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*A Century of Commitment*

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# CELEBRATING 100 YEARS

THE ILLINOIS STATE ACADEMY OF SCIENCE CAME INTO BEING IN 1907, WITH THE FIRST ORGANIZATIONAL MEETING HELD DECEMBER 7TH IN SPRINGFIELD, ILLINOIS.

FOLLOWING IS THE INAGUARAL ADDRESS, THE ADVANTAGES OF A STATE ACADEMY OF SCIENCE, BY T.C. CHAMBERLIN, AS PRINTED IN VOLUME 1 (1908) OF THE *TRANSACTIONS* OF THE ILLINOIS STATE ACADEMY OF SCIENCE.

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# FROM THE 1908 INAUGURAL ISSUE OF *TRANSACTIONS* OF THE ILLINOIS STATE ACADEMY OF SCIENCE

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# The Advantages of a State Academy of Science

T.C. Chamberlin

The opening address, by Professor Chamberlin, on *The Advantages of a State Academy of Science*, was given in the extemporaneous form, and the following outline very imperfectly represents what was said.

Professor Chamberlin introduced his address by conveying the felicitations of the Chicago Academy of Sciences, and sketched some of the salient features of its history of a little more than fifty years as a means of giving concrete illustration to some of the problems which the new academy must face. Special attention was directed to the radical change in the nature and relations of scientific activity since the oldest academies of the interior were established. In the pioneer days, an almost virgin field was open to naturalists, and enthusiasts in this field constituted the largest factor in the membership of its academies of science during their early stages of development. The results of these pioneer workers were much more fully within the appreciation of all their colleagues and of the intelligent public than are the products of the more highly specialized investigations of today. So widely has research deployed in the last fifty years, and so far has it reached into the more recondite phases of each field, that there is now far less community of interest and of intelligent appreciation, even among scientific workers themselves. This fundamental change brings new problems of organization and of adjustment. In like manner, the function of an academy as an avenue of publication has assumed a new aspect. Fifty years ago, an appropriate means of publication was one of the greatest needs which the academies supplied to the pioneer workers, for, aside from these academies, the available opportunities of giving publicity and permanence to scientific results were few and unsatisfactory. As the regional element was dominant in the results of the early naturalists, it was fitting that there should be a local means of publication. Today, however, the results of research are, in general, more serviceable to scientific workers if they are gathered into the special journals devoted to the several departments of science.

While the function of publishing the results of regional investigations still remains, and may well continue to be subserved by the regional academies of science, and while certain adaptations of other results may serve an important regional purpose, the question whether an academy should endeavor to be the avenue of miscellaneous publication to the same extent as in the early days is one of the problems that invite serious consideration of a new academy.

Attention was also directed to the problems presented by the geographic distribution of the centers of scientific activity within the State and by the not altogether felicitious relations of these centers to the capital of Illinois.

The advantages of a state academy to those who are just entering upon scientific careers, to amateurs dissociated from institutions of research, to trained workers in relative isolation, and to workers in scientific centers, were specifically set forth. The values to be derived from opportunities of reading papers before fellow workers, of submitting results to discussion, of participating in the discussion of others' results, of extending scientific acquaintance, of co-operation, of mutual stimulus to endeavor, of personal education by contact with other workers, were dwelt upon in detail. The value of the academy as a means of disseminating the spirit, the method, and the love of science among the people of the State was especially emphasized. The function of advising relative to legislation on scientific matters was urged as highly important.

The address closed with an earnest advocacy of the value of the spirit and method of science to the state and nation as an essential element in the solution of its great social, political, and ethical problems. The habit of conscientious search for the precise truth and the systematic control and guidance of opinion and action in accordance with the canons of scientific procedure were urged as means of supreme value in the elevation and purification of the common thought and feeling of our people. More than anything else, are the intellectual and moral methods of science a protection against current evils and a guarantee of safety in the future.

# Errata

The paper by Bluett, Hulin, Hubert, & Anderson on Monitoring the Status of Mink (*Mustela vison*) in Illinois which appeared in Issue #1&2 of *Transactions* volume 99 (2006) was inadvertently printed ≤ symbols where ≥ symbols should have appeared instead. Corrected pages are reprinted following this notice. The reprinted pages include the original paper numbering for easy insertion into previously printed volumes.

