. – 1, 2, 4.  
*R. bulbosus* L. – 1.  
*R. hispidus* Michx. – 3, 12.  
*R. recurvatus* Poir. – 1, 3, 11, 18.  
*Rhamnus alnifolia* L'Her – 6.  
*R. caroliniana* Walter – 1, 3, 4, 6, 8, 11, 13, 14, 15, 16, 18, 19, 20, 21, 22.  
*Rhododendron canescens* (Michx.) Sweet – 5, 17.  
*R. periclymenoides* (Michx.) Shinners – 1.  
*R. sp.* – 12.  
*Rhus aromatica* Aiton – 13, 19, 20, 22.  
*R. copallina* L. – 3, 7, 8, 12, 13, 15, 17.  
*R. glabra* L. – 9, 10, 21, 22.  
*Rhynchosia tomentosa* (L.) Hook. & H. J. Arn. – 20, 21.  
*Robinia pseudoacacia* L. – 9, 13, 15, 21, 22.  
*Rosa carolina* L. – 20.  
*R. multiflora* Thunb. – 5, 6, 8, 13, 15, 17, 18, 22.  
*R. palustris* Marshall – 1, 2.  
*R. setigera* Michx. – 17.  
*Rubus sp.* – 1, 2, 3, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 21, 22.  
*Rudbeckia fulgida* Aiton – 3, 5, 6, 7, 8, 12.  
*R. hirta* L. – 10, 15.  
*R. triloba* L. – 3, 17.  
*Ruellia caroliniensis* (J. F. Gmel.) Steud. – 3, 9, 10, 13, 14, 19, 20, 21.  
*R. purshiana* Fernald – 14, 22.  
*R. strepens* L. – 19.  
*Sabatia angularis* (L.) Pursh – 6, 20, 21.  
*Saccharum alopecuroides* (L.) Nutt. (*Erianthus*) – 20.  
*Salix nigra* Marshall – 2.  
*Salvia lyrata* L. – 2, 3, 5, 6, 9, 14, 17, 19, 20, 22.  
*S. urticifolia* L. – 14, 20, 21.  
*Sambucus canadensis* L. – 1, 2, 9, 10, 11, 15, 16, 18.  
*Samolus parviflorus* HSK – 3.  
*Sanguinaria canadensis* L. – 5, 8, 9, 19, 20.  
*Sanicula canadensis* L. – 1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 21, 22.  
*Sassafras albidum* (Nutt.) Nees – 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15, 16, 17, 18.  
*Saururus cernuus* L. – 1.  
*Saxifraga virginiana* Michx. – 4.

- Schizachyrium scoparium* (Michx.) Nash – 7, 17, 20.  
*Scirpus atrovirens* Willd. – 2.  
*Scleria oligantha* Michx. – 9.  
*Scutellaria elliptica* Muhl. var. *elliptica* – 3, 6, 11, 13, 14, 18.  
*S. elliptica* Muhl. var. *hirsuta* (Short & R. Peter) Fernald – 5, 7, 8.  
*S. incana* Biehler var. *punctata* (Chapm.) C. Mohr – 5.  
*S. integrifolia* L. – 3, 18.  
*S. ovata* Hill – 20, 21.  
*S. parvula* Michx. – 21.  
*Sedum ternatum* Michx. – 4, 20, 21.  
*Sericocarpus asteroides* (L.) Nees (*Aster*) – 7, 10, 13, 17.  
*Setaria pumila* (Poir.) Roem. & Schult. – 22.  
*Sicyos angulata* L. – 2.  
*Silene antirrhina* L. – 20.  
*S. stellata* (L.) W. T. Aiton – 9.  
*S. virginica* L. – 5, 9, 19, 21, 22.  
*Silphium compositum* Michx. – 17.  
*S. trifoliatum* L. – 6, 19.  
*Sisyrinchium albidum* Raf. – 7.  
*S. angustifolium* Nutt. – 1, 2, 3, 4, 6, 11, 12, 14, 18, 19.  
*Smallanthus uvedalia* (L.) Mack (*Polymnia*) – 4, 9.  
*Smilax bona-nox* L. – 1, 3, 5, 9, 13, 17, 18, 19, 20, 21, 22.  
*S. glauca* Walter – 2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18.  
*S. rotundifolia* L. – 1, 2, 3, 5, 6, 8, 9, 10, 11, 12, 13, 14, 15, 16, 18, 19, 21, 22.  
*Solanum carolinense* L. – 22.  
*Solidago arguta* Aiton var. *caroliniana* A. Gray – 13.  
*S. bicolor* L. – 10.  
*S. caesia* L. – 5, 6, 9, 10, 12, 15, 16, 18.  
*S. canadensis* L. var. *hargerii* Fernald – 1, 2, 3, 7, 9, 15, 18, 19, 22.  
*S. curtisii* Torr. & Gray – 16.  
*S. erecta* Pursh – 5, 8, 10, 12, 17, 21.  
*S. flexicaulis* L. – 4.  
*S. gigantea* Aiton – 19.  
*S. nemoralis* Aiton – 6, 7, 8, 10, 12, 13, 15, 16, 17, 20, 22.  
*S. odora* Aiton – 7, 17.  
*S. speciosa* Nutt. – 7.  
*S. sphacelata* Raf. – 4, 22.  
*S. ulmifolia* Muhl. – 20, 22.  
*Sphenopholis nitida* (Biehler) Scribn. – 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 16, 18.  
*S. obtusata* (Michx.) Scribn. var. *major* (Torr.) Erdman – 10, 12, 16.  
*S. obtusata* (Michx.) Scribn. var. *obtusata* – 3, 5, 6, 11, 19, 20, 21.  
*Spigelia marilandica* L. – 5, 9, 12.  
*Sporobolus clandestinus* (Biehler) Hitchc. – 20, 21.  
*Stachys tenuifolia* Willd. – 1.  
*Stellaria media* (L.) Vill. – 4, 21.  
*S. pubera* Michx. – 5, 6, 12.  
*Stenanthium gramineum* (Ker Gawl.) Morong. – 5.  
*Stylosanthes biflora* (L.) BSP – 17.  
*Symphotrichum cordifolium* (L.) G. L. Nesom (*Aster*) – 5, 9, 19, 22.  
*S. dumosum* (L.) G. L. Nesom (*Aster*) – 7, 12, 17.  
*S. laeve* (L.) A. Love & D. Love var. *concinnum* (Willd.) G. L. Nesom (*Aster*) – 14.  
*S. lanceolatum* (Willd.) G. L. Nesom (*Aster*) – 2, 14.  
*S. lateriflorus* (Willd.) G. L. Nesom (*Aster*) – 1, 2, 3, 4, 5, 6, 8, 10, 12, 14, 15, 18, 19.  
*S. oblongifolium* (Nutt.) G. L. Nesom (*Aster*) – 22.  
*S. ontarione* (Wiegand) G. L. Nesom (*Aster*) – 2, 15, 16.  
*S. oolentangiense* (Riddell) G. L. Nesom (*Aster*) – 12.  
*S. patens* (Aiton) G. L. Nesom (*Aster*) – 7, 8, 17.  
*S. pilosum* (Willd.) G. L. Nesom (*Aster*) – 1, 3, 4, 5, 7, 8, 10, 11, 12, 15, 16, 18, 22.  
*S.rophyllum* (DC) G. L. Nesom (*Aster*) – 4, 8.  
*S. undulatum* (L.) G. L. Nesom (*Aster*) – 5, 7, 8, 9, 10, 12, 13, 14, 18.  
*Taenidia integerrima* (L.) Drude – 22.  
*Tephrosia virginiana* (L.) Pers. – 7, 17.  
*Thalictrum dioicum* L. – 20, 21.  
*T. revolutum* L. – 6, 16.  
*Thaspium barbinode* (Michx.) Nutt. – 4, 6, 20, 21.  
*Thlaspi arvense* L. – 19.  
*Tiarella cordifolia* L. – 4, 5, 12.  
*Tilia americana* L. – 4, 6.  
*Tipularia discolor* L. – 11, 12.  
*Toxicodendron radicans* (L.) Kuntze (*Rhus*) – 1, 2, 3, 4, 5, 9, 10, 12, 13, 17, 18, 19, 20, 21, 22.  
*Tridens flavus* (L.) Hitchc. (*Triodia*) – 19, 20, 21.  
*Trillium luteum* (Muhl.) Harb. – 4, 5, 14.  
*Triosteum angustifolium* L. – 14.  
*T. aurantiacum* E. P. Bicknell – 6.  
*Tsuga canadensis* (L.) Carriere – 13.  
*Ulmus alatus* Michx. – 1, 2, 5, 6, 8, 9, 12, 14, 18, 19, 21, 22.  
*U. americana* L. – 1.  
*U. rubra* Muhl. – 1, 3, 4, 5, 6, 8, 10, 11, 13, 14, 18, 19, 21.  
*Uvularia grandiflora* Sm. – 4, 9.  
*U. perfoliata* L. – 10, 14.  
*U. sessilifolia* L. – 1.  
*Vaccinium arboreum* Marshall – 3, 7, 17, 21.  
*V. pallidum* Aiton – 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 16, 17, 18, 21.  
*V. stamineum* L. – 5, 6, 7, 8, 9, 10, 11, 12, 13, 16, 17, 18.  
*Valerianella radiata* (L.) Dufr. – 14, 22.  
*Verbena urticifolia* L. – 15, 16.  
*Verbesina alternifolia* (L.) Britton – 19, 22.  
*V. occidentalis* (L.) Walter – 8, 9, 15, 18, 19, 20, 21.  
*V. virginica* L. – 4, 5.  
*Vernonia gigantea* (Walter) Trel. – 3, 12, 15.  
*Veronica arvensis* L. – 16, 18.  
*V. hederifolia* L. – 11, 18.  
*Viburnum acerifolium* L. – 10, 18.  
*V. prunifolium* L. – 22.  
*V. rufidulum* Raf. – 3, 4, 5, 8, 9, 10, 14, 19, 20, 21.  
*Vicia caroliniana* Walter – 2, 12.  
*Vinca minor* L. – 6.  
*Viola canadensis* L. – 5, 12, 19.

*V. palmata* L. – 6.  
*V. pedata* L. – 8, 20, 21.  
*V. pubescens* Aiton – 5, 12.  
*V. sororia* Willd. – 5, 6, 9, 10, 11, 16, 18, 19, 21.  
*V. sp.* – 1, 2, 15, 17.  
*Vitis rotundifolia* Michx. – 1, 3, 4, 5, 7, 9, 10, 12, 15, 18,  
19, 20, 21.  
*V. sp.* – 1, 2, 3, 4, 5, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17,  
18, 19, 20.

# FLORA OF SEVERAL EAST TENNESSEE WETLAND VEGETATION STANDS

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**ABSTRACT.** A study of the vascular flora of 20 wetland vegetation sample areas, chiefly in the Valley and Ridge of East Tennessee, has been made. Stands were in bottoms of small tributaries of the Tennessee River and on major streams such as the Conasauga, Hiwassee, Little Tennessee and Powell rivers. Four stands were dominated by marsh vegetation including a sinkhole marsh; one was a shrub stand dominated by *Alnus serrulata*. Other stands were dominated by trees—12 taxa shared dominance among the stands. The total flora was 565 taxa of which 11.0 percent were introduced. A large weed element of both native and introduced taxa was included. Also 50.8 percent were obligate or facultative wet and facultative wetland taxa. Other taxa were either unclassified or upland mesophytes or xeromesophytes—the persistence of which on flood prone sites is problematic.

## INTRODUCTION

The flora of the Southern Appalachians is relatively well known (White 1982, Chester et al. 1993, 1997, Wofford 1989, Wofford and Kral 1993, Wofford and Chester 2002). Regional studies are those of Robinson and Shanks (1959), Webb et al. (1988), and De Selm (in progress). The excellent study of the effects of flooding in woody plants in Henry County should be mentioned (Hall et al. 1946, Hall and Smith 1952). Local studies include those of Van Horn (1986), Bullington (1997), and earlier studies by De Selm and Shanks (1963, 1967) and De Selm (1973, 1984).

Local vegetation studies which included some bottomland sampling are those of Martin (1971), Oxendine (1971), and Hedge (1979). General descriptions of wetland vegetation in the southeastern United States are to be found in Hodges (1998), Richardson (2000), Sharitz and Mitsch (1995), Larson et al. (1981), and Teskey and Hinkley (1977). The anatomical and physiological adaptations and conditions of organ submersion are discussed fully in Kozlowski (1984).

The rapid conversion of bottomlands to agricultural and urban uses has made remaining sites even more valuable. The function and value of streams and watersheds has been the object of much study (Borman and Likens 1979, Johnson and Van Hook 1989, Swank and Crossley 1988, Mitsch and Gosselink 1986, Tiner 2005).

This study was stimulated by examination of 53 wetlands in the Valley and Ridge since 1984 with the knowledge that the brief examination of each site reveals only a fraction of the whole flora. This paper includes data from a year-long examination of 20 sites (in 2006) as well as data from earlier observations on some of them.

## THE STUDY AREA

The Valley and Ridge Physiographic Province extends from the Hudson River valley southward into Alabama (Fenneman 1938). The area of this study lies within the Tennessee and Conasauga River drainages. This part of the Valley is underlain by Paleozoic sandstones, limestones, dolomites and shales all extensively folded and faulted. The resulting erosional valleys and ridges extend in a northwest to southwest direction. The major streams cut across most geologic beds; minor streams may do so or not but more often follow valley trends. Elevations vary from about 800 to 1500 feet (Rodgers 1953, Hardeman 1966). Soils of these bottom sites are mapped in 10 series and described as first bottoms or foot slopes, loamy in texture, deep, grayish, or reddish to brownish, well to poorly drained and subject to flooding, acid to mildly alkaline, flat or

with slopes to about 2% and are classified as Eutrocrepts, Dystochrepts, Haplodulls and Haploquepts (Fox et al. 1958).

The humid temperate climate has precipitation well distributed throughout the year with short, mainly summer, droughts. About 10% of East Tennessee months (1931-1969) had a mild to severe drought (Vaiksnoris and Palmer 1973). Precipitation (mostly rain) averages 44 to 50 inches per year (Dickson 1960, 1931-1960 data) or 47-51 inches (De Selm and Schmidt 2001, 1961-1990 data). By 1950, 24 hour precipitation events of 7.6 inches had been recorded (U.S. Department of Commerce, Weather Bureau 1956). River sites flood most years where water level is not controlled by dams. Stream edges and bottoms are wet in winter and spring.

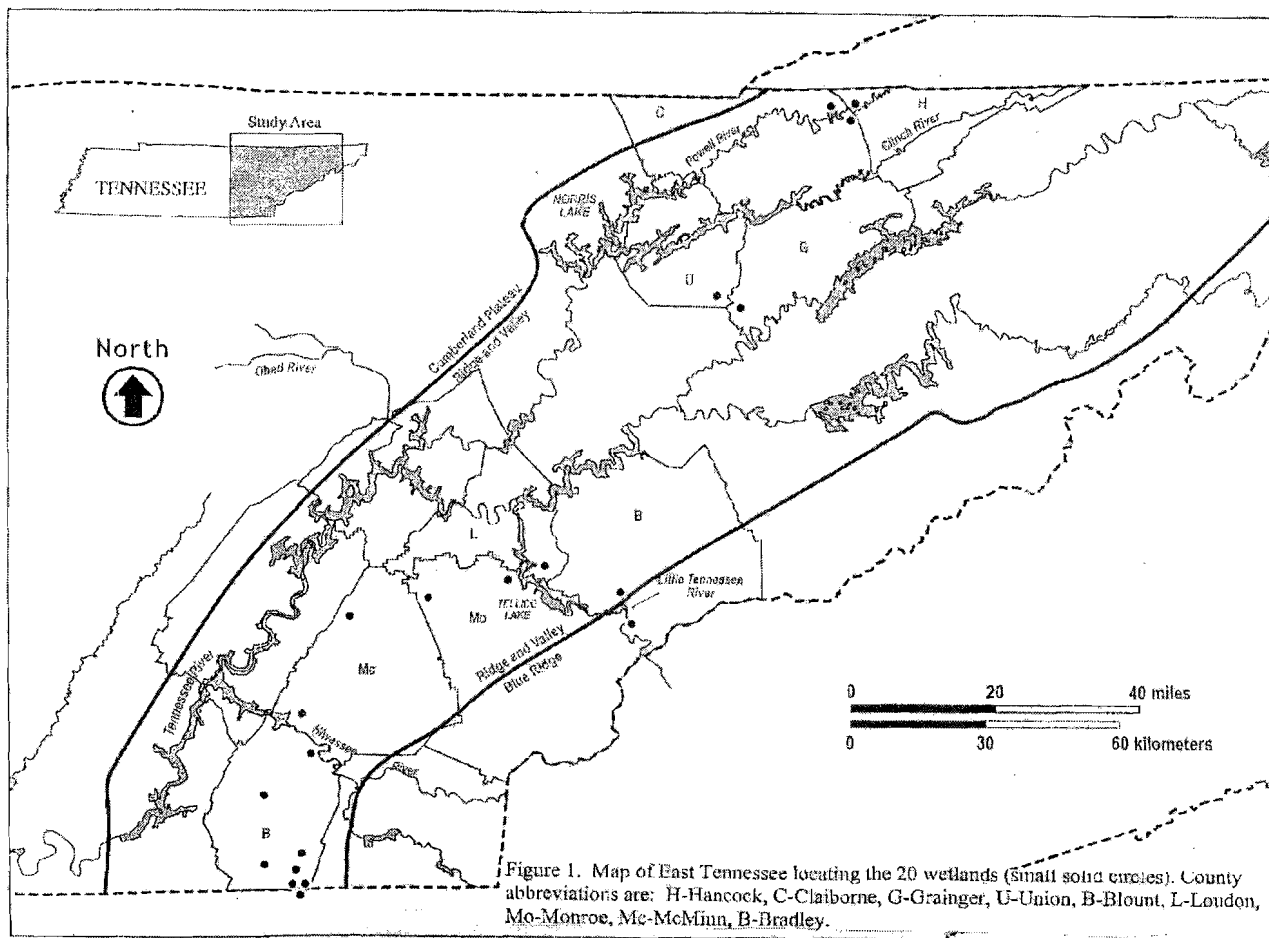
The East Tennessee flora is diverse and well known but the total for the Valley and Ridge is not compiled. The Oak Ridge Reservation flora (842 taxa, Mann et al. 1985) suggests that the valley flora may be large. The vegetation ecology is described in Braun (1950), De Selm (1984), and Stephenson et al. (1993) who considered the study area in the Appalachian Oak Forest Region of the eastern Deciduous Forest.