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# Monitoring the Status of Mink (*Mustela vison*) in Illinois

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## ABSTRACT

Methods to census mink (*Mustela vison*) at large spatial scales are lacking. Therefore, we used museum records, trapper questionnaires, and sign surveys to determine their distribution in Illinois. We also evaluated the potential for using museum records and sign surveys to detect trends in relative abundance. From 1999 to 2005, biologists detected the presence of mink during 326 visits to 77 stations in 74 counties. Curators of 6 collections provided information about 166 specimens from 35 counties. Few ($n$ = 17) were recent (1980-2004) records. A total of 293 trappers reported capturing 1,321 mink during the 2003-04 and 2004-05 trapping seasons. Altogether, we documented recent occurrences of mink in 92 of 102 counties. Harvest estimates and questionnaires are adequate for monitoring the status of mink; museum records are not. Sign surveys can be implemented at a cost of <$14,000 (US) annually to derive quantitative estimates of relative abundance from site occupancy data if status becomes a concern.

## INTRODUCTION

Quantitative methods to determine absolute or relative abundance of mink (*Mustela vison*) at a large spatial scale are lacking (Eagle and Whitman 1987). Therefore, status assessments consist of expert opinion supported by data from harvest records (Forbes 1912, Soper and Payne 1997), museum voucher specimens (Hoffmeister 1989), and questionnaires returned by fur-takers (Mohr 1943), government officials (Wildhagen 1956, Bevanger and Ålbu 1986) or other authorities (Gerell 1967, Bevanger and Henriksen 1995). Such assessments are adequate for immediate conservation needs (Larivière 2003) but lack rigor required for direct comparisons at a later time.

We documented the current distribution of mink in Illinois to determine whether changes have occurred since Hoffmeister's (1989) assessment. Our sources of data included museum records and sign surveys. We evaluated suitability of these data for applying analytical innovations that allow detection of trends in relative abundance. We also provide costs for determining site occupancy so managers can decide if adequate resources are available to do so.

## METHODS

### Sign Surveys

Trained staff from the Illinois Department of Natural Resources (IDNR) conducted sign surveys at a sample of Basin Survey Sites established by the Illinois Environmental Protection Agency (1996) and IDNR to monitor surface water quality, diversity and abundance of fishes, and other indicators of the biotic integrity of riverine systems. We selected 75 of 102 counties for sampling based on the existence of Basin Survey Sites, delineations of watersheds [≥3 stations per population management unit as defined by Bluett et al. (1995)], and assigned work areas (typically, each biologist sampled 2 counties).

Practical considerations limited strict random selection of sites within counties. Sites that might have been difficult to locate or access (e.g., in the center of a large river with no corresponding landmarks on shore) were not considered. Those that were part of the Ambient Water Quality Monitoring Network (AWQM) were given preference. For example, if a county had 10 stations, 2 of which were part of the AWQM, we listed the 2 AWQM stations in random order followed by 2 standard Basin Survey Sites in random order. If no AWQM stations occurred in a county, 4 standard Basin Survey Sites were listed in random order.

We do not believe that our sampling strategy biased results because AWQM stations are considered representative of the stream reaches where they are located (Illinois Environmental Protection Agency 2002) and differ from standard Basin Survey Sites primarily because a greater number of chemical, physical, and biological characteristics are assessed at AWQM stations than standard Basin Survey Sites. Biologists evaluated sites in the order listed, selecting the first with conditions deemed suitable for detecting the presence of mink (e.g., waterways with rock or sod-bound shorelines were rejected). With a few exceptions, sites selected the first year were sampled during subsequent years.

Biologists conducted sign surveys once per year during 1 Feb through 31 Mar in the southern furbearer zone (i.e., south of U.S. Route 36) and 15 Feb through 15 Apr in the northern zone. Snow cover was not a prerequisite for conducting surveys and seldom existed during sampling. We avoided sampling shortly (<48 hrs) after rainfall that might obscure or eliminate sign and while rivers were rising quickly or at flood stage.

Using hip chains to determine distances, biologists traveled ≤300 m upstream and downstream from survey mid-points (i.e., road bridges identified as Basin Survey Sites or AWQM stations), and searched both shorelines for tracks, scats, and other signs of the presence of mink, river otter (*Lontra canadensis*), and beaver (*Castor canadensis*; i.e., a total of 1200 m of shoreline unless the presence of all 3 species was documented in a shorter distance). Data collected by staff included the presence of target species and types of evidence encountered. They also reported the percentage of shoreline with conditions deemed suitable to detect an animal's presence. Suitable conditions consisted of a band of sand or mud substrate along the water's edge; width of the band varied from a few centimeters to approximately 2 meters from the water's edge depending on substrate, slope, presence of rank vegetation, and other attributes of the bank. We calculated detection rates by dividing the number of sites where mink were detected by the total number of sites sampled.

Costs, tracked by IDNR's Programmatic Accounting System for reimbursement under Federal Aid in Wildlife Restoration Project W-99-R, were based on man-hours coded to the project for all tasks (i.e., data collection, entry, and analyses; preparation of reports), included an indirect cost of 23.3%, and are reported in US dollars.

### Museum Specimens

Hafner et al. (1997) identified mammal collections in the Western Hemisphere. Using this guide, we sent letters to curators of large collections (>500 specimens) located in Illinois to obtain information about dates and locations that mink were collected. An initial request was mailed during December 2004; non-respondents received a second request during October 2005. We also searched 7 on-line databases (Burke Museum of Natural History and Culture, Yale Peabody Museum, Florida Museum of Natural History, University of Massachusetts at Amherst Mammalogy Collection, University of Alaska Museum of the North, Harvard University Museum of Comparative Zoology, and University of California, Berkeley Museum of Vertebrate Zoology) for information about specimens housed at out-of-state institutions. We judged the relative value of our sample by comparing sizes of collections housed by respondents and on-line sources to collections documented by Hafner et al. (1997).

### Trapper Questionnaires

Each year, the Illinois Natural History Survey sends questionnaires to a stratified random sample of licensed trappers to determine their harvest, harvest effort, and opinions about management programs. Most (78%) of the 665 trappers contacted after the 2003-04 season responded (Miller et al. 2004), as did most (79% of 684) contacted after the 2004-05 season (Hubert et al. 2005). Respondents comprised approximately 18% of all licensed trappers during the 2003-04 season and 17% during 2004-05 (Miller et al. 2004, Hubert et al. 2005). More detailed methods and summaries were described in unpublished reports to IDNR (Miller et al. 2004, Hubert et al. 2005). We used raw data to link captures by successful mink trappers to the inquiry, "In which county did you do most of your trapping?"

## RESULTS

### Sign Surveys

Biologists made 454 visits to 78 stations in 75 counties during 1999 through 2005. They detected mink during 326 visits (71.8%) to 77 stations in 74 counties during this period (Fig. 1). Mink were detected frequently (≥67% of visits) at 49 stations and infrequently (≤33% of visits) at 12 (Appendix I). Detection rates varied from 0.69 to 0.73 during 2000 through 2004, when 70-75 stations were visited annually. The greatest detection rate (0.85) occurred in 1999 when 41 stations were sampled; the least (0.64) occurred in 2005 ($n = 47$).

Costs were similar in 2003 (235.5 man-hours; $10,218.55; 73 survey locations) and 2004 (231.5 man-hours; $10,723.25; 70 survey locations). Scaled-back efforts in 2005 (47 survey locations) cost $7,388.10 for 164 man-hours. During 2003 through 2005, the average cost per survey location per year was 3.32 man-hours valued at $149.10, including indirect costs.

### Museum Specimens

Curators of 6 collections in Illinois (Field Museum of Natural History, Illinois Natural History Survey, Illinois State Museum, Illinois State University, Southern Illinois University at Carbondale, and University of Illinois Museum of Natural History) provided information about 166 specimens of mink with associated dates and/or locations of collection. Our on-line search yielded information about 2 additional specimens. Based on a recent assessment of mammal collections (Hafner et al. 1997), institutions in our sample housed approximately 96% of specimens kept in Illinois and 19% of those in North America.

Locations were available for 146 specimens from 35 counties. Dates were available for 145 specimens; the most recent was collected in 2002. Seventeen specimens were collected during 1980-2004, 71 during 1955-1979, 36 during 1930-1954, 17 during 1905-1929, and 4 during 1899-1904. Runs of years ($\geq 2$) without collections were more common from 1980-2004 ($n = 6$) than 1955-1979 ($n = 1$), 1930-1954 ($n = 2$), and 1905-1929 ($n = 2$). The longest run (16 yrs) occurred from 1909-1924.

### Trapper Questionnaires

Questionnaires distributed after the 2003-2004 trapping season resulted in 517 usable responses from trappers residing in 85 of 102 counties; these included responses from 140 successful mink trappers who reportedly captured 695 mink. Questionnaires distributed after the 2004-2005 season resulted in 535 useable responses from trappers residing in 77 counties; these included responses from 153 successful mink trappers who captured 626 mink. Data from both years suggested captures occurred in 74 of 93 counties where respondents (including those who did not capture mink) did most of their trapping. Reports for most of the 74 counties included responses from multiple successful mink trappers (58 counties) during multiple years (36 counties) and were confirmed by detection of mink during sign surveys (56 counties).

## DISCUSSION

Our findings indicated a statewide distribution of mink. This result is not surprising given past assessments in Illinois (Forbes 1912, Mohr 1943, Hoffmeister 1989) and the species' widespread range elsewhere in North America (Larivière 1999). However, our work provides a more contemporary and complete reference than Hoffmeister (1989), who documented 62 museum specimens and 2 published reports from 24 counties. It also provides an opportunity to examine the relative value of available sources of data. For example, lack of recent (1980-2004) museum specimens limited usefulness of these data for determining distribution. Questionnaires provided results similar to but less precise and accurate than sign surveys. If necessary, we could obtain more detailed information about locations by modifying the survey instrument, as was the case for long-tailed weasels (*Mustela frenata*) in Illinois (Richter 2005).