Graham (1999) discussed the history of the development of the Deciduous Forest flora and vegetation which was influenced by early, long geologic warm periods followed by episodes of Pleistocene cooling and the warm postglacial Hypsithermal, the Little Climatic Optimum and the Little Ice Age (Lamb 1977, Pielou 1991, Stahle and Cleaveland 1994, Fagan 2000, 2004, Wilson et al. 2000, Gribbin 2001, Burroughs 2005). These climatic pulses have been instrumental in facilitating migration of various floristic elements into the flora from near and distant places. Bottomland vegetation would have experienced the cool periods with increased cold air drainage, flooding during wet Pleistocene periods and burial during periods of Pleistocene and early Holocene terrace building (Graham 1999, Delcourt et al. 1993). The entry and expansion of Native American populations locally during the past 10,000 years has included the use of bottoms and terraces for village, fields, and buried grounds; plant gathering was also more extensive in lowlands than on uplands (Lewis and Kneberg 1958, Swanton 1946, Delcourt and Delcourt 1998). After about 1790, the area was opened to European-Americans who, when settling the land, logged the forests, drained some valleys and cultivated row crops in the valleys. Burning and stock grazing were common practices outside crop fields and home sites (Killebrew et al. 1874, Folmsbee et al. 1969). Modern pressures on vegetation include continued logging, grazing by stock and by the growing deer herd (McShea et al. 1997), herb collecting, invasion of wild areas by weeds, and foreign insects and diseases (cf. Nolt et al. 1997, Nash 1999), fire suppression and climate change (Weart 2003, Lovejoy and Hannah 2005).

## METHODS AND SAMPLE AREAS

Twenty stands were selected from a group of 54 wetlands from 12 counties. These 20 stands occurred in nine counties, four were selected in spring, 2006, and the remaining 16 were first examined 1984-2005 (Fig. 1). Selection was based on the variety of overstory dominants, or site conditions and floristic richness. Each stand was examined for a 30-60 minute period about each 21 days March through mid-November. A 100-200 meter transect was paced through each stand and this transect was used to survey each stand per visit. Specimens of unknown plants were collected and determined using Gleason and Cronquist (1991), appropriate volumes of Flora North America (Flora North America Editorial Committee 1993, et seq.), Chester et al. (1993, 1997), Case and Case (1997), Jones (2005), Hicks (1992), Campbell (2002), Isley (1990), McKinney (1997), and Soreng, (2001, 2002, 2003), and Soreng and Pennington (2003). Some nomenclature was checked using Kartesz (1994). Floras were collected and recorded by site.

Site geology was determined from maps in Rodgers (1955) or Hardeman (1966) or more modern state or federal quadrangle geologic maps. Soil series were determined from county soil survey publications. Sites are described briefly in Appendix I.



## RESULTS

The flora of the bottomland sites totaled 565 taxa based on more than 2400 species site records (Appendix II). Here, 11.9 percent were introduced. This total includes six taxa, as *Vitis* sp. (only *V. rotundifolia* was determined to species) and *Rubus* sp. determined only to genus. One liverwort is included. Large families were the Asteraceae (75 taxa), Poaceae (76 taxa) and Cyperaceae (52). Large genera were *Carex* (41 taxa), *Dichanthelium* (11) and *Polygonum* (10). There were 105 woody taxa representing 18.7% of the total flora which is about 26% of the state's woody flora (Wofford and Chester 2002). A few rare taxa occurred (Bailey 2004) including *Cardamine rotundifolia* (State Special Concern), *Carex comosa* (State Threatened), *Gratiola floridana* (State Endangered), *Potamogeton amplifolius* (State Endangered) and *Silphium pinnatifidum* (State Threatened).

In addition several uncommon taxa were collected. For example, *Eichhornia crassipes* was collected at site 15 in 2003 but was not seen there subsequently. *Verbena brasiliensis* was collected at site 12 in Bradley County. This is known all over Georgia (Jones and Coile 1988), but its similarity to *V. bonariensis* speaks for more study. *Trachelospermum difforme* though not an official rare species (Bailey 2004) is rare in East Tennessee and *Trillium catesbaei* is unusual in the Valley and Ridge.

The large number of introduced taxa is of interest. This percentage (11.9%) is much less that of the State flora. (18.6%, Wofford and Kral 1993), but greater than (3.7%) in the mesic forests of the northern Tennessee Valley and Ridge (DeSelm 2006). The bottomland position with flowing water (part of the year to all year

depending on the site) and winter flooding facilitates propagule movement between sites. Propagules are also moved by animals and gravity, and perhaps wind, from adjacent toe-slopes and side-slopes. Many taxa have been introduced by landowners (and their predecessors) or land users, and browsing stock and other forces have likely moved them from site to site. The destruction of the natural vegetation, of drainage gradients, and plantings (e.g. forage plants) have both modified environments and introduced heliophiles into the more open vegetation/periodically disturbed stands. Both introduced and native plants may be classed as weeds, and they compete vigorously with other native plants. The weedy flora consisted of 112 taxa according to Underwood (1965) or 246 taxa according to the Weed Science Society of America (1989). It should be noted that the Society list includes many tree taxa which they class as “weedy”. Nonetheless, a large proportion of the wetland flora is introduced and/or weedy.

Another important element is the recognized wetland species group. The U.S. Fish and Wildlife Service National List of Plant Species that occur in Wetlands (Reed 1997, Jones 2005) have been used to characterize species and floras. Here 12.6% of the native taxa were obligate wetland taxa, 108 (21.7%) were facultative wet taxa and an additional 90 (17.8%) were facultative taxa which may occur in wetlands. In the absence of large, open water areas, many obligate wetlands plants as submerged, floating and emergent macrophytes (illustrated in Beal and Thieret 1986) were absent. Thus, in spite of no large open water areas in the samples, the wetland and facultative taxa fraction totaled to nearly one half of the flora.

The remaining native taxa, were unclassified or classed as upland taxa (Reed 1997, Jones 2005). A few in the writer’s experience occur mainly in uplands in barrens vegetation: *Danthonia spicata* occurred on low mounds at the base of large *Quercus phellos* stems on the Conasauga River bottom, and *Solidago rugosa* subsp. *aspera* occurred bordering the *Alnus* stand on the Little Tennessee River. Perhaps 20% of the unclassified and upland taxa occurred in xeric or subxeric vegetation. A larger proportion, however, occurred in mesic forests adjacent to the wetlands. Examples of mesic understory herbs seen were *Actaea pachypoda*, *Claytonia virginica*, *Iris cristata*, *Phryma leptostachya*, and *Stellaria pubera*.

Stands were ordered on the basis of presumed water availability—distance of surface above summer water level (number in parenthesis in Sites, Appendix I). The occurrence of certain plant groups was compiled across the ordered series. *Polygonum* occurrences were weighted toward the “wet” end which included the four marshes but occurred in 19 of 20 stands. *Juncus* occurrences were distributed similarly. Ferns and fern allies were weighted toward the middle of the series—they occurred in 11 stands. The Cyperaceae (mainly *Carex*) was distributed unevenly across the array though occurrences ranged from one to 18 among all stands. Grass taxa occurred in all stands; occurrences were from four to 14 per stand. Total grass occurrence for the “wet” seven stands was 71, the “middle” six was 55 and the “dry” seven stands was 62; thus they responded somewhat like *Polygonum* and *Juncus*.

Obligate wetland native taxa abundance peaked in the wet marshes and abundance declined irregularly in other stands. Facultative-wet wetland taxa responded similarly. The importance of certain mesic versus wetland tree taxa was also compared across this stand array, but a trend in composition across the array could not be shown. The chosen array of stands was imperfect. No group’s abundance changed regularly across the array. Other factors such as competition, past and current land uses, and intensity and frequency of flooding influenced stand composition.

The flooding factor operated in parallel with past stream straightening and deepening/ditching everywhere which resulted in lowered water tables and drying of bottomland soils.

The frequency of flooding could be determined from dendrochronological records (Sigafos 1964) or from TVA or other records on the Powell River drainage (Cleaveland 2000, McGinnes et al 1983) suggesting time of invasion of overstory taxa. This might be developed into a chronological sere/zonation similar to the flood topographic zones seen on the Wabash and Tippecanoe rivers in Indiana where community composition was believed to have been related to flood-height frequency on the river edges (Lindsey et al. 1961).

## STAND COMPARISONS

Stand flora totals varied by 60% (80-150 taxa). (See Appendix I for certain stand characteristics). The stands most depauperate of species, 80-90 taxa, were ones which were believed to have a long grazing history. The two most floristically rich forested sites were in shallow ravines. The largest flora was at Blue Springs marsh (150 taxa). Others varied around a median of 105 taxa. Stand tree taxa varied from 16 to 29. In the open stands, the marshes and *Alnus* stands, the median was 14, in forested stands, the median numbers of tree taxa was 18. Shrub and woody vine taxa varied from 10 to 27, in open stands the median was 13, in forested stands it was 17 taxa. Herbaceous taxa varied in numbers from 53 to 121, the open stand median was 93, the forested stand median was 80 taxa. The sedge family was represented by stand numbers varying from one to 18 taxa, in the forest the median was eight - in open stands it was 14. Grass taxa varied from 6-21, in open stands the median was 12, in forested stands the median was 15 taxa. Totals for most categories above varied somewhat with numbers of non-native taxa which ranged 3.3 to 20%. Non-natives in ravines and flats at the base of ridges ranged from 3.3 to 8.8 with a medium of 6. In open stands, the range was 6.1-17.3 with a median 12.5. However, in no stand was the extent of flooding, grazing nor logging known from records.

## SUMMARY AND CONCLUSIONS

This small sample of remnant Valley and Ridge wetland vegetation yielded, with essentially one year of intensive study, a flora of 565 taxa (including a floating liverwort). This is about 20 percent of the published Tennessee flora but may be 18-19 percent of the currently known flora. The bottomland position of the sites, with water flow through most samples, periodic flooding, past land uses including stock grazing, logging and water table manipulation, and current deer browse has doubtless reduced the number of native taxa but has also increased the non-native and native weedy proportions. The wetland element of obligate taxa at 12.6%, facultative wet taxa at 21.7% percent and facultative taxa (sometimes reported from wetlands) at 17.8% occurred. Other native taxa were undetermined or were upland taxa. The 2006 study year experienced higher than average, September, October and November precipitation levels raising water levels in some sites. Soils of most sites are usually drier during this period most years-it may be that taxa usually growing during this period were missed (as *Fimbristylis perpusilla*, Wofford and Jones 1988 found in a dry year).

Stand composition could not be regularly related to soil drainage class nor soil height above river or stream water level. This suggests that other land use practices/conditions have modified the sites and floras. Such practices include, 1) logging (frequency and cutting diameter limit), 2) past stock grazing longevity/intensity and current and past deer browse intensity (Dils 1957), 3) stream straightening and ditching around adjacent fields lowered water tables. Also the weight of large stock animals compress the soil increasing bulk density, decreasing infiltration, which increases run-off or localized ponding. (Lutz and Chandler 1946, Dils 1953, Hursh 1951). Annual or periodic stream river flooding both removes stream border parts of sample areas and deposits soil material, litter (and trash), and seed and fruit from upstream.

A surprising number of taxa recurred among the forested stands which had been seen in upland mesic (De Selm 2006) and upland oak forests (De Selm this proceedings). These taxa were among and under the wetland taxa - dominated overstory. The hypothesis is proposed that the wetland overstory composition is controlled by a periodic or episodic (one decade to several decades) flood interval. The understory flora, composed of hydric, mesic or xeromesic taxa, is periodically submerged or buried by soil deposits, survive differentially and survivors sprout back. Some upland taxa reinvade from adjacent slopes, during interflood periods or from diaspores in annual flood deposits derived from upstream bank erosion or slope wash.

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## Appendix I

### Site Descriptions

- 1 (15). Lea Lakes Rd. 99-229, Grainger County between Lea Creek and Lea Lake Rd., 0.9 m above summer water level (aswl), dominants: *Platanus* and *Liriodendron*, no past grazing but, slight deer browse is evident. Jim Keller owner. Bedrock Grainger Form., soil Atkins series. This may be related to the Society of American Foresters Type 94 Sycamore-sweetgum-elm (Eyre 1980).
- 2 (18). Corryton Rd. 99-195, Union County. Luttrell to Corryton Rd. at Peters Rd. 1.2 m aswl, dominants: *Fraxinus pennsylvanica* - *Acer negundo*. Severe past stock grazing probable. Bedrock: Martinsburg shale, soil: Lindside series. Similar stands were seen by Martin (1971) and Hedge (1979). This may be related to the *Fraxinus pennsylvanica*- *Ulmus americana*- (*Celtis occidentalis*, *laevigata*) Temporarily Flooded Forest (Weakley et al. 1998).
- 3 (13). Yeary Rd. at Mullins Ck. 06-01, Claiborne County, Yeary Rd. near Mullins Ck. crossing, terrace 0.1-0.8 m aswl, dominants *Platanus* - *Acer negundo*. Some past stock grazing was probable. Bedrock: Chickamauga limestone. This may be related to Society Type 94 (Eyre 1980).
- 4 (5). Yeary Rd. on Powell R., 05-07, Claiborne County, on Yeary Road adjacent to the Powell R. near Buckanon Ford near river mile 99, dominants: *Platanus* and *Betula nigra*. Stock grazing and deer browsing were not evident. This was the only river border site without agricultural or animal use and little other human use known to the writer. Part of it has been subjected to automobile parking and received trash from fisherman. It may be under water for some periods in winter through March. Chickamauga limestone under river gravel. This may be related to the Society type 61 River birch-sycamore (Eyre 1980).
- 5 (6). Powell R. Rd. on Powell R. 06-02. Hancock County about 1.5 miles east from Browntown Rd. at Ailanthus Hill, downstream 0.1 mile from McDowell Shoal near river mile 107. 0.1-1.2 m aswl, dominants: *Acer negundo* and *Platanus*. There may be slight deer browse and fishermen traffic; the site was under water for some periods in winter through March. Bedrock: Chickamauga limestone. This may be related to the *Acer negundo* Temporarily Flooded Forest Alliance (Weakley et al. 1998).
- 6 (14). Alleghany Loop Rd., 99-32, Blount County on Four Mile Creek on a terrace, 0.1 to 1.3 m aswl, dominants *Liquidambar* and *Liriodendron*. Some roadside dumping and some deer browsing here. Bedrock was the Grainger formation, soil the Melvin series. This was the Society Type 87 Sweetgum-yellow poplar (Eyre 1980) and may have been the *Liquidambar styraciflua* - (*Liriodendron tuplipifera*, *Acer rubrum*) Temporarily Flooded Forest of Weakley et al. (1998).
- 7 (7). Alder stand on Rt. 129, 99-41, Blount County on Rt. 129 south of Pumpkin Center at boat launch site on Little Tennessee River/Tellico Reservoir. Dominant was *Alnus serrulata*, on the reservoir edge, adjacent to an old field. This stand may have developed within only a few decades. Water level was controlled at about 0.3 dm. Field partially bush-hogged annually. Bedrock: Sandsuck formation, soil: Sequatchie series. The stand was about one km into the Blue Ridge Province from the east edge of the Valley and Ridge Province (Neuman and Nelson 1985). This may be in the *Alnus serrulata* Temporarily Flooded Shrubland Alliance (Weakley et al. 1998).
- 8 (2). Black Pond, 00-310, Loudon County on Rt. 411, a spring-fed sinkhole marsh, with an open pond - *Leersia oryzoides* - *Typha latifolia* - *Salix nigra* zonation. Shown to me by Mr. Paul Durr. Subsurface deposit of 2.5 meters is about 3000 years old at base (Delcourt and Delcourt 1985). Stock grazing and duck hunting have occurred in the past. In 2000 the owner was David Mashburn; bedrock: Conasauga shale, soil: Emory series.
- 9 (17). Eve Mill Rd., 00-21, Monroe County on Eve Mill Rd. on Fork Creek, dominated by *Acer negundo* and *Celtis occidentalis*. A terrace one meter aswl, past heavy stock grazing probable, currently some peripheral roadside dumping and road edge mowing. Bedrock: Newalla Form, soil: Emory series. This may be related to the *Acer negundo*. Temporarily Flooded Forest Alliance (Weakley et al. 1998).