Mink, considered common to abundant in most of their range (Larivière 2003), are harvested legally in nearly all states and provinces where they occur (Novak et al. 1987). Managers often rely on harvest records to infer status because direct methods to census or monitor populations at large spatial scales are lacking (Ray 2000, Larivière 2003). The secure status of mink suggests this approach is adequate (Larivière 2003). However, other methods are desirable (Linscombe et al. 1982, Ray 2000, Larivière 2003) because changes in capture effort caused by varying pelt values (Clark et al. 1985), numbers of trappers, and other factors (Bluett 1992) sometimes mask underlying relationships between population and harvest levels (Erickson and Sampson 1978, Erickson 1981).

Various forms of sign surveys (e.g., track-boards, sand-transects, searches of natural substrates along shorelines) have been used to monitor occurrence, habitat use, and activity of mink at relatively small spatial scales such as a site or watershed (e.g., Burgess and Bider 1980, Humphrey and Zinn 1982, Mason and MacDonald 1983, Loukmas and Halbrook 2001). Our use of this method to determine distribution at a statewide scale is the first we are aware of. We observed high detection rates with little variation among years when we conducted sign surveys at >70 sites. These characteristics suggest sign surveys would have been well suited for calculating trend and possibly relative abundance if we had used multiple sampling to estimate detection error, a requisite for applying recent innovations for analyses of presence-absence data (e.g., Strayer 1999, Royle and Nichols 2003, MacKenzie 2005, Stanley and Royle 2005). We believe this approach would be useful in jurisdictions where the status of mink is a concern.

Costs are an important consideration for resource managers seeking to implement monitoring programs (Field et al. 2005). Based on our experience, sampling 70 sites annually would cost 232.4 man-hours valued at $10,437, including indirect costs. Re-sampling one-third of these sites each spring to estimate detection error would add 77 man-hours valued at $3,429. These costs are greater than those for detecting only mink (i.e., our protocol required biologists to sample a total of 1200 m of shoreline unless the presence of mink, river otter, and beaver was documented in a shorter distance). Detection rates for river otter (26.8–35.7%; Bluett et al. 2004) were lower than those for mink. Therefore, the maximum distance was sampled at most sites. Distance or time elapsed from the beginning of the survey route until evidence of mink is first encountered might be useful metrics that would incur few if any additional costs (E.C. Hellgren, Cooperative Wildlife Research Laboratory at Southern Illinois University, personal communication).

Fewer sites were sampled during 1999, when sign surveys were initiated in southern Illinois, and 2005, when they were phased-out by eliminating sites where evidence of river otters had been observed $\geq 3$ times. Detection rates observed during 1999 and 2005 were not anomalous, per se, but it seems improbable that the greatest and least values occurred during these years by chance alone. Possible explanations include differences among observers, sample sizes, populations, site characteristics, or a combination of factors. Our experience supports the notion that design is an important consideration for monitoring wildlife at large geographic scales (Pollock et al. 2002, Stanley and Royle 2005) and suggests some approaches might be less effective than others for monitoring mink, especially if the number of sites sampled annually is small (e.g., <70).

Several researchers have developed statistical approaches for inferring threat or decline from museum records (e.g., Solow 1993, Burgman et al. 1995, McCarthy 1998). In general, these methods assume a relationship between relative abundance and accessions, are most meaningful when used with information from other sources, and are best suited for comparisons within taxa or other aggregations of species (Burgman et al. 1995). Some approaches assume that collection effort is relatively constant over time; others allow for differences that might occur because of changes in policies, funding levels, restrictions, or other abiotic influences on numbers of accessions of a particular species (McCarthy 1998).

We do not advocate use of these methods for monitoring the status of mink in Illinois because collection records do not appear to reflect relative abundance. For example, the number of collection records we documented from 1980–2004 ($n$ = 17) was small compared to the estimated harvest of mink by trappers during that period ($n$ = 199,966; Illinois Department of Natural Resources, unpublished data). Museums' efforts to collect mink probably declined during 1980-2004, as evidenced by more runs of absences and fewer specimens than the quarter-century preceding this period. The total number of mammal specimens housed by respondents increased approximately 21% from 1983-1995 (Yates et al. 1987, Hafner et al. 1997), indicating that collection of mink deviated from this trend.