- 10 (9). South of Sweetwater, 06-03, Monroe County, on county road 132 at 134 across a railroad embankment from Sweetwater Creek, dominated by *Fraxinus pennsylvanica* and mixed *Ulmus* spp. This is on a creek branch but water level is controlled by embankment and raised road levels. Site is fenced, and may have been grazed in dry years; owners in 2006 were August and Cris Hadern. Bedrock: Knox dolomite, soil: Newark series. This may be related to the *Fraxinus pennsylvanica* Temporarily Flooded Forest (Weakley et al. 1998).
- 11 (11). Rogers Creek Area, 02-09, McMinn County, on Possum Rd., near Rt. 186. Partly forested, partly woodland old field with stream entrenched 0.1-0.5m into a terrace. Grazing history probable in the old field part; forest *Acer rubrum* - *Liquidambar* dominated. Bedrock: Conasauga shale, soil: Greendale series. This may have been a Red maple Society Type 108 (Eyre 1980), and related to the *Acer (rubrum, saccharinum)* - *Fraxinus* sp. - *Ulmus americana* Temporarily Flooded Forest (Weakley et al. 1998).
- 12 (8). West of Calhoun, 02-20, McMinn County, on Lamontville Rd. at Tarpo Rd. on Sivils Branch about 1.4 miles north of the Hiwassee River/Chickamauga Lake. Stream entrenched to 0.3m. Bedrock: Knox Group, soil: hamblen series. Forest is *Acer rubrum* - *Liquidambar* dominated and related to the types noted above (Eyre 1980, Weakley et al. 1998). There has probably been past grazing, and current deer browse was possible. The forest stand has a wet meadow on its north edge which was also sampled.
- 13 (19). Charleston Area, 02-183, Bradley County, on Water Street east from Charleston on the Hiwassee River/Chickmauga Lake just east of the boat launch. Terrace here was 1.5m aswl, stand dominated by *Acer saccharinum*. Probably grazed in the past, the west border is mowed, there may also be deer browsing and fishermen trampling. Bedrock: Conasauga shale, soil: Stasser series. This may be related to the *Acer saccharinum* Temporarily Flooded Forest Alliance (Weakley et al. 1998).
- 14 (1). Blue Springs Rd. Marsh. 03-08, Bradley County. Located 0.3 miles north from Rt. U.S. 74, on South Mouse Creek. Marsh bisected by a raised but culverted factory entrance road. Part of the area above marsh level was mowed, the adjacent field was mowed and upland was probably in agriculture or in pasture in the past. Main area dominant was *Leersia oryzoides*. Water flow currently influenced by beaver activity. Owner in 2003 was John Pesterfield. Bedrock: Conasauga shale, soil: Greendale series.
- 15 (4). Armstrong Rd. Marsh, 03-06, Bradley County, at Ownby Rd., south from State Rt.74 (Spring Place Rd.) Water level controlled by raised road levels and culvert drainage efficiency. West edge forested, south and east edges were mowed. Dominated by *Carex* spp. and *Scirpus* spp. Heavily invaded by *Cornus* and *Rosa*. A home fish pond upstream may be the source of the *Eichhornea* found in 2003. Bedrock, Conasauga shale, soil: Mullins series.
- 16 (10). Humbard Rd. 02-200, Bradley County, about one km south of Straw Hill Rd. on a small branch of Coahulla Creek. Stream cut 0.2-0.4 meters into valley bottom, forest dominants *Acer negundo* - *Platanus*. Probably stock grazed in the past. Bedrock: Conasauga shale, soil: Prader series. This may be part of the *Acer negundo* Temporarily Flooded Forest Alliance (Weakley et al. 1998).
- 17 (3). Hughes Lake Rd. Marsh. 02-192, Bradley County, at the Georgia State line, on Hughes Branch. Vegetation was in patches rather than zones, drainage influenced by beaver. Part of the area may have once been in agriculture, pasture and/or loblolly pine plantation; the road edge was mowed. Bedrock: Conasauga shale, soil: Prader series.
- 18 (12). Sugar Creek Branch, 02-191, Bradley County, on Hughes Lake Rd. 0.2 miles north from Sugar Ck. culvert, terrace entrenched 0.2-0.8m. The east edge has been cleared for a pine plantation and the east part of the stand has lost a few trees by southern pine beetle activity and wind. Dominants were *Fraxinus americana* and *Platanus*. Probably if this was grazed by stock in the past and present deer browse is probable. Bedrock: Conasauga shale, soil: Prader series.
- 19 (16). Mill Creek on Spring Place Rd. 06-04, Bradley County, forested terrace in a narrow valley, terrace entrenched one meter. Dominants were *Acer negundo* and *Juglans nigra*. This may have had some stock grazing in the past and may get some deer browsing currently. Bedrock: Conasauga shale, soil: Prader series. This may be part of the *Acer negundo* Temporarily Flooded Forest Alliance (Weakley et al. 1998).

20 (20). Conasauga River bottom, 02-194; Murray County, Georgia, on Rt. 225 (Spring Place Rd.) at Coffee Church Rd. near Perry Creek. Dominants were *Quercus phellos* and *Liquidambar*. The open understory suggested past stock grazing and current heavy deer browse in this flat bottom which was about 2 meters above the river and one km to the east of it. Bedrock was Conasauga shale. *Quercus phellos* (willow oak) stands are reported by Martin (1971), Oxendine (1971) and De Selm (1973), and are related to the *Quercus phellos* Seasonably Flooded Forest Alliance (Weakley et al. 1998) and may represent the Society Type 92, Sweetgum-willow oak (Eyre 1980).

## Appendix II

### Wetland flora

#### Site codes follow numbers in Appendix I

- Acalypha ostryifolia* Riddell – 12, 14, 16.  
*A. rhomboidea* Raf. – 8, 13, 14, 16.  
*A. virginica* L. – 5, 9.  
*Acer negundo* L. – 2, 3, 4, 5, 7, 8, 9, 12, 13, 14, 15, 16, 17, 19, 20.  
*A. rubrum* L. – 1, 6, 10, 11, 12, 15, 17, 18, 19, 20  
*A. saccharinum* L. – 13.  
*A. saccharum* Marshall – 1, 2, 3, 9, 11, 12, 15, 16, 18, 20  
*Achillea millifolium* L. – 14.  
*Actaea pachypoda* Elliott – 1.  
*Adiantum pedatum* L. – 3.  
*Aesculus flava* Aiton – 1, 2, 3, 6, 11.  
*Agalinus purpurea* (L.) Pennell – 17.  
*Ageratina altissima* (L.) R.M. King & H. Rob.  
(*Eupatorium rugosum*) – 1, 3, 5, 6.  
*Ageratina aromatica* (L.) Spach. – 4  
*Agrimonia parviflora* Aiton – 7, 11, 14.  
*A. rostellata* Wallr. – 3, 6.  
*Agrostis gigantea* Roth. – 9, 13, 14, 16.  
*A. perennans* (Walter) Tuck. – 4, 5, 12, 20.  
*Ailanthus altissima* (Mill.) Swingle – 3, 11, 16.  
*Albizia julibrissin* Durazz. – 19.  
*Alisma subcordatum* Raf. – 4, 5, 8, 10, 15, 17, 18, 20.  
*Alliaria petiolata* (M.Bieb.) Cavara & Grande – 4, 5.  
*Allium canadense* L. – 1, 2, 5, 9, 10, 11, 12, 16, 18, 19.  
*A. cernuum* Roth. – 4, 6, 7, 14.  
*A. vineale* L. – 1, 2, 3, 6, 8, 9, 11, 13, 16, 19.  
*Alnus serrulata* (Aiton) Willd. – 1, 4, 5, 6, 7, 8, 10, 11, 12, 14, 17  
*Amaranthus spinosus* L. – 4.  
*Ambrosia artemisiifolia* L. – 4, 12, 14, 15, 17.  
*A. trifida* L. – 1, 2, 3, 4, 5, 6, 8, 9, 10, 12, 13, 14, 15, 16, 19.  
*Amelanchier arborea* (F. Michx.) Fernald – 12.  
*Ampelamus albidus* (Nutt.) Britton – 10, 13, 14, 20.  
*Ampelopsis cordata* Michx. – 8, 10, 12, 14.  
*Amphicarpaea bracteata* (L.) Fernald – 1, 2, 3, 4, 5, 6, 7, 9, 11, 12, 14, 17, 18, 19.  
*Andropogon gerardii* Vitman – 4.  
*A. glomeratus* (Walter) BSP – 15.  
*A. virginicus* L. – 7, 12, 13, 14, 15, 17.  
*Anemone quinquefolia* L. – 1, 12.  
*A. virginiana* L. – 4, 9, 11, 17.  
*Anemonella thalictroides* (L.) Spach. – 1, 3, 5, 6, 11.  
*Anthoxanthum odoratum* L. – 7, 8, 10.  
*Apios americana* Medic. – 1, 4, 5, 7, 10, 12, 13, 14, 16, 17.  
*Apocynum cannabinum* L. – 4, 7, 8, 14, 15, 16, 17.  
*Arisaema dracontium* (L.) Schott. – 16, 19.  
*A. triphyllum* (L.) Schott. – 1, 6.  
*Aristolochia macrophylla* Lam. – 13.  
*Arnoglossum atriplicifolia* (L.) H. Roi (*Cacalia*) – 6, 11.  
*Aronia arbutifolia* (L.) Pers. – 12.  
*Artemisia annua* L. – 13, 14, 15.  
*A. vulgaris* L. – 5  
*Arthraxon hispidus* (Thunb.) Makino. – 14, 15, 17.  
*Arundinaria gigantea* (Walter) Muhl. – 1, 2, 3, 4, 6, 8, 11, 16, 17, 20.  
*Asclepias* sp – 1, 4.  
*A. tuberosa* L. – 17.  
*Asimina triloba* (L.) Dunal – 1, 3, 4, 6, 9, 14, 18, 19.  
*Asplenium platyneuron* (L.) BSP. – 3, 11, 12, 13, 15, 18, 20.  
*Athyrium felix foemina* (L.) Roth. subsp. *asplenioides* (Michx.) Hulten – 6, 12.  
*Barbarea verna* (Mill.) Asch. – 4, 5.  
*B. vulgaris* R. Br. – 4, 14.  
*Berchemia scandens* (Hill) K. Koch – 17, 20.  
*Betula lenta* L. – 6.  
*B. nigra* L. – 4, 5, 13.  
*Bidens bipinnata* L. – 13.  
*B. discoidea* (Torr. & Gray) Britton – 10.  
*B. frondosa* L. – 4, 5, 9, 13, 14, 16, 17, 18.  
*B. polylepis* S.F. Blake – 14.  
*B. tripartita* L. – 4, 8, 10.  
*Bignonia capreolata* L. – 5, 6, 9, 10, 11, 12, 13, 15, 16, 17, 18, 19, 20.  
*Boehmeria cylindrica* (L.) Sw. – 1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 12, 13, 14, 16, 17, 18, 19, 20.  
*Botrichium virginianum* (L.) Sw. – 1, 6, 11, 12, 20.  
*Brachyelytrum erectum* (Schreb.) P. Beauv. – 6.  
*Brassica rapa* L. – 4.  
*Bromus commutatus* Schrad – 2, 7, 8, 10, 14, 15, 18.  
*B. hordeaceus* L. – 14, 15.  
*B. pubescens* Muhl. – 6.  
*B. racemosus* L. – 9, 10, 11, 13, 15.  
*B. sterilis* L. – 10.  
*B. willdenowii* Kunth – 10, 13.  
*Buglossoides arvensis* (L.) I. M. Johnston – 2, 3, 8, 9, 11, 13, 15, 18, 19.  
*Calystegia sepia* (L.) R. Br. – 1, 3, 4, 7, 8, 14, 15.  
*Campsis radicans* Seem ex Bureau – 1, 2, 4, 5, 6, 7, 8, 10, 11, 13, 14, 15, 16, 17, 18, 19, 20.  
*Cardamine hirsuta* L. – 2, 3, 4, 8, 9, 11, 13, 14.  
*C. rotundifolia* Michx. – 11.  
*Carex albolutescens* Schwein. – 7.  
*C. annectens* E. P. Bichnell – 8.  
*C. blanda* Dewey – 1, 2, 6, 11, 14, 16, 17, 18, 19.  
*C. cephalophora* Muhl. ex Willd. – 6.  
*C. cherokeensis* Schwein – 7, 12, 13, 14, 15, 16, 17, 18, 19.  
*C. comosa* Boott – 10.  
*C. crebriflora* Wiegand – 16, 17, 18, 19.  
*C. crinita* Lam. – 1, 6, 7, 8, 10, 11, 12, 17, 18, 20.  
*C. debilis* Michx. – 1, 6, 7, 10, 11, 12.  
*C. digitalis* Willd. – 3, 6.