The mink's status appears secure in Illinois. Given limited resources, we believe harvest records and trapper questionnaires provide adequate monitoring tools. If these sources of data indicate cause for concern, sign surveys, which were discontinued in 2006, could be re-instituted with multiple sampling efforts at a subset of locations to estimate detection error, trend, and relative abundance. Our data provide a baseline for future comparisons of the distribution of mink in Illinois and possibly a means of identifying underlying causes of decline linked to water quality, abundance of prey, or other metrics associated with Basin Survey Sites.

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Issue 1 of 2007 continues with the article by
Meteer, Bachman, Wiegand, and Rhykerd.

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# Impact of Vermicompost on Growth of Two Native Illinois Prairie Plants in Biodiesel Contaminated Soil

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## ABSTRACT

The use of biofuel is rapidly increasing and is projected to have a positive impact on the economy of Illinois. With its increase in use, the likelihood of accidental spills also increases and methodologies to successfully re-vegetate biodiesel contaminated soils are needed. The objective of this study was to determine if vermicompost enhances growth of big blue stem (*Andropogon gerardii* Vitman) and partridge pea [*Chamaecrista fasiculate* (L.) Moench] in biodiesel contaminated soil. The experimental design was a completely randomized 2 x 4 factorial design with 3 replications per treatment. Seedlings of big bluestem and showy partridge pea were germinated in a commercial potting soil and grown for 42 days at which time plugs were transplanted. Plugs were transplanted into pots with dimensions of 10cm x 10cm x 9cm (l x w x h) containing loamy topsoil, loamy topsoil amended with 20% vermicompost (VC), loamy topsoil amended with 5g biodiesel $kg^{-1}$, or loamy topsoil amended with both 5g biodiesel $kg^{-1}$ and 20% VC. Three plugs were transplanted per pot and were grown for an additional 49 days. Plant heights were measured on 49 days after transplanting (DAT) and destructively sampled to measure plant root and shoot biomass. Results show both big bluestem and showy partridge pea were able to survive being transplanted into biodiesel contaminated soil and differences in plant height between amended soils were not significant. Further research to determine if these plants and the added vermicompost can enhance remediation of biodiesel contaminated soils is recommended.

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## INTRODUCTION

Diesel fuel is an integral component of sustainable agriculture. Petroleum diesel is a mixture of hydrocarbons containing many toxic compounds including volatile low molecular weight alkanes, naphthalenes, and polycyclic aromatic hydrocarbons (PAH). Biodiesel fuel is composed mainly of triglycerides, making it a cleaner-burning, less toxic alternative to standard petroleum diesel. The increased use and production of biodiesel offers many benefits to the Illinois farmer, economy, and environment. Recent legislation offers sales tax exemptions up to 20% for biodiesel blends containing 1-10% biodiesel and a total tax exemption for diesel blends that contain above 10% biodiesel. This legislation could increase the demand for biodiesel fuels and result in price increases of 5 cents per bushel for Illinois soybeans, which would increase the state's economic output by more than $22.5 million (National Biodiesel Board, 2003).

Diesel or biodiesel fuel spills pose an environmental threat to soil and are toxic to plants. Soil contaminated with 5% diesel significantly reduced seedling germination (Adam and Duncan, 1999; Russell, 2005). Additionally, Rosa et al. (2005) showed that the rate of nitrogen fixation by soybean nodules was significantly reduced in soil contaminated with 1% biodiesel. Biodiesel spills on soil, while less damaging than petroleum diesel spills, still pose a threat to the environment and therefore, technologies to remediate biodiesel contaminated soils are needed.

Contaminated soils are frequently remediated by excavation and placing contaminated soils into landfills or incinerated. However, this technology is expensive and costs range from $100-400 per ton for land filling and $200 – 1,500 per ton for incineration (Schnoor, 1997). A low cost alternative to these technologies is phytoremediation, or using plants to naturally enhance remediation of the soil, for which the costs ranges from $10-35 per ton.

Phytoremediation may enhance remediation by several mechanisms (Cunningham et al., 1995). Plant roots can absorb contaminants, translocate them to vegetation which can be harvested and removed, thereby removing them from the environment. Absorbed contaminants can also be degraded by the plant into harmless metabolites. Roots can also enhance soil remediation by stimulating microbial activity in the rhizosphere and the increase in microbial activity may enhance decomposition of organic compounds.

Phytoremediation has been successfully used to enhance remediation of contaminated soils. For example, *Lolium perenne* L. (perennial ryegrass) significantly reduced the concentration of petroleum hydrocarbons compared to an unvegetated control (Günther et al., 1996) and in a field study phytoremediation significantly accelerated remediation of petroleum hydrocarbons compared to unvegetated controls (Schwab and Banks, 1999). However, phytoremediation is not always effective. In field study using *Sorghum halapense* (L.) Pers. (Johnsongrass), *Elymus Canadensis* L. (Canada wildrye), and a rotation of Johnsongrass-Canada wildrye did not enhance the disappearance of hydrocarbons from soil (Sung et al., 2002; Sung et al., 2003; and Sung et al., 2004).