- C. eburnea* Boott – 6.  
*C. festucacea* Schkuhr – 7, 8, 10, 11, 12, 13, 15.  
*C. floccosperma* Dewey – 1, 2, 9, 11, 12, 19.  
*C. frankii* Kunth. – 8, 10, 14, 15.  
*C. gracilescens* Steud. – 15.  
*C. granularis* Muhl. ex Willd. – 6.  
*C. grayi* J. Carey – 13, 19.  
*C. hirsutella* Mack. – 9.  
*C. intumescens* Rudge – 1.  
*C. kraliana* Naczi & Bryson – 1, 3, 5, 6, 9, 17, 18, 19.  
*C. laxiflora* Lam. – 10.  
*C. leavenworthii* Dewey – 6, 13, 14, 17, 20.  
*C. laevivaginata* (Kukenth.) Mackenzie – 6.  
*C. leptalea* Wahlenb. – 6.  
*C. leptonevia* (Fernald) Fernald – 7, 16, 17, 20.  
*C. louisianica* L. H. Bailey – 13, 15.  
*C. lupulina* Muhl. ex Willd. – 12.  
*C. lurida* Wahlenb. – 1, 6, 7, 8, 10, 14, 15, 17, 18.  
*C. muhlenbergii* Schkuhr ex Willd. – 2.  
*C. nigromarginata* Schwein. – 11.  
*C. normalis* Mackenzie – 8.  
*C. prasina* Wahlenb. – 6.  
*C. retroflexa* Muhl. – 2.  
*C. rosea* Schkuhr ex Willd. – 6, 11.  
*C. scoparia* Schkuhr – 10, 12, 16, 19, 20.  
*C. squarrosa* L. – 15, 20.  
*C. swanii* (Fernald) Mack. – 15.  
*C. tribuloides* Wahlenb. – 8, 10.  
*C. typhina* Michx. – 20.  
*C. venusta* Dewey – 6, 7, 15, 16, 19.  
*C. vulpinoidea* Michx. – 6, 8, 10, 13, 14, 15, 17.  
*Carpinus caroliniana* Walter – 1, 3, 5, 6, 11, 12, 17.  
*Carya cordiformis* (Wangenh.) K. Koch – 2, 9, 16, 18.  
*C. glabra* (Mill.) Sweet – 1, 12, 18.  
*C. laciniata* (F. Michx.) Loudon – 8, 10, 19.  
*C. ovata* (Mill.) K. Koch – 10, 11, 15, 16, 20.  
*Catalpa speciosa* Warder ex Engelm. – 13.  
*Celtis laevigata* Willd. – 1, 2, 14, 15, 19.  
*C. occidentalis* L. – 1, 3, 8, 9, 10, 11, 12, 13, 14, 16, 17, 18, 19, 20.  
*Cephalanthus occidentalis* L. – 8, 10, 12, 14, 17.  
*Cercis canadensis* L. – 1, 6, 7, 11, 16, 17, 18, 19.  
*Chaerophyllum procumbens* (L.) Crantz. – 9, 18.  
*C. tainturieri* Hook. – 1, 2, 3, 4, 11, 19.  
*Chamaecrista fasciculata* (Michx.) Greene – 7, 12, 17.  
*C. nictitans* (L.) Moench. – 11.  
*Chasmanthium latifolium* (Michx.) H. O. Yates – 1, 4, 5, 9, 13, 17, 19, 20.  
*C. laxum* (L.) H. O. Yates subsp. *laxum* – 12, 20.  
*C. laxum* (L.) H. O. Yates subsp. *sessiliflorum* (Poir.) L. G. Clark – 11.  
*Chelone glabra* L. – 1, 12, 18.  
*Chenopodium ambrosioides* L. – 13.  
*Chimaphila maculata* (L.) Pursh – 6, 11.  
*Cicuta maculata* L. – 7, 12, 14, 17, 18, 20.  
*Cinna arundinacea* L. – 1, 2, 4, 5, 9, 11, 12, 14, 16, 18, 19, 20.  
*Circaea lutetiana* (L.) Asch & Magnus subsp. *canadense* (L.) Asch & Magnus. – 3.  
*Claytonia virginica* L. – 1, 5, 9, 11, 16, 19.  
*Clematis viorna* L. – 19.  
*C. virginiana* L. – 1, 2, 5, 7, 12, 17, 18, 19.  
*Cocculus carolina* (L.) DC – 1, 3, 9, 13, 15, 19.  
*Collinsonia verticillata* Baldwin ex Elliott – 1, 3.  
*Conoclinium coelestinum* (L.) DC (*Eupatorium*) – 5, 13, 16, 17, 19.  
*Conyza canadensis* (L.) Cronquist – 14, 15, 18, 19.  
*Cornus amomum* Mill. – 4, 7, 8, 11, 14, 15, 17.  
*C. florida* L. – 1, 3, 6, 8, 11, 12, 16, 17, 20.  
*C. foemina* Mill. – 1, 12, 16, 18, 20.  
*Corylus americana* Walter – 4, 11.  
*Crataegus crusgalli* L. – 20.  
*Cryptotaenia canadensis* (L.) DC – 1, 2, 3, 4, 5, 6, 9, 16, 19.  
*Cuscuta gronovii* Willd. – 10.  
*Cynoglossum virginianum* L. – 3.  
*Cyperus echinatus* (L.) – 13.  
*C. lancastriensis* Porter – 8.  
*C. strigosus* L. – 4, 13, 14, 17.  
*Cystopteris bulbifera* (L.) Bernhardt – 6.  
*Danthonia spicata* (L.) Beauv. – 6, 16, 20.  
*Decumaria barbara* L. – 18.  
*Dentaria diphylla* Michx. – 1.  
*D. heterophylla* Nutt. – 2, 3, 5, 11.  
*Desmodium canadense* (L.) DC – 7, 14.  
*D. laevigatum* (Nutt.) DC – 4.  
*D. obtusum* (Muhl. ex Willd.) DC – 14, 18.  
*D. paniculatum* (L.) D.C. var. *dillenii* (Darl.) Isley – 1, 4, 6, 7, 10, 12, 14, 15, 18, 20.  
*D. paniculatum* (L.) DC var. *paniculatum* – 14, 17.  
*D. pauciflorum* (Nutt.) DC – 1.  
*Dichantherium acuminatum* (Sw.) Gould & C.A. Clark subsp. *acuminatum* – 7.  
*D. acuminatum* (Sw.) Gould & C.A. Clark subsp. *fasciculatum* (Torr.) Freckmann & Lelong – 15.  
*D. boscii* (Poir.) Gould & C.A. Clark – 6, 13.  
*D. clandestinum* (L.) Gould – 1, 4, 5, 7, 11, 12, 13, 14, 16, 19.  
*D. commutatum* (Scholt.) Gould – 1, 6, 10, 11, 13, 19.  
*D. dichotomum* (L.) Gould subsp. *microcarpon* (Muhl. ex Elliott) Freckmann & Lelong – 11, 12, 13, 20.  
*D. dichotomum* (L.) Gould subsp. *yadkinense* (Ashe) Freckmann & Lelong – 4.  
*D. latifolium* (L.) Gould & C.A. Clark – 4  
*D. laxiflorum* (Lam.) Gould – 11.  
*D. ovale* (Elliott) Gould & C.A. Clark subsp. *villosissimum* (Nash) Freckmann & Lelong – 15.  
*D. scoparium* (Lam.) Gould – 11, 12.  
*D. sphaerocarpon* (Elliott) Gould – 11, 12.  
*Diodia virginiana* L. – 4, 8, 10, 13, 14.  
*Dioscorea villosa* L. – 1, 3, 6, 12, 18, 19, 20.  
*Diospyros virginiana* L. – 14, 20.  
*Dryopteris intermedia* (Muhl. ex Willd.) A. Gray – 5, 13.  
*Duchesnea indica* (Andr.) Focke – 9, 10, 13, 14.  
*Dulichium arundinaceum* (L.) Britt. – 8.  
*Echinochloa crusgalli* (L.) P. Beauv. – 13, 14.

- E. muricata* (P. Beauv.) Fernald var. *microstachya* Wiegand – 10, 13, 14.  
*E. muricata* (P. Beauv.) Fernald var. *muricata* – 8.  
*Eclipta prostrata* (L.) L. – 8, 13, 14.  
*Eichhornia crassipes* (Mart.) Solms – 15.  
*Eleocharis obtusa* (Willd.) Schultes – 8, 10.  
*E. tenuis* (Willd.) Schultes – 4, 17.  
*Elephantopus carolinianus* Raesch. – 3, 4, 5, 6, 9.  
*E. tomentosus* L. – 11, 13.  
*Elymus glabriflorus* (Vasey ex L. H. Dewey) Scribn. – 4, 9, 10, 15.  
*E. hystrix* L. – 3.  
*E. riparius* Wiegand – 4, 19.  
*E. villosus* Muhl. – 1, 2, 4, 5, 11, 15, 16.  
*E. virginicus* L. – 1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20.  
*Epilobium coloratum* Biehler – 14.  
*Equisetum hyemale* L. subsp. *affine* (Engelm.) Calder & R.L. Taylor – 4.  
*Eragrostis pectinacea* (Michx.) Nees – 13.  
*E. spectabilis* (Pursh) Steud. – 13.  
*Erigeron annuus* (L.) Pers. – 2, 3, 4, 5, 6.  
*E. philadelphicus* L. – 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19.  
*E. strigosus* Muhl. – 2, 11, 14, 18.  
*Euonymus alatus* (Thunb.) Siebold – 2.  
*E. americana* L. – 1, 6, 11, 12, 15, 16, 20.  
*Eupatorium fistulosum* Barratt. – 1, 4, 5, 6, 9, 13, 17, 18.  
*E. hyssopifolium* L. – 7.  
*E. perfoliatum* L. – 4, 5, 12, 13, 15, 17.  
*E. purpureum* L. – 1, 4, 5, 7, 12, 20.  
*E. rotundifolium* L. – 12.  
*E. serotinum* Michx. – 5, 13, 14, 15, 16, 17, 18.  
*E. sessilifolium* L. – 14, 17.  
*Euphorbia commutata* Engelm. – 14.  
*E. maculata* L. – 13.  
*Eurybia divaricata* (L.) G.L. Nesom (*Aster*) – 1, 3, 4, 5  
*E. macrophyllum* (L.) Cassini (*Aster*) – 6.  
*Fagus grandifolia* Ehrh. – 1, 3, 5, 6, 11, 12, 18.  
*Festuca pretensis* Huds. – 1, 2, 3, 4, 5, 7, 9, 10, 11, 13, 14, 15, 17, 18.  
*F. subverticillata* (Pers.) Alexeev – 1, 3, 4, 19.  
*Fraxinus americana* L. – 1, 2, 4, 5, 6, 8, 9, 10, 11, 14, 16, 17, 18, 20.  
*F. pensylvanica* Marshall – 2, 4, 5, 7, 8, 10, 14, 16, 17, 19, 20.  
*Galactia volubilis* (L.) Britton – 9.  
*Galium aparine* L. – 1, 2, 3, 4, 5, 6, 10, 11, 12, 13, 14, 15, 18, 19, 20.  
*G. circaezans* Michx. – 6, 12.  
*G. obtusum* Bigelow – 7, 14, 17, 18, 19, 20.  
*G. pilosum* Aiton – 12.  
*G. tinctorium* L. – 4, 8, 10, 11, 14, 17.  
*G. triflorum* Michx. – 1, 2, 3, 4, 6, 7, 11.  
*Gamochaeta purpurea* (L.) Cabrera (*Gnaphalium*) – 7, 13, 18.  
*Gentiana decora* Pollard – 6.  
*Geranium carolinianum* L. – 8, 12, 13, 14, 15, 19.  
*G. dissectum* L. – 13.  
*G. maculatum* L. – 3.  
*Geum canadense* Jacq. – 1, 2, 3, 4, 5, 6, 9, 10, 11, 12, 15, 16, 18, 19, 20.  
*Glecoma hederacea* L. – 3, 4, 5, 13.  
*Gleditsia triacanthos* L. – 8, 9, 19.  
*Glyceria striata* (Lam.) Hitchc. – 1, 3, 6, 8, 9, 11, 12, 14, 15, 16, 17, 18, 19.  
*Gratiola floridana* Nutt. – 12.  
*Helenium flexuosum* Raf. – 10, 17, 18.  
*Helianthus decapetalus* L. – 4, 5.  
*H. hirsutus* Raf. – 7, 15.  
*H. microcephalus* Torr. & A. Gray – 12.  
*H. tuberosus* L. – 4, 5.  
*Hibiscus moscheutos* L. – 10, 14.  
*Holcus lanatus* L. – 7.  
*Houstonia caerulea* Willd. ex Roem. & Schult. – 6, 12.  
*H. purpurea* L. – 11.  
*Humulus japonicus* (L.) Siebold & Zucc. – 5.  
*Hydrangea arborescens* L. – 3.  
*Hymenocallis occidentalis* (Le Conte) Kunth. – 1.  
*Hypericum crux-andreae* (L.) Crantz – 12, 15.  
*H. densiflorum* Pursh – 20.  
*H. hypericoides* (L.) Crantz – 12, 20.  
*H. mutilum* L. – 12.  
*H. punctatum* Lam. – 1, 4, 5, 15, 17, 18, 20.  
*Impatiens capensis* Meerb. – 1, 2, 3, 4, 6, 7, 13, 14, 16, 17, 18, 19, 20.  
*Ipomoea batatas* (L.) Lam. – 10, 11.  
*I. coccinea* L. – 12.  
*I. hederacea* Jacq. – 14.  
*I. lacunosa* L. – 10, 13, 14.  
*I. pandurata* (L.) G. Mey. – 3, 4, 7, 8, 10, 11, 12.  
*I. purpurea* (L.) Roth – 18.  
*Iris cristata* Soland. ex Aiton – 1, 6.  
*I. pseudacorus* L. – 18, 20.  
*Isoetes engelmannii* A. Braun – 4.  
*Itea virginica* L. – 3, 10, 18, 20.  
*Iva annua* L. – 8.  
*Juglans nigra* L. – 1, 2, 3, 5, 6, 9, 10, 11, 13, 16, 17, 19.  
*Juncus acuminatus* Michx. – 8.  
*J. coriaceus* Mack. – 2, 6, 11, 12, 13, 15, 17, 18, 20.  
*J. dichotomus* Elliott – 13, 15.  
*J. dudleyi* Wiegand – 13, 15.  
*J. effusus* L. var. *solutus* Fernald & Wiegand – 2, 7, 8, 10, 11, 12, 13, 14, 15, 16, 17.  
*J. interior* Wiegand – 17.  
*J. marginatus* Rostk. – 17.  
*J. secundus* P. Beauv. – 8.  
*J. tenuis* Willd. – 7, 8, 13, 14, 15, 17, 18.  
*Juniperus virginiana* L. – 1, 2, 3, 6, 7, 9, 11, 12, 13, 14, 15, 16, 17, 19, 20.  
*Justicia americana* (L.) Vahl – 4.  
*Krigia biflora* (Walter) S.F. Blake – 11.  
*Lactuca canadensis* L. – 1, 12, 13, 17, 18.  
*L. floridana* (L.) Gaertn. – 2, 3, 5, 11, 12, 13, 14, 16, 17, 18.  
*L. saligna* L. – 12, 14, 18.  
*Lamium purpureum* L. – 2, 3, 5, 8, 9, 10, 13, 14.  
*Laportea canadensis* (L.) Wedd. – 1, 3, 5, 12, 19.

- Leersia oryzoides* (L.) Sw. – 1, 4, 5, 8, 10, 12, 14, 16.  
*L. virginica* Willd. – 1, 2, 3, 4, 5, 6, 9, 10, 11, 12, 13, 15, 16, 17, 18, 19, 20.  
*Lemna minuta* Kunth. – 8, 10, 14, 16, 17.  
*Lespedeza cuneata* (Dum.) G. Don. – 4, 7, 15.  
*Leucospora multifida* (Michx.) Nutt. – 17.  
*Ligustrum sinense* Lour. – 1, 2, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20.  
*Lindera benzoin* (L.) Blume – 1, 2, 3, 4, 5, 6, 9, 19.  
*Lindernia dubia* (L.) Pennell – 11.  
*Liquidambar styraciflua* L. – 1, 3, 6, 8, 11, 12, 17, 18, 19, 20.  
*Liriodendron tulipifera* L. – 1, 2, 4, 5, 6, 7, 8, 12, 17, 18, 19, 20.  
*Lobelia cardinalis* L. – 1, 8, 9, 10, 12, 13, 14, 18, 19.  
*L. puberula* Michx. – 4, 5.  
*L. siphilitica* L. – 15.  
*Lonicera japonica* Thunb. – 1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15, 16, 17, 19, 20.  
*L. maackii* (Rupr.) Maxim. – 10.  
*Ludwigia alternifolia* L. – 1, 15.  
*L. microcarpa* Michx. – 17.  
*L. palustris* (L.) Elliott – 8, 10, 12, 17.  
*Luzula bulbosa* (A. Wood) Smyth – 1, 11.  
*Lycopus americanus* Muhl. 1. – 4, 12, 13, 17.  
*L. rubellus* Moench. – 10, 17.  
*L. virginicus* L. – 2, 3, 11, 12, 20.  
*Lysimachia ciliata* L. – 4.  
*L. nummularia* L. – 2, 3, 4.  
*Lythrum alatum* Pursh – 13, 15, 17, 18.  
*Magnolia acuminata* (L.) L. – 6.  
*M. tripetala* L. – 1.  
*Maianthemum racemosum* (L.) Link (*Smilacina*) – 3, 5, 6, 12.  
*Matelea gonocarpus* (Walter) Shinnery – 16, 19.  
*Mecardonia acuminata* (Walter) Small – 11.  
*Medicago lupulina* L. – 14.  
*Melica mutica* Walter – 1, 6, 16.  
*Melilotus alba* Medik. – 14, 18.  
*M. officinalis* (L.) Pall. – 14.  
*Melothria pendula* L. – 14.  
*Menispermum canadense* L. – 2, 13, 19.  
*Microstegium vimineum* (Trin.) A. Camus – 1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 18, 19, 20.  
*Mikania scandens* (L.) Willd. – 15.  
*Mimulus alatus* Aiton – 5, 12, 13, 15, 17.  
*M. ringens* L. – 15.  
*Mitchella repens* L. – 12, 20.  
*Morus rubra* L. – 1, 2, 3, 10, 11, 12, 13, 15, 16, 18, 20.  
*Mosla dianthera* (Buch.-Ham. ex Roxb.) Maxim. – 16.  
*Muhlenbergia frondosa* (Poir.) Fernald – 4.  
*M. schreberi* J.F. Gmel. – 2, 3, 4, 13, 14.  
*Murdannia keisak* (Haesk.) Aland. – Mazz. 12.  
*Myosotis macrosperma* Engelm. – 9.  
*Myriophyllum* sp. – 18.  
*Nothoscordum bivalve* (L.) Britton – 19.  
*Nyssa sylvatica* Marshall – 1, 3, 4, 5, 7, 9, 10, 11, 12, 13, 16, 17, 19, 20.  
*Obolaria virginica* L. – 6.  
*Oenothera biennis* L. – 14.  
*Onoclea sensibilis* L. – 11.  
*Ostrya virginiana* (Mill.) K. Koch. – 1, 4, 6, 11, 12.  
*Oxalis dillenii* Jacq. – 4.  
*O. stricta* L. – 3, 5, 9, 12, 13, 14, 5.  
*O. violacea* L. – 3, 6, 11, 18.  
*Oxypolis rigidior* (L.) Raf. – 6.  
*Packera aurea* (L.) A. Love & D. Love (*Senecio*) – 4, 5, 13.  
*P. glabella* (Poir.) C. Jeffrey (*Senecio*) – 12, 14, 19.  
*P. obovata* (Muhl. ex Willd.) W.A. Weber & A. Love (*Senecio*) – 4.  
*Panicum anceps* Michx. – 4, 11, 17.  
*P. dichotomiflorum* Michx. – 13.  
*P. rigidulum* Bosc ex Nees subsp. *elongatum* (Pursh) Freckmann & Lelong – 13.  
*P. rigidulum* Bosc ex Nees subsp. *pubescens* (Vasey) Freckman & Lelong – 17.  
*P. rigidulum* Bosc ex Nees subsp. *rigidulum* – 10.  
*Parietaria pensylvanica* Muhl. ex Willd. – 6.  
*Parthenocissus quinquefolia* (L.) Planch. – 1, 2, 3, 4, 5, 6, 9, 10, 11, 12, 16, 17, 18, 19, 20.  
*Paspalum dilatatum* Poir. – 7, 13, 14, 15.  
*P. floridanum* Michx. – 14, 15.  
*P. laeve* Michx. – 14, 15.  
*P. pubiflorum* Rupr. – 14.  
*P. setaceum* Michx. var. *ciliatifolium* (Michx.) Vasey – 13.  
*Passiflora incarnata* L. – 12.  
*P. lutea* L. – 1, 4, 13.  
*Paulownia tomentosa* (Thunb.) Steud. – 13.  
*Pedicularis canadensis* L. – 6.  
*Peltandra virginica* (L.) Raf. – 8.  
*Penstemon calycosus* Small – 17.  
*P. laevigatus* (L.) Aiton – 15.  
*Penthorum sedoides* L. – 10, 17.  
*Perilla frutescens* (L.) Britton – 1, 3, 5, 9, 18.  
*Phalaris arundinacea* L. – 3, 4, 5, 10.  
*Phegopteris hexagonoptera* (Michx.) Fee (*Thelypteris*) – 3, 11.  
*Phlox amplifolia* Britton – 4.  
*P. divaricata* L. – 3.  
*Phryma leptostachya* L. – 3, 6, 13.  
*Phyla lanceolata* (Michx.) Greene – 8.  
*Phytolacca americana* L. – 9, 13.  
*Pilea pumila* (L.) A. Gray – 1, 3, 4, 5, 6, 8, 9, 10, 12, 16.  
*Pinus echinata* Mill. – 6.  
*P. taeda* L. – 12, 13, 15, 16, 17, 18, 20.  
*Plantago major* L. – 4, 5.  
*P. virginica* L. – 13.  
*Platanthera peramoena* (A. Gray) A. Gray (*Habenaria*) – 11.  
*Platanus occidentalis* L. – 1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12, 13, 14, 16, 17, 18, 19, 20.  
*Plucheia camphorata* (L.) DC – 8, 10.  
*Poa annua* L. – 9, 10, 13.  
*P. autumnalis* Muhl. ex Elliott – 6, 11, 14, 16, 17, 19.  
*P. chapmaniana* Scribn. – 1.  
*P. cuspidata* Nutt. – 1, 3, 6, 11, 18, 19.

- P. languida* Hitchc. – 3, 4.  
*P. pretensis* L. – 2, 3, 4, 5, 7, 8, 9, 10, 11, 13, 14, 15, 16, 17, 18, 19.  
*Podophyllum peltatum* L. – 1, 3, 6, 11.  
*Polygonatum biflorum* (Walter) Elliott – 1, 11, 12, 20.  
*Polygonum amphibium* L. var. *emersum* Michx. – 19.  
*P. caespitosum* Blume var. *longisetum* (Britton) Steward – 14.  
*P. convolvulus* L. – 14.  
*P. hydropiper* L. – 12, 14.  
*P. hydropiperoides* Michx. – 1, 4, 5, 8, 9, 10, 11, 12, 13, 14, 16, 17, 18, 20.  
*P. lapathifolium* L. – 14.  
*P. pensylvanicum* (L.) Small – 8, 14, 15, 17.  
*P. persicaria* L. – 14.  
*P. punctatum* Elliott – 1, 4, 8, 14, 16.  
*P. sagittatum* L. – 1.  
*P. scandens* L. – 4, 14.  
*P. virginicum* L. – 1, 3, 4, 5, 9, 19.  
*Polymnia canadensis* L. – 5.  
*Pleopeltis polypodioides* (L.) E.G. Andrews & Windham subsp. *michauxiana* (Weatherby) E.G. Andrews & Windham (*Polypodium*) – 20.  
*Polystichum acrostichoides* (Michx.) Schott. – 1, 3, 5, 6, 11, 12, 13, 20.  
*Ponciris trifoliata* (L.) Raf. – 12.  
*Pontederia cordata* L. – 8.  
*Potentilla simplex* Michx. – 11, 12, 20.  
*Potamogeton amplifolius* Tuck. – 4.  
*Prenanthes* sp. – 6, 11.  
*Proserpinaca palustris* L. – 10, 17.  
*Prunella vulgaris* L. var. *lanceolata* (Barton) Fernald – 1, 4, 6, 7, 17.  
*Prunus angustifolius* Marshall – 16.  
*P. serotina* Ehrh. – 1, 2, 3, 6, 11, 12, 13, 14, 16, 18, 20.  
*Pseudognaphalium obtusifolium* (L.) Hilliard & Burt. (*Gnaphalium*) – 18.  
*Pteridium aquilinum* (L.) Kuhn – 12.  
*Ptilimnium costatum* (Elliott) Raf. – 19.  
*P.* sp. – 10, 13, 17, 18.  
*Pynanthemum loomisii* Nutt. – 6.  
*P. muticum* (Michx.) Pers. – 12.  
*P. pycnanthemoides* (Leavenw.) Fernald – 11, 12.  
*P. tenuifolium* Schrad. – 17.  
*P. virginianum* (L.) Durrand & A.B. Jacks. – 17.  
*Pyrrhopappus carolinianus* (Walter) DC – 13, 15.  
*Pyrus communis* L. – 14.  
*Quercus alba* L. – 6, 11, 12, 17, 18, 20.  
*Q. falcata* Michx. – 12, 15, 16, 20.  
*Q. michauxii* Nutt. – 8, 20.  
*Q. pagoda* Raf. – 16, 20.  
*Q. nigra* L. – 13, 19, 20.  
*Q. phellos* L. – 12, 13, 15, 16, 19, 20.  
*Q. rubra* L. – 1, 2, 3, 6, 11, 12, 16, 18, 19, 20.  
*Q. shumardii* Buckley – 18.  
*Q. stellata* Wangenh. – 15, 18.  
*Q. velutina* Lam. – 20.  
*Ranunculus abortivus* L. – 3, 5, 9, 10, 11, 12, 13, 14, 16, 18, 19.  
*R. bulbosus* L. – 4, 5, 6, 8, 10, 13, 14, 15, 16.  
*R. fascicularis* Muhl. ex Bigelow – 4, 17, 18, 19, 20.  
*R. hispidus* Michx. – 1.  
*R. recurvatus* Poir. – 11, 12.  
*Rhamnus caroliniana* Walter – 1, 11, 12, 14, 16.  
*Rhexia mariana* L. – 12.  
*Rhododendron periclymenoides* (Michx.) Shinnars – 6, 12, 20.  
*Rhus glabra* L. – 1, 11.  
*Rhynchospora corniculata* (Lam.) A. Gray – 10, 17.  
*Ricciocarpos nutans* (L.) Eorda – 10.  
*Robinia pseudoacacia* L. – 5, 7, 13, 19.  
*Rorippa nasturtium-aquaticum* (L.) Hayek. (*Nasturtium*) – 17.  
*R. palustris* (L.) Besser subsp. *fernaldiana* (Butters & Abbe) Jonsell – 4, 8, 14.  
*R. sessiliflora* (Nutt.) Hitchc. – 8.  
*Rosa carolina* L. – 1, 7, 8, 10, 15, 16.  
*R. multiflora* Thunb. – 1, 2, 7, 9, 11, 13, 14, 16, 18, 20.  
*R. palustris* Marshall – 1, 2, 3, 4, 7, 9, 10, 11, 13, 18, 20.  
*R. setigera* Michx. – 11, 16.  
*Rubus* sp. – 1, 2, 6, 7, 8, 9, 10, 11, 12, 14, 15, 16, 17, 18, 19, 20.  
*Rudbeckia fulgida* Aiton – 6, 7, 12.  
*R. fulgida* Aiton var. *umbrosa* (C.L. Boynt. & Beadle) Cronquist – 11, 17.  
*R. laciniata* L. – 1, 3, 4, 5, 6, 7, 9, 11, 19.  
*Ruellia caroliniana* (J.F. Gmel.) Steud. – 17.  
*R. strepens* L. – 1, 2, 15, 16, 19.  
*Rumex conglomeratus* Murray – 1, 2, 4, 5, 9, 10, 14, 16, 17.  
*R. crispus* L. – 8, 9, 10, 13, 14, 15, 16, 18.  
*R. obtusifolius* L. – 4.  
*Sagittaria latifolia* Willd. – 1, 8, 19.  
*Sabatia angularis* (L.) Pursh – 17.  
*Salix nigra* Marshall – 4, 5, 7, 8, 10, 12, 13, 14, 15, 16, 17.  
*Salvia lyrata* L. – 3, 6, 11, 17.  
*Sambucus canadensis* L. – 2, 3, 4, 6, 7, 9, 10, 11, 12, 13, 14, 16, 18, 19, 20.  
*Samolus floribundus* HBK. – 17.  
*Sanguinaria canadensis* L. – 3.  
*Sanicula canadensis* L. – 1, 2, 3, 6, 11, 12, 17, 20.  
*S. odorata* (Raf.) Pryer & Phillippe – 1.  
*S. smallii* E.P. Bicknell – 9, 11, 18, 19.  
*Scirpus atrovirens* Willd. – 1, 7, 10, 11, 12, 14, 15, 17, 18.  
*S. cyperinus* (L.) Kunth – 8, 11, 14, 15, 17.  
*S. pendulus* Muhl. ex Elliott – 14, 15, 17.  
*Scleria oligantha* Michx. – 6, 10.  
*Scutellaria integrifolia* L. – 12, 20.  
*S. lateriflora* L. – 2, 8, 12, 16, 20.  
*Sedum ternatum* Michx. – 2, 3, 5.  
*Setaria parviflora* (Poir.) Kerguelen – 7, 13, 14, 15, 17.  
*S. pumila* (Poir.) Roem. & Schult. – 17.  
*Sherardia arvensis* L. – 15.  
*Sicyos angulata* L. – 5.  
*Silphium pinnatifidum* Elliott – 15, 17.  
*S. trifoliatum* L. – 16.

- Sisymbrium officinale* (L.) Scop. – 5.  
*Sisyrinchium albidum* Raf. – 17.  
*S. angustifolium* Nutt. – 6, 10, 11, 16, 17, 18, 20.  
*S. mucronatum* Michx. – 9, 15.  
*Smallanthus uvedalia* (L.) Mack. (*Polymnia*) – 1.  
*Smilax bona-nox* L. – 4, 6, 7, 9, 10, 11, 13, 14, 16, 18, 19.  
*S. glauca* Walter – 6, 12, 13, 20.  
*S. rotundifolia* L. – 1, 2, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20.  
*S. tamnoides* L. – 2, 4.  
*Solanum carolinense* L. – 4, 7, 10, 12, 13, 14, 15.  
*Solidago altissima* L. – 14, 15.  
*S. caesia* L. – 1, 6.  
*S. canadensis* L. var. *hargerii* Fernald – 5, 7, 10, 11, 13, 14, 15, 17.  
*S. flexicaulis* L. – 4.  
*S. gigantea* Aiton – 3, 4, 5, 7, 12, 13, 14, 15, 17, 18.  
*S. rugosa* Mill. subsp. *aspera* (Aiton) Cronquist – 7.  
*S. ulmifolia* Muhl. – 1, 14.  
*Sonchus asper* (L.) Nutt. – 8, 14, 16.  
*S. oleraceus* L. – 13.  
*Sorghum bicolor* (L.) Moench. – 14.  
*Sparganium americanum* Nutt. – 17.  
*Sphenopholis nitida* (Biehler) Scribn. – 1.  
*S. obtusata* (Michx.) Scribn. var. *major* (Torr.) Erdman – 9, 13, 14, 18.  
*S. obtusata* (Michx.) Scribn. var. *obtusata* – 12, 15.  
*Sporobolus indicus* (L.) R.Br. – 7.  
*Stellaria media* (L.) Vill. – 2, 3, 4, 5, 9.  
*S. pubera* Michx. – 1, 5, 6, 11.  
*Symphytotrichum lanceolatum* (Willd.) G.L. Nesom (*Aster*) – 4, 8, 9, 10, 11, 12, 13, 16, 17.  
*S. lateriflorum* (L.) A. Love & D. Love (*Aster*) – 1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 19.  
*S. novae-angliae* (L.) G. L. Nesom (*Aster*) – 15, 17.  
*S. ontarione* (Wiegand) G.L. Nesom (*Aster*) – 7, 13, 14, 15.  
*S. pilosum* (Willd.) G.L. Nesom (*Aster*) – 7, 13, 14, 15.  
*S. urophyllum* (Lindley ex DC) G.L. Nesom (*Aster*) – 5.  
*Thalictrum revolutum* DC – 1, 5, 9, 17, 19, 20.  
*Thaspium barbinode* (Michx.) Nutt. – 1.  
*T. trifoliatum* (L.) A. Gray – 6  
*Thelypteris noveboracensis* (L.) Nieuwl. – 1.  
*Thlaspi arvense* – L. – 4.  
*Tiarella cordifolia* L. – 1, 3, 6, 11.  
*Tilia americana* L. – 3.  
*Tipularia discolor* (Push) Nutt. – 6, 11.  
*Toxicodendron radicans* (L.) Kuntze (*Rhus*) – 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16, 17, 18, 19, 20.  
*Trachelospermum difforme* (Walter) A. Gray – 16.  
*Tradescantia subaspera* Ker Gawl. – 13, 19.  
*Trifolium pratense* L. – 4, 5.  
*T. repens* L. – 4, 13, 14.  
*Trillium catesbaei* Elliott – 1, 6.  
*T. luteum* (Muhl.) Harb. – 1, 11.  
*Tripsacum dactyloides* (L.) L. – 14, 15.  
*Tsuga canadensis* (L.) Carriere – 6.  
*Typha latifolia* L. – 7, 8, 14, 15, 17, 20.  
*Ulmus alata* Michx. – 1, 3, 6, 8, 9, 10, 11, 12, 15, 16, 18, 19, 20.  
*U. americana* L. – 2, 6, 9, 10, 11, 13, 16, 17, 18, 20.  
*U. rubra* Muhl. – 1, 3, 4, 5, 6, 8, 9, 10, 11, 12, 13, 15, 16, 17, 18, 19, 20.  
*Vaccinium arboreum* Marshall – 2.  
*V. pallidum* Aiton – 12, 20.  
*Valerianella radiata* (L.) Dufur. – 2, 3, 4, 9, 11, 12, 13, 14, 15, 17, 18, 19.  
*Verbena brasiliensis* Vell. – 13.  
*V. urticifolia* L. – 2, 4, 9, 12, 13, 14, 15.  
*Verbesina alternifolia* (L.) Britton – 2, 3, 4, 5, 9, 19.  
*V. occidentalis* (L.) Walter – 1, 2, 5, 8, 13.  
*V. virginica* L. – 5, 7, 13.  
*Vernonia gigantea* (Walter) Trel. – 1, 4, 7, 12, 13, 14, 15, 16, 17, 19.  
*V. noveboracensis* (L.) Michx. – 17.  
*Veronica arvensis* L. – 3, 15.  
*V. hederifolia* L. – 2, 9, 13.  
*V. peregrina* L. – 9.  
*V. serpyllifolia* L. – 9.  
*Viburnum cassinoides* L. – 18.  
*V. prunifolium* L. – 18.  
*V. rufidulum* Raf. – 2, 11.  
*Vicia sativa* L. subsp. *nigra* (L.) Ehrh. – 2, 7, 8, 9, 11, 12, 14, 15.  
*Viola cucullata* Aiton – 9, 10.  
*V. palmata* L. – 11.  
*V. sororia* Willd. – 3, 6, 9, 11, 19.  
*V. sp.* – 1, 2, 3, 4, 5, 13, 14, 20.  
*V. striata* Aiton – 3.  
*Vitis rotundifolia* Michx. – 1, 2, 3, 11, 14, 16, 17, 20.  
*V. sp.* – 1, 2, 3, 4, 5, 6, 10, 11, 12, 13, 14, 15, 16, 17, 19, 20.  
*Xanthium strumosum* L. – 4, 8, 10, 14.  
*Xanthorhiza simplicissima* Marshall – 1, 5.  
*Yucca filamentosa* L. – 20.

# RESTORATION AND MAINTENANCE OF STATE NATURAL AREAS

Kevin C. Fitch

Tennessee Department of Environment and Conservation, Division of Natural Areas, Nashville, TN

**ABSTRACT.** The mission of the Tennessee Division of Natural Areas is to restore and protect the plants, animals, and natural communities that represent the natural biological diversity of Tennessee. The Division carries out its mission through four program areas including the Natural Areas Program. The Natural Areas Program was established in 1971 with the passage of the Natural Areas Preservation Act. Seventy-five Natural Areas (108,621 acres) are currently protected under this act. Many of these Natural Areas are managed through Cooperative Management Agreements with other local, state, and federal agencies, as well as with non-governmental organizations. The Natural Areas Program seeks to include adequate representation of all natural communities that make up Tennessee's natural landscape, and provide long-term protection for Tennessee's rare plant communities and the rare, threatened, and endangered plant and animal life included. Natural areas represent some of Tennessee's best examples of intact ecosystems and serve as reference areas for how natural ecological processes function. The Natural Areas staff utilizes all available research specific to the ecosystems included within each Natural Area to formulate adaptive management strategies allowing for the application of appropriate management techniques and the establishment of appropriate goals and objectives. For example, control of invasive exotics within grasslands may precede the application of prescribed fire to prevent the spread of invasives following disturbance. Additionally, mowing may be utilized to control the invasion of woody species during a one to two year period with prescribed fire applied during the interim. This allows for the control of woody species annually while allowing for litter to accumulate so that prescribed fire can be applied in the most effective manner in adjacent forested burn units (i.e., litter continuity is critical for the spread of prescribed fire within forests and woodlands). The Natural Areas Program currently manages and oversees 75 Natural Areas, 19 of these (over 5,500 acres) include a mosaic of forest/woodland with grasslands and cedar glades or barrens imbedded. Invasive species management and prescribed fire are adaptively applied for the expansion and maintenance of rare species and communities included.