Vermicompost is believed to be a material that can enhance soil remediation. Vermicompost is produced through the degradation of organic wastes through the action of earthworms that results in the bio-oxidation and stabilization of the wastes. This is a different process than traditional composting which requires a thermophilic stage, while vermicompost undergoes a mesophilic stage. The resulting vermicompost material is a finely divided peat-like substance with excellent structure, porosity, aeration, drainage, and moisture holding capacity (Edwards, 1985; Atiyeh et al., 2000).

Vermicompost has been reported to have greater numbers of microorganisms than native soil (Daniel and Anderson, 1992) More than 50 species of bacteria have been isolated from vermicompost associated with *Lumbriscus terretris* (Parle, 1963). Anastasi et al. (2004) reported a wide biodiversity of fungal species in vermicompost when compared to traditional compost. Species count total of 139 fungal species with 74 species being unique to the vermicompost evaluated.

In limited studies and applications, vermicomposts have been shown to be effective in the remediation of soil contaminated with hydrocarbon compounds, such as biodiesel. The fungal and bacterial content of vermicompost has been implicated in the degradation of polycyclic aromatic hydrocarbons (PAHs). When used as a soil inoculant vermicompost may be well suited to promote growth of PAH degrading fungi and bacteria (Lowery and Hurley, 2005).

Clearly there is a need for more research to identify technologies that will enhance remediation of contaminated soils. The objective of this study was to examine the potential of using big blue stem (*Andropogon gerardii*), and partridge pea (*Chamaecrista fasiculate*), a grass and legume prairie species native to Illinois, and vermicompost to establish vegetation soil contaminated with biodiesel.

## MATERIALS AND METHODS

The experimental design was a completely randomized 2 x 4 factorial design with 3 replications per treatment. Experiments were conducted in a greenhouse at Illinois State University. The daytime temperature was set at 24 °C and nighttime temperature at 18 °C. The day temperature was equivalent to the outside ambient temperature on days when the outside temperature was above the set point. On days when the outside temperature was at or below the set point, then the inside temperature was within 1-2 °C range of the set point. For night periods, the inside temperature was within 1-2 °C of the set point, except during those nights when the outside temperature remained above the set point.

Seedlings of big bluestem and showy partridge pea were germinated in peat-based potting media and grown for 42 days at which time plug height was recorded. Three plugs were transplanted into each container having dimensions of 10cm x 10cm x 9cm (L x W x H) containing either a loamy topsoil (control), a loamy topsoil amended with 20% VC (VC control), a loamy topsoil contaminated with 5g biodiesel $kg^{-1}$ (B100), or a loamy topsoil amended with 20% VC and contaminated with 5 g biodiesel $kg^{-1}$ (VC B100).

Properties of the loamy top soil are presented in Table 1. Soil texture was determined using the hydrometer method as described by Gee and Bauder (1986). Soil reaction (pH), organic matter (OM), potassium (K), cation exchange capacity (CEC), nitrate-nitrogen ($NO_3$-N), and phosphorus (P) were measured by the commercial laboratory Mowers Soil Testing Plus Inc. Toulon, IL following the methods presented in the Recommended Chemical Soil Test Procedures for the North Central Region (North Central Regional Publication No. 221, 1998). Soil pH was measured using a 1:1 soil:distilled water ratio. Soil OM was determined by chromic acid oxidation. Available K was determined by atomic absorption. Soil CEC was determined by summing the exchangeable bases, which were measured using atomic absorption. Soil $NO_3$-N was measured using a nitrate ion-selective electrode. Soil P was measured using the Bray P-1 method. The soil was selected to represent a typical highly productive Illinois soil that is subject to oil contamination.

These plants were grown for an additional 49 days after which data was collected. Plants were destructively sampled to measure fresh and dry root and shoot biomass. Roots and shoots were separated at the crown. Soil was washed from the roots under a gentle stream of water. Roots and shoots were then placed in separate paper bags and placed in an oven at 60 °C for 72 hours. Statistical analysis was performed using analysis of variance (ANOVA) and if significant by means separation using least significant difference (LSD), *P*=0.05.

## RESULTS

Both big bluestem and showy partridge pea were able to survive being transplanted into soil contaminated with 5g biodiesel $kg^{-1}$ soil (Table 2). Plant growth responses were different for big bluestem than showy partridge pea and as such all comparisons are reported within each species. Plant height of plugs at transplant for big blue stem and partridge pea were 10.12 cm ± 0.14 and 1.60 cm ± 0.03, respectively.