# LINKING FOREST RESPONSE TO MEASURABLE SOIL WATER AND NUTRIENT CHARACTERISTICS AT LAND BETWEEN THE LAKES, KENTUCKY AND TENNESSEE: CAUTIONS FOR FUTURE RESEARCH

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**ABSTRACT.** For decades, forest researchers have attempted to relate forest growth (e.g., site index) or productivity (stand volume or stand basal area as a surrogate for above ground biomass) to measurable soil water and nutrient characteristics. Early (1965 to 1985) attempts at relating site index to soil or topography were not completely successful with regression models generally accounting for 60 to 85% of the variation. Biological relationships were seldom identified because the independent factors were not directly related to productivity. At Land Between The Lakes (LBL), a National Recreation Area in Kentucky and Tennessee, site index of *Quercus alba* (white oak), and soil and topographic data were collected from 75 stands. The objective was to develop a highly accurate model for predicting site index while defining biologically important relationships. From a soil pit in each stand, samples for texture and nutrient analyses were collected from each horizon to depth of rooting. Aspect, elevation, slope position, and distance to the opposing slope or to the lake edge were also recorded. Statistically, site index was only weakly related to soil texture (percent sand, silt, or clay), water holding capacity (percent water between field capacity and permanent wilting point), and nutrient levels (PPM) of either the A or B horizon. Subsequently, percent available water (determined from texture), and bulk density and horizon depth from field data were integrated into a quantitative measure of available water capacity (AWC in cm) for a given horizon. This horizon AWC value was reduced by the percentage of stone (particles > 2.0 mm) in the horizon. Adjusted AWC was summed for all horizons to a maximum of 90 cm (maximum rooting depth) or to a horizon impermeable to roots (bedrock or fragipan) if less than 90 cm. The final profile value was considered an estimate of the soil water reservoir available to the tree. Horizon nutrient levels (PPM from A & L Soil Testing Laboratories) were converted to kg/ha. Values for the horizons were summed to the same soil depth used to estimate soil water reservoir to obtain an estimate of the nutrient reservoir for the profile (kg/ha). *Quercus alba* site index was most strongly related to three soil factors [calcium (lnCa;  $r = 0.61$ ,  $p < 0.0001$ ), AWC (cm;  $r = 0.46$ ,  $p < 0.0001$ ), and Potassium ( $r = 0.28$ ;  $p < 0.0001$ )]. Site index also was related to three topographic factors [distance to opposing slope or to lake shore ( $r = -0.78$ ;  $p < 0.0001$ ), slope position ( $r = 0.67$ ); and transformed aspect ( $r = 0.66$ ;  $p < 0.0001$ ). A multiple regression model using the six soil and site factors accounted for 90 percent of the variance (adjusted R = 89.9). Because site index was not directly related to soil testing laboratory results (PPM), soil texture fractions, or to surface samples alone, it is apparent that unconverted texture, water, or nutrient values are inadequate to characterize the soil and identify definitive forest growth-soil relationships.

# TWO NEW SPECIES OF *GRATIOLA* (PLANTAGINACEAE) FROM EASTERN NORTH AMERICA WITH A REVIEW OF THE *GRATIOLA NEGLECTA* SPECIES COMPLEX

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**ABSTRACT.** *Gratiola* section *Nibora*, a North American taxon as currently circumscribed includes six species: *G. ebracteata*, *G. flava*, *G. floridana*, *G. heterosepala*, *G. neglecta*, and *G. virginiana*. *Gratiola ebracteata* and *G. heterosepala* are restricted to western North America and the remaining four species are mostly eastern North American. The species with the largest range and greatest degree of morphological variability is *G. neglecta*. A recent investigation of *G. neglecta* involving fieldwork, morphological analysis, phylogeographic study, and molecular phylogenetics has resulted in the discovery of two undescribed species, both of which are endemic to rock outcrop communities of eastern North America. The first new species is endemic to calcareous outcrops and prairies and has a highly disjunct range with populations in Tennessee, Alabama, Illinois, Texas, and Ontario, Canada. The second new species is endemic to granite outcrops in the Georgia Piedmont where it is only known from 13 counties. Both species are compared to their widespread congener, *G. neglecta*, and their systematic relationships are also discussed.

## FLOW DIAGRAMS FOR PATHWAYS OF PLANT SUCCESSION IN THE MIDDLE TENNESSEE CEDAR GLADES

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**ABSTRACT.** Elsie Quarterman's comprehensive study of cedar glade vegetation in the Central (Nashville) Basin of Tennessee did not include flow diagrams for any of the multiple pathways of succession she described in her Ph.D. thesis (Duke, 1948) or in her major publication on the glades (Ecology 31: 234-254, 1950a). Thus, based primarily on Quarterman's study, but also including studies by other plant ecologists and unpublished observations by the authors, we have constructed conceptual models (flow diagrams) for the various (inferred) successional pathways from bare limestone bedrock to climatic climax mixed hardwood forest and to a subclimax redcedar forest. These diagrams will make it easier to interpret the interrelationships of the various plant communities (vegetation zones) in the middle Tennessee cedar glade vegetation complex and will be an aid to conservation planning in the Nashville Basin.



# MORPHOLOGY, ANATOMY, AND ONTOGENY OF THE WATER GAP IN SEEDS OF *IPOMOEA LACUNOSA* (CONVOLVULACEAE)

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**ABSTRACT.** Convolvulaceae is the most advanced plant family (asterid clade) that produces seeds with physical dormancy (PY, water-impermeable seed coat). The initial route of water entry into seeds with PY is a specialized structure ("water gap") in the seed or fruit coat that serves as an environmental signal detector for germination. Heretofore, no studies have accurately documented the presence of a water gap in Convolvulaceae. Thus, our primary objective was to identify the water gap in seeds of *Ipomoea lacunosa* (Convolvulaceae) and to describe it morphologically, anatomically, and ontogenetically. Treatments simulating natural conditions were used to break PY (i.e. open water gap) in seeds of *I. lacunosa*. Morphological and anatomical differences in the hilum area were observed between nondormant and dormant seeds, using light and scanning electron microscopy. Seed development was monitored from ovule (0 DAP) to mature seed (32 DAP). Dormancy break involved formation of a slit around one or both bumps on the seed coat adjacent to the hilum. Dye-tracking experiments showed that dye entered the seed only via the disrupted bumps, and these results were confirmed by a blocking experiment. The bump originated from the same cell layers as the regular seed coat. However, bump development involved a different series of periclinal and anticlinal cell divisions than did that of the regular seed coat. In the bump, the sclereid layer below the palisade layer consists of six sublayers of elongated sclereids and of two sublayers of square-shaped sclereids, whereas in the regular seed coat it consists of four square-shaped layers. Orientation of the palisade and sclereid layers also changed in the transition area between elongated and square-shaped sclereid cells, which is the place where the water gap opens. Differences in water gap anatomy in Convolvulaceae will be compared with that in other families with PY.

## FULLY DEVELOPED EMBRYOS AND PHYSIOLOGICAL DORMANCY IN NYMPHAEACEAE, A FIRST REPORT FOR THE BASALMOST ANGIOSPERMS (ANITA GRADE AND CHLORANTHACEAE)

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**ABSTRACT.** Rudimentary, broad and small linear embryos occur among members of the most primitive (basal) extant angiosperms collectively called the ANITA grade (i.e. *Amborella*, Nymphaeales and Austrobaileyales). *Amborella* (rudimentary) and Austrobaileyales (rudimentary in Austrobaileyaceae, Illiciaceae and Schisandraceae and small linear in Trimeniaceae) have kinds of embryos that are known to be underdeveloped; consequently, they must grow inside the seed prior to radicle emergence (germination). On the other hand, it is not known if broad embryos need to grow before radicles can emerge, and thus whether they are underdeveloped or fully developed. Thus, we addressed the following question: is the broad embryo of Nymphaeales also underdeveloped? Although embryo length:seed length ratio in *Nymphaea* cv. Albert Greenburg, *N. capensis* var. *zanzibariensis* and *N. immutabilis* was 0.311, 0.349 and 0.234, respectively, embryos did not grow prior to radicle emergence. Thus, they are fully developed at seed maturity. If *Amborella* and Nymphaeales are equally the most basal angiosperms, as recent extensive molecular phylogenetic studies indicate, then we must conclude that the broad embryo is equally as primitive as the rudimentary embryo.

**SOME ASPECTS OF THE GERMINATION ECOLOGY OF THE COLD  
DESERT HALOPHYTE *HALOCNEMUM STROBILACEUM*  
(CHENOPODIACEAE) FROM NORTHWEST CHINA**

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**ABSTRACT.** The small leafy succulent shrub *Halocnemum strobilaceum* occurs in saline habitats from northern Africa and Mediterranean Europe to western Asia, and it is a dominant species in salt deserts such as those of northwest China. We tested the effects of temperature, light/darkness and NaCl salinity on seed germination and of salinity on seed germination recovery, radicle growth and radicle elongation recovery, using seeds from northwest China. The results were compared with those previously reported on this species from “salt steppes” in the Mediterranean region of Spain. Seed germination was tested over a range of temperatures in light and in darkness and over a range of salinities at 25°C in light. Seeds that did not germinate in the NaCl solutions were tested for germination in deionized water. Seeds from which radicles had barely emerged (< 1.0 mm) in deionized water were transferred to NaCl solutions for 10 days and then back to deionized water for 10 days to test for radicle growth and recovery. Seeds germinated to higher percentages in light than in darkness and at high than at low temperatures. Germination percentages decreased with increase in salinity from 0.10 to 0.75 M NaCl. Seeds that did not germinate in NaCl solutions did so after transfer to deionized water. Radicle elongation was increased by low salinity, and then it decreased with increase in salinity, being completely inhibited by  $\geq 2.0$  M NaCl. Elongation of radicles from salt solutions < 3.0 M resumed after seedlings were transferred to deionized water. It is concluded that the seed and early seedling growth stages of the life cycle of *H. strobilaceum* are very salt tolerant, and their physiological responses differ between the Mediterranean “salt steppe” of Spain and the inland cold salt desert of northwest China. These differences may be due to maternal and/or genetic effects.

# **FIRE AND THE RIPARIAN ECOSYSTEM**

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**ABSTRACT.** Fire has played an important role in shaping the distribution of plant communities. The use of fire in the United States has come full circle; heavy use in the 1800's, suppression in the 1900's, and now approximately 1,600,000 hectares each year are subjected to prescribed burns in the South to achieve various forest management objectives. However, few studies have examined fire properties and behavior in Eastern deciduous hardwood forest riparian zones, thought to be refugia. Riparian ecosystems often vary from upland counterparts in vegetative composition, hydrology and fuel loading, which alter fire properties and frequency. However, with landscape burns becoming more common, effects of fire on riparian zones must be elucidated. Study sites were chosen at Land Between The Lakes National Recreation Area, a 67,000 hectare highly dissected interfluvium between Kentucky Lake and Lake Barkley. A total of 19 plots were selected, 10 sites will be burned in the spring of 2007, four were burned in the spring of 2006 and the remaining five will serve as non-burned controls. For each site, vegetative data were collected during summer 2006 and will again be collected in summer 2007. Fuel loads were collected for the four previously burned sites during the summer of 2006. For the spring 2007 burn plots, fuel loads and soil samples will be collected shortly before and again shortly after the prescribed fire. Previously burned sites showed a heterogeneous burn pattern, ranging from unburned area to those of low intensity. Fuels remained unburned throughout plots.

# **ENVIRONMENTAL EDUCATION AND THE AT-RISK STUDENT**

**Laurina Lyle**

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**ABSTRACT.** Alternative education in the United States has a mixed and varied history dating from the beginning of public schools. Finding appropriate instruction and curricula by which to educate students classified as "alternative students" has been problematic. In some cases the alternative school is characterized by innovation and provides opportunities for highly motivated students. In other instances, the alternative school removes disruptive students from the regular school setting and provides a setting for remediation. Often, this placement is punitive where students are labeled at-risk. Public alternative schools in Tennessee are structured for students of the later description. While alternative schools succeed in reducing conflict in regular schools by removing the student from the classroom, they do little to increase the at-risk student's community compatibility. The problem posed in this research was to find both an educationally sound and equitable educational experience for at-risk students placed in an alternative school setting. Intuitively, educators sense the alternative school as implemented in Tennessee is a solution that falls short of an acceptable education strategy. My research explored alternative strategies of curriculum design, instruction, and learning for at-risk students through environmental education. Environmental education (EE) is an educational practice that seeks to motivate individuals to embrace and adopt behaviors leading them to becoming more environmentally responsible citizens. Alternative education and EE share this common purpose; however, there has been little research questioning or investigating the provision of EE in short-term, non-residency alternative school settings.

**CONTRIBUTED PAPERS**

**SESSION II: AQUATIC BIOLOGY AND ZOOLOGY**

**Saturday, March 31, 2007**

**Moderated by:**

*Andrew N. Barrass*  
**The Center of Excellence for Field Biology  
Austin Peay State University**



# AGGREGATE EXTRACTION IMPACTS ON UNIONID MUSSEL SPECIES RICHNESS AND DENSITY

Don Hubbs, David McKinney, David Sims, Susan Lanier and Patrick Black

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**ABSTRACT.** Kentucky Reservoir on the Tennessee River supports a diverse freshwater mussel community including federally listed endangered species. Resource extraction operations have been conducted on the Tennessee River since at least the 1920's. The condition of abandoned dredge sites as aquatic habitat for benthic organisms, including freshwater mussels, is relatively unknown. Objectives of this study were to determine the condition of abandoned dredge sites as aquatic habitat for freshwater mussels, compare species richness and density between sites in relation to years post dredging, collect information relevant to future permitting consultations, and provide a greater understanding of the effects of resource extraction in a large regulated river. Six hundred 0.25 m<sup>2</sup> quadrat samples were collected and processed from the twelve study sites. Both mean density (54.51 mussels · m<sup>-2</sup>; SD = 58.335) and species richness (15 taxa; SD = 1) were significantly higher at reference sites than at the dredged sites ( $P < 0.0001$ ). Correlation analysis indicated no significant relationship ( $r = 0.2059$ ,  $P > 0.10$ ) between mean mussel density and time (in years) since the last dredge event. The Wilcoxon's rank sum tests indicated significantly lower mussel abundance ( $P < 0.05$ ) and richness ( $P < 0.05$ ) at the dredge sites relative to the reference sites. Based on data obtained during this study, we will advocate additional protection of specific sites within the lower Tennessee River reach currently permitted for commercial dredging.

## INTRODUCTION

Freshwater mussels (Unionidae) are large bivalve mollusks that live in the sediments of rivers, streams and lakes. Mussels are a food source for many species of fish and terrestrial animals such as raccoons, otters, and muskrats. Adult mussels are suspension feeders that improve water quality by filtering contaminants, sediments, and nutrients. The long life span of unionids (decades to centuries), coupled with their sensitivity to toxic chemicals makes these organisms important indicators of water quality (Strayer et al. 2004). Freshwater mussels are a renewable resource, providing important ecological and economic benefits. Aboriginal peoples utilized mussels for food, tools and ornamentation. Modern commercial exploitation has progressed from pearl hunting and shell button blank material to the production of mother of pearl inlay and cultured pearl nuclei (Parmalee and Bogan 1998). Olson (2005) noted that Tennessee leads the United States in pearl and mother of pearl shell production. According to Hubbs (2003), greater than 90% of Tennessee's multi-million dollar commercial mussel shell harvest is taken from the Kentucky Reservoir portion of the Tennessee River, and this area produces more commercial shell products than anywhere else in the world (Neves 1999).

Riverine ecosystems account for the highest species richness of freshwater mollusks among various habitat types because these ecosystems are more permanent in regards to evolutionary time scale (Neves et al. 1997). The mussel fauna of the southeastern United States evolved in rivers suited to their life history needs where clean water flowed over shoals composed of sand and gravel. Southeastern rivers once supported a freshwater mollusk species richness of unparalleled proportion (Ahlstedt et al. 2004). In large river systems freshwater mussels typically occur in dense aggregations (10 - 100 mussels · m<sup>-2</sup>) known as "mussel beds". Freshwater mussels are intolerant of adverse changes in water and habitat quality, and cannot survive excessive exposure to fine sediment, which clogs the gills and interferes with respiration, feeding and reproduction (Dennis 1984). Except for a brief parasitic larval stage on fish, freshwater mussels spend their entire lives partially or completely buried in the river bottom. Sedentary by nature, freshwater mussels require a stable bottom environment with good current to bring food and disperse reproductive elements and metabolic waste products. Thus, an abundant and diverse mussel bed is an indicator of good habitat quality.