Height and percent increase from transplant of the big bluestem at DAT 49 was 11.48 cm (13%), 11.93 cm (18%), 11.40 cm (12%), and 9.89 cm (-3%) for control, VC control, B100, and VC B100, respectively. Height and percent increase from transplant of the showy partridge pea at DAT 49 was 3.88 cm (142%), 2.19 cm (31%), 1.47 cm (-8%), and 2.13 cm (33%) for control, VC control, B100, and VC B100, respectively. Negative height measurements were an indication that little growth occurred after transplantation. Height of the big bluestem treatment amended with B100 was not significantly lower than the control; the VC B100 treatment was significantly lower than the VC control (Table 2). The height of the showy partridge pea grown in the control soil was 3.88 cm and decreased significantly to 2.19 cm with the addition of vermicompost and the VC B100 treatment at 2.13 cm. Comparing the control soil to the B100 shows a significant decrease in plant height from 3.88 cm to 1.47 cm, respectively (Table 2).

The addition of B100 tended to reduce shoot and root fresh and dry weights of big bluestem and showy partridge pea (Tables 3 and 4). The shoot dry weight of big bluestem decreased from 0.43 g in the control to 0.38 in the presence of B100 and it decreased from 0.50 g in the vermicompost amended control to 0.27 g in the B100 amended vermicompost treatment. The root dry weight of big bluestem was not significantly reduced in the presence of B100 (0.64 g) compared to the control (0.68 g), however, it did decrease significantly in the VC B100 treatment (0.51 g) compared to the VC control (0.70 g).

Showy partridge pea produced much less plant biomass than big bluestem (Tables 3 and 4). The fresh shoot and root weights of showy partridge pea tended to decrease significantly with the addition of B100 (Table 4). Shoot and root dry weights for the B100 treatment was significantly reduced compared to the controls. Showy partridge pea biomass was reduced by the addition of VC (Table 4). For example the dry weight of showy partridge pea decreased from 0.06 g in the control to 0.03 g in the VC control treatment. Showy partridge pea growing in the B100 amended VC treatment showed an increase in biomass.

## DISCUSSION

Plant growth has been used to evaluate the suitability of plants for vegetating contaminated soils (Issoufi et al., 2006; Spiares et al., 2001a; and Spiares et al 2001b). Of the plant parameters measured in this study, Issoufi et al., (2006) and Spiares et al., (2001b) have stated that production of root biomass is the most critical when evaluating the potential of plants to enhance remediation. Increasing root biomass is a major factor because microbial populations in the rhizosphere are generally 10-100 times larger than that of non-rhizosphere soil (Pierzynski et al., 2005). Jordahl et al., (1997) found that population of selected hydrocarbon degraders were five times more abundant in rhizosphere soil than non-rhizosphere soil. Increasing microbial population in the rhizosphere leads to an increase in microbial activity, which may increase metabolic and cometabolic transformations of biodiesel into less toxic products and reduce the time required to remediate soil. Because big blue stem produced from approximately 7 to 32 times more roots on a dry weight basis than showy partridge pea, it appears to have a greater potential to enhance remediation than showy partridge pea.

The addition of vermicompost to biodiesel contaminated soil tended to reduce plant growth, especially with the partridge pea, when compared to plants grown in contaminated soil without added vermicompost. Perhaps the C:N or C:P ratio of the added vermicompost was too great, causing immobilization of N and P, resulting in a nutrient limitation, which limited plant growth. Chang et al., (1996) found that the optimal C:N and C:P ratios in hydrocarbon contaminated soils were 60:1 and 800:1 respectively and rates of remediation were slowed when either nutrient was limiting. Therefore, fertilizing the vermicompost amended treatments with N and P fertilizers may have enhanced plant growth. Another possible cause of reduced growth may have been the process of transplantation from the 128-cell plug trays to the treatments media and containers. Generally, native plant species do not transplant well due to root sensitivity or deep taproots and the natural soil conditions are hard to duplicate in containers. Further research is recommended to determine the mechanism that caused this less than optimum growth of both species.

## CONCLUSIONS

Both big bluestem and showy partridge pea grew in soil contaminated with 5 g biodiesel $kg^{-1}$ soil and may be useful at restoring vegetation of contaminated soils. Additional research to evaluate management practices to enhance the growth of these plants in contaminated soils and evaluate if they along with additions of vermicompost are capable of enhancing remediation are recommended.