Habitat alteration resulting from in stream activities has been identified as a contributing factor in the precipitous decline of North American freshwater mussel resources. Watters (2000) concluded that hydraulic impacts to freshwater mussel habitats are often catastrophic, both immediately and over time. He further noted

that impacts resulting in mussel declines rarely have a single causative agent. Yokley (1976) observed decreased mussel shell growth rates at sites located downstream of commercial dredging operations. Dennis (1984) demonstrated that high concentrations of suspended silt interfere with food uptake of freshwater mussels. Loss of productive substrates resulting from altered stream morphology may result in long term declines in aquatic invertebrate abundance and corresponding declines in the organisms that depend on them as food.

Aggregate resource extraction operations have been conducted on the Tennessee River since at least the 1920's. In Tennessee, commercial dredging operations are regulated by the United States Army Corps of Engineers (USACE), Tennessee Valley Authority (TVA) and the Tennessee Department of Environment and Conservation (TDEC) in consultation with the US Fish and Wildlife Service (USFWS) and Tennessee Wildlife Resources Agency (TWRA). In-stream aggregate mining is accomplished using draglines, shovels or dredges. The hydraulic suction dredge is the most common implement currently employed in the removal of sand and gravel deposits on the Tennessee River. Commercial operations abandon dredging sites when the production of marketable aggregates fails to produce acceptable profits. Dredge operators must continually seek areas that have not been depleted of sand and gravel resources to maintain profitability.

The condition of mined areas as habitat for freshwater mussels is not well documented. However, Nelson (1993) noted that in-stream mining increases bedload movement and turbidity, changes substrate composition and stability, and alters stream morphology. Further, substrate type is directly tied to benthic production where more diverse invertebrate assemblages are associated with complex gravel substrates. He also indicated that increased sedimentation and turbidity can limit primary productivity, secondary production, destroy fish spawning habitat, and stocks. These impacts vary with habitat type, biota, and extent of mining activity.

Dredge operators must apply for new permits at five year intervals; current permits are valid until January 2007. In 1989, the permitting process resulted in ~ 89 km of the lower Tennessee River, between Tennessee River km (TRK) 131 – 314, being excluded from commercial dredging activity. This process also resulted in the protection of nine islands in the lower Tennessee River, prohibition on dredging adjacent to the mouths of tributary streams, and within 46 m of the shoreline. Objectives of this study were to determine the condition of abandoned dredge sites as aquatic habitat for freshwater mussels, compare species richness and density between sites in relation to years post dredging, collect information pertinent to future permitting consultations, and provide a greater understanding of the effects of resource extraction in a large regulated river.

## METHODS

### Study Area

Kentucky Reservoir is operated by the TVA for flood control, water supply, and hydroelectric power generation. It flows 296 km northward from Pickwick Dam (completed in 1938) at TRK 333 in Hardin County, TN to Kentucky Dam (completed in 1944) at TRK 36 near Gilbertsville, Kentucky. The Tennessee portion of the reservoir contains 3,171 shoreline km and approximately 44,918 surface ha, ending at TRK 80 in Stewart County, TN. Main channel and over-bank width ranged from 0.40 - 3.2 km and offer diverse and abundant habitats for freshwater mussels. The study reach is located south of the confluence with the Duck River at TRK 179. Commercial sand and gravel dredging is currently permitted on approximately 77 km of this 152 km reach. Lotic habitats are maintained by minimum flow and hydroelectric power generation releases which dominate this reach.

Recent records for several endangered mussel species exist for this reservoir reach (Hubbs 2002). Population densities can exceed 100 mussels · m<sup>-2</sup>. In this reach, mussels are typically found in water depths ranging 1 – 10 m, buried in sand and gravel deposits around the inside river bends and at the head and tail areas of mainstream islands. Mussel recruitment in these habitats is generally high, and they have served as important areas for commercial mussel harvest for many years.

## Site Selection

TWRA and USACE personnel selected study sites during September 2000. Potential study sites were located by referencing USACE commercial dredging activity file data followed by field verification. During two days of field reconnaissance, a boat equipped with a differentially corrected Global Positioning System (GPS) and liquid crystal display depth sounder traversed each potential site. Nine dredged sites were selected based on evidence of dredging activity (e.g. clearly defined trenches, holes and sudden changes of river bed contour) indicated by depth soundings (Fig. 1). Once a dredged area was located, the GPS coordinates for the site were recorded along with references to physical structures (navigation lights, buoys or other permanent structures) and approximate river km location from USACE navigation charts. Dredged site depths ranged from 6 - 20 m, and had not been dredged for periods ranging from 1 - 15 y.

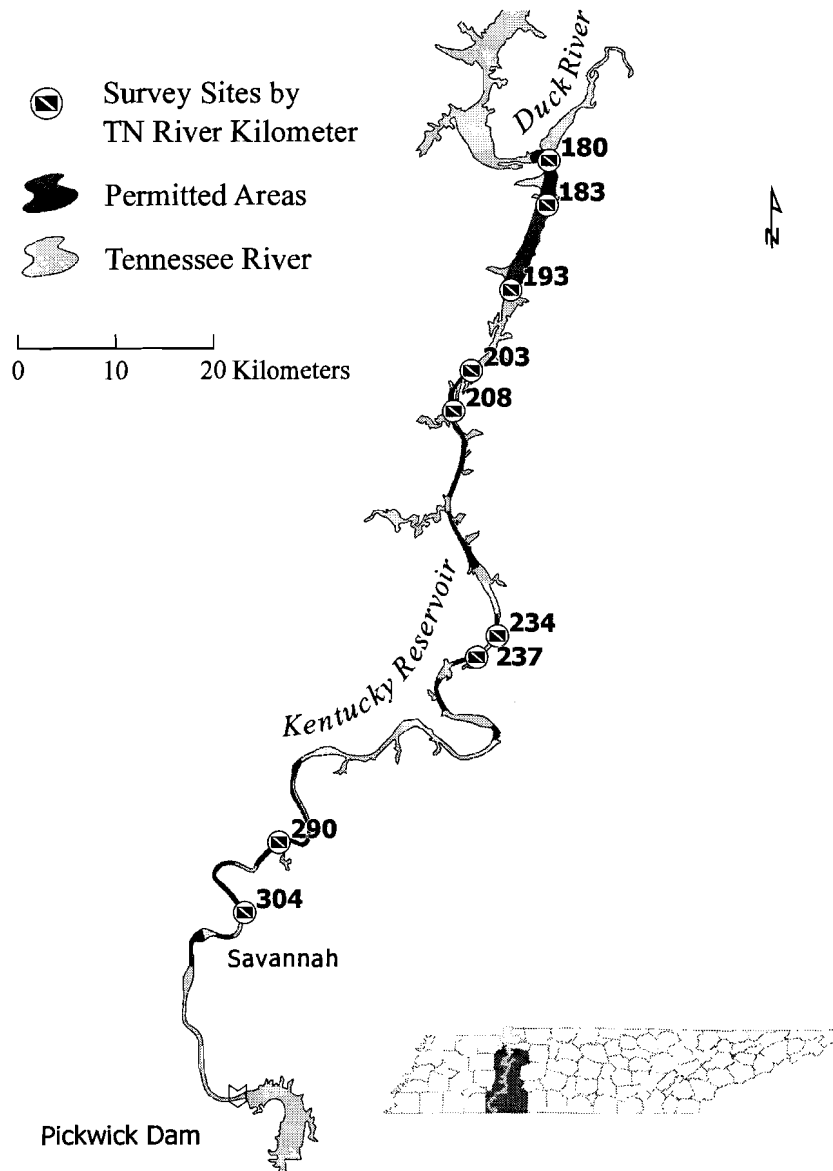


Figure 1. Kentucky Reservoir permitted commercial sand and gravel dredging areas and abandoned dredge sites sampled during 2001 – 2002.



Three reference sites were chosen based on relative proximity to the previously selected dredge sites, habitat characteristics, and presence of an extant mussel population. Reference sites were dispersed throughout the study reach in areas where dredging was permitted for only one side of the river. Reference sites appeared to have physical characteristics similar to dredge sites prior to resource extraction, and their representation of the mussel fauna inhabiting the immediate vicinity. Reference site depths ranged from 7 - 13 m.

### Freshwater Mussel Sampling

Freshwater mussel sampling began in May 2001, and was completed in September 2002. Sites were located by navigating to the dredged area using previously recorded GPS and sonar data. Once the site location was established, a 150 m sample reach was marked with survey flagging, and individual stations were selected and sampled by anchoring the boat and deploying the divers. Each site was sampled at five stations, approximately 30 m apart.

Work began at the downstream end of each site and progressed upstream. Divers employed SCUBA and surface air supply equipment during sample collection. At each station, 10 replicate quadrat ( $0.25 \text{ m}^2$ ) samples were collected by hand. Samples were spaced at a distance of ~ 2 m. Visibility was generally > 1 m and underwater flashlights were used to assist mussel gathering. All live mussels and substrate within each  $0.25 \text{ m}^2$  metal frame were removed to a depth of ~ 10 cm. All mussels were identified to species, counted, and measured (length in mm). Mussels not retained as voucher specimens were returned to the river prior to repositioning the boat at the next station.

### Data Analysis

Freshwater mussel data were analyzed using Statistical Analysis System (SAS) software. Quadrat counts were pooled across sites and anchor points within the dredge and reference site types. A Wilcoxon's rank-sum test was used to test for differences in mussel density between dredge and reference sites. To test for differences in species richness between dredge and reference sites, the total number of different species reported at each sample site was compared using a Wilcoxon's rank sum test.

## RESULTS

We found a total of 15 mussel species at dredge sites and species richness ranged from 0 - 9 species per site. Mean richness at dredge sites was 3.67 species ( $P < 0.0001$ ,  $SD = 2.916$ ). Ebony shell (*Fusconaia ebena*) was the most abundant species (54.6%), followed by pink heelsplitter (*Potamilus alatus*, 10%), mapleleaf (*Quadrula quadrula*, 8.2%) and threeridge (*Amblema plicata*, 6.4%); (Table 1). We found 110 mussels at dredged sites and abundance ranged from 0 - 42 mussels per site. Mean mussel density ranged from 0 - 3.36 mussels  $\cdot \text{m}^{-2}$ . The mean density from all 450  $0.25 \text{ m}^2$  quadrat samples was estimated at 1.02 mussels  $\cdot \text{m}^{-2}$  ( $P < 0.0001$ ,  $SD = 3.042$ ).

Density and species richness values were significantly higher ( $P < 0.0001$ ) at reference sites than at dredged sites. A total of 19 species were encountered at reference sites and richness ranged from 14 - 16 species ( $\bar{X} = 15.0$ ). Total abundance was 2,044 mussels (Table 1). Both mean density (54.51 mussels  $\cdot \text{m}^{-2}$ ;  $SD = 58.335$ ) and species richness (15 taxa;  $SD = 1$ ) were significantly higher at reference sites than at the dredged sites. Ebony shell was the most abundant species and comprised 83.9% of all mussels (Table 1).

Six hundred  $0.25 \text{ m}^2$  quadrat samples were collected and processed from the twelve study sites (Table 1). Correlation analysis indicated no significant relationship ( $r = 0.2059$ ,  $P > 0.10$ ) between mean mussel density and time (in years) since the last dredge event. The Wilcoxon's rank sum tests indicated significantly lower mussel abundance ( $P < 0.05$ ) and richness ( $P < 0.05$ ) at the dredge sites relative to the reference sites.

**Table 1.** Mussel species occurrence and density estimates collected during quantitative sampling from 2001 - 2002.

River km	Dredge Sites									Reference Sites				
	180	183	193	203	208	234	237	290	304	Total	203	234	304	Total
<b>Species</b>														
<i>Amblema plicata</i>	2						5			7		2	3	5
<i>Arcidens confragosa</i>										0	1			1
<i>Cyclonaias tuberculata</i>										0	1		5	6
<i>Elliptio crassidens</i>							1			1	8	29	6	43
<i>Ellipsaria lineolata</i>			1					1		2	5	11	10	26
<i>Fusconaia ebena</i>	4						3	36	17	60	96	983	636	1715
<i>Fusconaia flava</i>	1									1				0
<i>Leptodea fragilis</i>			1							1	3	11	4	18
<i>Ligumia recta</i>								1		1		1	3	4
<i>Megaloniaias nervosa</i>				1			1		1	3	7	5	2	14
<i>Obliquaria reflexa</i>										0	2	10	13	25
<i>Pleuroberna cordatum</i>	1									1	1	5	3	9
<i>Potamilus alatus</i>	1	2	3		1		2	2		11	5	5	2	12
<i>Quadrula apiculata</i>	2	1	2							5	3	1		4
<i>Quadrula metanevra</i>									2	2			20	20
<i>Quadrula nodulata</i>										0	3			3
<i>Quadrula pustulosa</i>	1							2	1	4	9	18	68	95
<i>Quadrula quadrula</i>	5			1			3			9	13	4	4	21
<i>Truncillia donaciformis</i>										0		10	5	15
<i>Truncillia truncata</i>	2									2		6	2	8
<b>Species Richness</b>	9	2	5	1	1	0	6	5	4	15	14	15	16	19
<b>Mussel Abundance</b>	19	3	8	1	1	0	15	42	21	110	157	1101	786	2044
	<b>Mean</b>										<b>Mean</b>			
<b>Density · m<sup>-2</sup></b>	1.5	0.2	0.6	0.1	0.1	0	1.2	3.4	2	1.02	13	88.1	63	54.5

## DISCUSSION

Our results indicate that freshwater mussel density, total abundance, and species richness were significantly lower at dredged sites than at adjacent reference sites, and suggest that mussel populations are slow to recover following dredging (up to 15y past). Substrates altered by dredging provide poor conditions for establishment of mussel populations. All three reference sites were located adjacent to dredge sites and habitat characteristics appeared similar to pre-dredging conditions. Ebony shell was the most abundant freshwater mussel species collected during this study. Ebony shell is the dominant freshwater mussel species in Kentucky Reservoir and appears well-suited to reservoir habitats. However, even this adaptable species was not able to colonize recently dredge sites.

Pennington (2001) reported that macroinvertebrate (excluding unionids) species richness in Kentucky Reservoir was greater at six of seven dredged locations than at adjacent reference sites. Macroinvertebrate abundance was higher at dredged sites than at reference sites. Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) species richness was reported as similar for both dredged and reference sites with approximately four species per site. Reporting that only the most recently dredged

location showed a statistically significant reduction in macroinvertebrate species richness, Pennington (2001) concludes that re-colonization of dredged locations by benthic macroinvertebrates is to be expected. However, the relatively short life cycle of most benthic macroinvertebrates inhabiting the study reach permitted them ample opportunity to colonize favorable habitats. Whereas, freshwater mussel life histories are protracted and complex; mussels require stable habitats that facilitate close association with their respective fish hosts during spawning to allow mussels an opportunity to complete their life cycle.

Upstream of Kentucky Reservoir, the mainstream Tennessee River is impounded by eight hydroelectric dams. The movement of sand and gravel in the Tennessee River is drastically altered by these huge impoundments. Reduced movement of sand and gravel through the lower Tennessee River makes these materials a limiting resource for freshwater mussels. The most valuable commercial material obtained by dredging in the lower Tennessee River is sand. The large conical depressions which remain after deep water suction dredging collect fine colloidal silts and clay. Although dredged areas tend to become level over time, the amount of embedded silt and clay retained in post-dredged areas is much greater than in historical shoals. Pennington (2001) reported that relative to control sites, substrate at dredged locations exhibited a reduction in gravel from 75% - 39% and an increase in sand, from 22% - 49%. Similarly, silt increased in dredged sites from 2% - 8% and clay from < 1% - 4%.

Our study examined a reach within the lower Tennessee River from Pickwick Dam (TRK 333) to confluence of the Duck River (TRK 179). This reach offers the longest river segment that still contains suitable habitat for conservation and restoration of surviving mainstem Tennessee River freshwater mussels, including commercially important, threatened, and endangered species. Shannon et al. (1993) noted that without habitat protection, conservation and restoration of freshwater mussel resources is not possible. Results of our study suggest that dredged sites afford poor mussel habitat relative to reference sites. Mussel populations at dredged locations will likely require decades to recover.

The next five-year permit process should, at a minimum, result in dredging being restricted to currently permitted lower Tennessee River segments in effect since 1989. The USACE should conduct an evaluation of the impact of current resource extraction on river channel and habitat stability both adjacent to dredge operations and upstream and downstream of extraction sites. Of particular concern is the stability of the important island complexes found between TRK 179 – 314. Resource extraction can result in new deep water habitat. Understanding the influence of these habitat alterations on the complex interactions between freshwater mussels and their host fish is essential for the conservation of these resources in this river reach. Based on data obtained during this study, TWRA will advocate additional protection of specific sites within the lower Tennessee River currently permitted for commercial dredging.

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# PRELIMINARY RESULTS OF FUNNEL TRAP SAMPLING OF POND MACROINVERTEBRATES AT THE MILAN ARMY AMMUNITION PLANT, CARROLL AND GIBSON COUNTIES, TENNESSEE

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**ABSTRACT.** Ten centimeter diameter clear PVC funnel traps were used to collect aquatic macroinvertebrates from ponds at the Milan Army Ammunition Plant, Carroll and Gibson counties, Tennessee. Over two five-day periods in June 2006, ten ponds, five with and five without cattle access, were sampled by using 2 horizontal and 2 vertical funnel traps in each. The traps were retrieved and the macroinvertebrates collected and identified. The insect orders Coleoptera and Hemiptera were the main groups focused on in this preliminary study although most taxa were identified to genus. The vertical traps contained more individuals of all aquatic macroinvertebrates, while the horizontal traps contained more taxa. The horizontal traps contained most of the same taxa as the vertical traps as well as some unique taxa. Horizontal traps captured significantly more coleopteran taxa than did the vertical traps. Horizontal traps appear to collect more hemipteran taxa than vertical traps although these results were not significant. The horizontal traps appear to capture samples that are more representative of the biodiversity of the macroinvertebrates in these lentic communities, although additional sampling methods may be required to assess the biodiversity in these systems.

## FUNCTION OF *HEXAGENIA* (MAYFLY) BURROWS: FLUID MODEL SUGGESTS BACTERIAL GARDENING

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**ABSTRACT.** Lake and stream bottoms experience an array of physical, chemical, and biological processes that create spatial variations both in the fluid column and in the sediment that provide a physical template for distinct niches. Burrowing insects are major ecological engineers of communities where they structure large areas of the benthic habitat through bioturbation and other activities including respiration, feeding, and defecation. The burrowing mayfly *Hexagenia*, when present in high densities, has a large impact on food-web dynamics and provides essential ecosystem services within the fluid column and benthic substrate, including sediment mixing, nutrient cycling, and ultimately, energy flow through the freshwater food web. It has long been recognized that particular benthic species are important in linking detrital energy resources to higher trophic levels and for determining how organic matter is processed in freshwater ecosystems; however, the unique contributions made by individual benthic species is largely absent from the literature. Here we present a model that describes the structure and function of a *Hexagenia* burrow. If testing supports this hypothesis, the model suggests that when high food concentration is available to *Hexagenia*, there exists a favorable tube length for harvesting bacteria that grow on the burrow walls. The burrow microhabitat created by *Hexagenia* serves as a case-study in understanding the influence of benthic burrowers on both energy flow through freshwater food webs and nutrient cycling.

# DIATOM COLONIZATION PATTERNS IN FRESH WATER SPRINGS, LAND BETWEEN THE LAKES NATIONAL RECREATION AREA, IN RELATION TO UNDERLYING GEOLOGY

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**ABSTRACT.** Diatoms (Bacillariophyta) are algae known for their sensitivity to chemical conditions in water. Therefore, they are a useful supplement to chemical analyses in assessments of water quality. Parent geology determines conductivity, alkalinity, pH and nutrient concentrations in spring ground waters that ultimately seep into streams. Spring water chemical factors may influence species composition of periphyton colonizing stream substrates. In October 2006, an exploratory study of diatom colonization patterns was carried out in several springs emerging from different geological materials in Land-Between The Lakes National Recreation Area located in western Kentucky and Tennessee. Two springs emerge from limestone geology (Panther and Mint in the south) and two springs emerge from siliceous/argillaceous geology (Barnett and Brown in the north). Unglazed quarry tiles were deployed in each stream a few meters downstream from each spring and were allowed to colonize for four weeks. The tiles were retrieved, diatoms were identified to genus, and biomass was determined from chlorophyll *a* analysis. Physiochemical characteristics and nutrient concentrations also were measured in each spring. There were significant differences between at least two of the springs in dissolved oxygen, alkalinity, pH, DO, turbidity, SiO<sub>2</sub>, SO<sub>4</sub>, Cl, and SRP concentrations. Discharge, chl *a*, NO<sub>3</sub>+NO<sub>2</sub> and NH<sub>4</sub> were not significantly different among any of the springs. Only conductivity was significantly different among all four springs. *Achnanthes*, *Cocconeis* and *Gomphonema* were dominant in the carbonate streams with limestone geology (Panther and Mint springs); these taxa are calciphilous and high conductivity (107–481 uS cm<sup>-1</sup>) provide optimal conditions for growth. *Diatoma*, *Eunotia*, and *Pinnularia* were more abundant in the streams with siliceous and argillaceous geology (Brown and Barrett springs); these taxa are considered acidophilous and low conductivities (48–163 uS cm<sup>-1</sup>) are optimal for growth. This study will be expanded over the next 8 months to test the hypothesis that springs with contrasting geologies (and therefore different water chemistries) will develop different diatom community compositions. Developmental sequence analysis of stream periphyton also will be used to test the hypothesis that different spring water origins as defined by stable isotope (<sup>13</sup>C) signatures will be reflected in the biomass of periphyton colonizing the substrata over time.

## SEASONAL VARIABILITY IN NITROGEN LOADING AND RELATED FACTORS AT PANTHER CREEK, LAND BETWEEN THE LAKES

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**ABSTRACT.** Recent nutrient transport and spiraling studies have focused on the sources and delivery of nutrients, notably nitrogen, to streams. However, much information is missing regarding how other physical quantities and natural processes within the channel affect the nitrogen levels after reaching the stream. This study expands our knowledge on nutrient spiraling in a low-order gravel bedded channel and surrounding watershed. The primary goal of this study was to create a physical description of a 600 m reach of Panther Creek in the Land Between The Lakes area of Tennessee. The predominant focus of the research is on nitrogen loading in the stream, specifically tracking the levels of ammonium and nitrate over time. Then, incorporating measurements such as the pH, temperature, specific conductivity, and amount of sunlight reaching the stream, a more complete description of the stream reach was created. We collected data over a period of 9 months, from July 2006 to March 2007; data collection will continue into May 2007. Current results suggest that seasonal variations in the relative contributions of base flow and storm flow contribute to important overall temporal variations in the nitrogen levels in the stream; these levels are then modulated locally by reactions associated with both hyporheic flows and variations in nitrogen uptake/release by benthic organisms. With an average rainfall of 134.5 cm per year, a significant amount of water enters the stream to add different chemical compounds including ammonium and nitrate. When completed, this study will provide key baseline data and analysis for several related studies on coupled physical-biological processes in the Land Between The Lakes area.

# THE IMPORTANCE OF GRAVEL BARS ON NUTRIENT SPIRALING IN LOW-ORDER STREAMS

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**ABSTRACT.** The importance of the connection between nutrient transport and local stream geomorphology is becoming increasingly important. Studies have shown that the interconnectivity of nutrient cycles in the downstream direction is in part controlled by the distribution and size of gravel bars in low order streams, as hyporheic flow occurs dominantly through alternate and mid-channel gravel bars. For this investigation multiple gravel bars in a 3<sup>rd</sup> order bedrock-alluvium stream were studied to determine general relationships between nutrient spiraling and hyporheic flow. The first goal was to understand (1) the extent to which water moves through hyporheic zones and (2) the basic chemistry of the hyporheic water. The second part of the study was to understand how nutrients, notably nitrogen, are affected in their cycling by the relatively long residence times encountered in gravel bars during hyporheic flow. Wells were installed along a 600 m reach of Panther Creek, KY in selected bars, as well as in a secondary location involving a grid installation pattern in one large bar. Results have shown that hyporheic flow through gravel bars is an important factor in influencing stream chemistry. Rhodamine WT was used in field tracer tests to track the travel times of water through bars as well as partitioning of water between the open channel and hyporheic flows. Further tests will be conducted utilizing a stable isotope study to determine how nitrogen is affected by hyporheic flow, and what implications this has for nutrient transport. We expect results to show that the spacing and size of gravel bars is a dominant control in key nutrient spiraling parameters, namely uptake lengths and overall nitrogen cycling rates. This has implications for how natural systems will respond to human impacts, both through the modification of the physical template of stream systems as well as increased anthropogenic loading of nitrogen.

# AN ESTIMATE OF DAILY METABOLISM IN A BEAVER-IMPOUNDED SYSTEM IN SOUTHERN LBL

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**ABSTRACT.** Metabolism was estimated in a 0.46 hectare beaver impounded system in southern Land Between The Lakes National Recreation Area during the months of September, October and November of 2006. Net daily metabolism (NDM) was estimated from diel oxygen curves using a single-station open-system approach modified from stream ecology methods. Gross primary production (GPP) ranged  $1.64 - 3.53 \text{ g m}^{-2} \text{ d}^{-1}$ , community respiration (CR) ranged  $0.05 - 3.10 \text{ g m}^{-2} \text{ d}^{-1}$ , and NDM ranged from  $-0.57$  to  $1.57 \text{ g m}^{-2} \text{ d}^{-1}$ . GPP increased as water temperature declined and CR continually declined with temperature resulting in a shift from net heterotrophy to net autotrophy from the September sampling period to the October sampling period. GPP began to decline as temperatures fell below  $18 \text{ }^{\circ}\text{C}$ , but the continual reduction in CR prevented a shift back towards net heterotrophy. The photosynthetic activity of a dense epipelagic algal community controlled by temperature and light is the factor likely influencing the metabolic shift. The results of the current study are preliminary and will be part of a year-long study to be presented next summer.



## **ENDEMICITY OF *BORRELIA BURGdorFERI*, THE BACTERIAL AGENT OF LYME DISEASE, IN MIDDLE TENNESSEE**

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**ABSTRACT.** Lyme disease is the most common tick-borne disease in the United States and is transmitted by the pathogenic bacterium *Borrelia burgdorferi*. *B. burgdorferi* is perpetuated in nature through a complex enzootic life cycle involving ticks of the *Ixodes* complex and various animal hosts. Historically, mice from the *Peromyscus* genus were commonly considered the prevailing host for *B. burgdorferi*. However, recent data indicate that birds play a much larger role than previously appreciated. This study focuses on identifying the true ecological niche of *B. burgdorferi* in middle Tennessee by surveying both rodents and birds. Additionally, this study compares typical ear biopsy surveillance methodologies to a more invasive approach where several tissues are analyzed for *B. burgdorferi* infection. A total of 172 rodents and 30 songbirds were collected from seven counties and analyzed by both DNA-based assays and typical microbial culturing for *B. burgdorferi* infection. The data revealed that 25% of rodents and 41% of birds harbored *B. burgdorferi*, indicating a significant presence of the Lyme disease-causing bacteria in the middle Tennessee region. Regarding the survey methods, if only ear biopsies were used then approximately 11% of the animals would have been properly identified as infected. These data give new insight to the true endemicity of *B. burgdorferi* in nature and a heightened awareness of Lyme disease risk in our community while also enhancing our knowledge of reliable *Borrelia* screening techniques.

## **HERPETOFAUNAL DIVERSITY AND ABUNDANCE AT CATTLE ACCESS AND NON-CATTLE ACCESS PONDS AT THE MILAN ARMY AMMUNITION PLANT: A PRELIMINARY REPORT**

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**ABSTRACT.** Little work has been done on the effects of cattle on co-existing populations of amphibians and reptiles, and much of the previous work deals with cattle ponds that are inhabited by fish. Fish are known predators of anuran and salamander populations, thus can limit their numbers in a given area. This ongoing study aims to compare the herpetofauna and water quality in and around 18 fishless ponds (nine with cattle present and nine where cattle are absent) at the Milan Army Ammunition Plant. Data obtained from June through December 2006 will be reviewed. Funding provided by a grant from American Ordinance.

# LETHAL AND SUBLETHAL EFFECTS OF NUTRIENT POLLUTION ON AMPHIBIANS

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**ABSTRACT.** Fertilizer application is a widespread practice that greatly affects aquatic ecosystems in a variety of ways. Previous studies show that nitrate toxicity could be a major problem for amphibians at elevated levels, though few studies examine sublethal effects. On the other hand, phosphate has not been evaluated at all for toxic effects. To examine nutrient toxicity, laboratory experiments were conducted to measure the response of American Toad and Cope's Gray Treefrog tadpoles to various concentrations of nitrate and phosphate. The phosphate experiments exposed Cope's Gray Treefrogs to five treatments with concentrations ranging from 0 to 200 mg/L P-PO<sub>4</sub> and lasted for 15 days. Nitrate was examined in both the American Toad and Cope's Gray Treefrog using seven treatments: four with constant concentrations, ranging from 0 to 5 mg/L N-NO<sub>3</sub>, and three pulses that simulated the quick increase in concentration to 5 mg/L and slow decline that would be associated with runoff from a rain event. Pulses were timed at different points during development. Phosphate was found to have no effect on any of the lethal or sublethal responses in Cope's Gray Treefrogs, indicating that phosphate may not be toxic to this species. Nitrate had no effect on American Toads but did affect the Cope's Gray Treefrog. Individuals from the treatment with the pulse late in development had more extreme directional asymmetry than other treatments in calcaneum length. The late pulse occurred during hind limb development; directional asymmetry in a hind limb trait suggests the disruption of the developmental process during the sudden increase in the concentration of nitrate.

## A STUDY OF AMPHIBIAN POPULATIONS INSIDE AND OUTSIDE A COMBINED SEWAGE OVERFLOW DRAINAGE IN MONTGOMERY COUNTY, TENNESSEE

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**ABSTRACT.** Combined Sewer Overflows (CSOs) carry both sanitary sewage and stormwater runoff. When the carrying capacity of the system is exceeded some of the mixture of sewage and water may overflow and find its way into streams and other bodies of water in the surrounding drainage basin. This study looked at the amphibian fauna along a first-order stream in a CSO drainage basin of Clarksville, Tennessee and compared it with that of two other streams of similar size and character: 1) another urban stream in an adjacent drainage of Clarksville that had separate sewage and storm-water systems and 2) an Environmental Protection Agency reference stream in a rural setting 20 km to the southeast. Sampling involved time-constrained searches that were conducted in spring, summer and fall at three sample sites along each stream from October 2004 through July 2006. Species richness of salamanders was lowest in the CSO drainage and highest in the reference stream but no significant difference was detected between or among any of the sites. Frogs were absent in both of the urban streams, but were numerous in the reference stream, representing 6 species. Abundance of individuals (excluding the frogs) was lowest in the CSO drainage, somewhat greater in the adjacent urban stream, and highest in the rural reference stream. Results indicate that amphibian abundance in an urban setting is lower in streams with CSOs than in those where sewage and stormwater are conveyed separately. Also suggested is a richer and more abundant amphibian fauna in rural versus urban drainages. Funding for this project was provided by Austin Peay State University's Center for Field Biology.

# **RECENT INVASION OF THE GREEN TREEFROG, *HYLA CINEREA*, INTO UPLAND REGIONS OF SOUTHEASTERN UNITED STATES**

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**ABSTRACT.** The distribution of the Green Treefrog, *Hyla cinerea*, has historically been considered closely tied to the Atlantic and Gulf Coastal plains of the southeastern United States. Surveys of sites in Kentucky and Tennessee conducted beginning June 2006, combined with historical data indicate that this species has been progressively invading upland ecoregions adjacent to the Coastal Plain in the period 1980-present, with much of the expansion occurring in the last 10 years. Formerly known only from the lowermost 65 river miles and from a small stretch near river mile 370, populations of this species may now be present throughout the lower 420 river miles of the Tennessee River in Kentucky, Tennessee, and Alabama. Dramatic range expansions have also occurred in the Cumberland and Ohio valleys in Tennessee, Kentucky, and Indiana, and in the Piedmont of South Carolina and Georgia. Efforts are made to describe the probable historical and current ranges of the species and possible reasons for its recent range expansion. Funding for this project was provided by Austin Peay State University's Center for Field Biology.

## **MONITORING OF SITE FIDELITY OF *PIPISTRELLUS SUBFLAVUS* AND OTHER BAT SPECIES: TRENDS AND CURRENT STATUS IN DUNBAR CAVE STATE NATURAL AREA, MONTGOMERY COUNTY, TENNESSEE**

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**ABSTRACT.** Site fidelity of *Pipistrellus subflavus*, *Eptesicus fuscus*, and *Myotis lucifugus* was monitored at Dunbar Cave throughout winter and spring seasons to determine spacing or aggregation within cave chambers. Chamber-specific marking techniques were used to observe seasonal variation of site fidelity throughout the winter hibernacula and spring emergence periods. Spatial dispersion and roosting site relationships of various species were monitored using GIS mapping. Species richness varied little among the chambers within the cave. Aggregations of individuals were found in the majority of chambers throughout the cave. Roost switching by marked individuals suggests a strategy to maintain a balance between human interaction and available habitat. During spring emergence, roost switching demonstrates cooperative social behaviors among occupied chambers. Some chambers, however, remain devoid of bats, perhaps related to contaminant residue on the limestone surfaces. Historically, population levels of bats have varied due to lengthy and ongoing human impacts on cave habitat.