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Table 1. Selected physical and chemical properties of soil and vermicompost amendment used to evaluate survival of Big Bluestem and Showy Partridge Pea in biodiesel contaminated soil. Values are averages of 3 samples.

| | Sand (%)[a] | Silt (%)[a] | Clay (%)[a] | pH (in water)[b] | OM (%)[b] | CEC (cmol$_c$ kg$^{-1}$)[b] | $NO_3$-N | P (mg kg$^{-1}$)[b] | K |
|---|---|---|---|---|---|---|---|---|---|
| Sand | 48 | 42 | 10 | 7.8 | 3.5 | 23 | 21.3 | 205.7 | 1725.3 |
| VC | | | | 7.0 | | 45 | 6200 | 458.0 | 659.5 |

[a] Hydrometer method (Gee and Bauder, 1986)
[b] Analyzed by Mowers Soil Testing Plus, Inc. Toulon, IL

Table 2. Plant height of big bluestem and showy partridge pea amended with vermicompost and contaminated with biodiesel 49 days after being transplanted.

| Treatment | Big Bluestem (cm)[a] | Showy Partridge Pea (cm)[a] |
|---|---|---|
| Control | 11.48 a | 3.88 a |
| VC Control[b] | 11.93 a | 2.19 a |
| B100[c] | 11.40 a | 1.47 a |
| VC B100[d] | 9.89 a | 2.13 a |
| | LSD 2.49 | LSD 1.55 |

[a] Means separation within column by least significant difference (LSD), $P$=0.05.
[b] Loamy topsoil amended with 20% VC
[c] Loamy topsoil amended with 5g biodiesel kg$^{-1}$ soil
[d] Loamy topsoil amended with 20% VC and 5g biodiesel kg$^{-1}$ soil

Table 3. Root and shoot biomass of big bluestem amended with vermicompost and contaminated with biodiesel 49 days after being transplanted.

| | Shoot weight | | Root weight | |
|---|---|---|---|---|
| Treatment | Fresh (g)[a] | Dry (g)[a] | Fresh (g)[a] | Dry (g)[a] |
| Control | 1.24 ab | 0.43 ab | 2.48 a | 0.68 a |
| VC Control[b] | 1.53 a | 0.50 a | 2.48 a | 0.70 a |
| B100[c] | 1.10 ab | 0.38 ab | 2.44 a | 0.64 a |
| VC B100[d] | 0.85 b | 0.27 b | 1.73 a | 0.51 a |
| | LSD 0.59 | LSD 0.18 | LSD 1.21 | LSD 0.27 |

[a] Means separation within column by least significant difference (LSD), $P$=0.05.
[b] Loamy topsoil amended with 20% VC
[c] Loamy topsoil amended with 5g biodiesel kg$^{-1}$ soil
[d] Loamy topsoil amended with 20% VC and 5g biodiesel kg$^{-1}$ soil

Table 4. Root and shoot biomass of showy partridge pea amended with vermicompost and contaminated with biodiesel 49 days after being transplanted.

| | Shoot weight | | Root weight | |
|---|---|---|---|---|
| Treatment | Fresh (g)[a] | Dry (g)[a] | Fresh (g)[a] | Dry (g)[a] |
| Control | 0.25 a | 0.07 a | 0.22 ab | 0.06 a |
| VC Control[b] | 0.35 a | 0.03 a | 0.24 a | 0.03 a |
| B100[c] | 0.09 a | 0.03 a | 0.08 b | 0.02 a |
| VC B100[d] | 0.11 a | 0.07 a | 0.13 ab | 0.07 a |
| | LSD 0.12 | LSD 0.04 | LSD 0.15 | LSD 0.04 |

[a] Means separation within column by least significant difference (LSD), $P$=0.05.

[b] Loamy topsoil amended with 20% VC

[c] Loamy topsoil amended with 5g biodiesel kg$^{-1}$ soil

[d] Loamy topsoil amended with 20% VC and 5g biodiesel kg$^{-1}$ soil

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# *Phaseolus vulgaris* L. Population Density Affects Intercropped *Ipomoea batatas* (L.) Lam.

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## ABSTRACT

Intercropping is a popular farming system in the tropics. Small-scale farmers combine different crops as they wish, but do not know the best plant population densities to use. It would be expedient to elucidate the plant population density of a grain legume that could be planted with a constant density of sweetpotato to obtain the best benefits. A field investigation was conducted in Swaziland to determine the most beneficial plant population size of field bean (*Phaseolus vulgaris* L.) that could be associated with a constant density of sweetpotato [*Ipomoea batatas* (L.) Lam.]. Five cropping systems [monocropped sweetpotato at 33,333 plants ha$^{-1}$; monocropped field bean at 100,000 plants ha$^{-1}$; sweetpotato (33,333 plants ha$^{-1}$) + field bean at 100,000 plants ha$^{-1}$; sweetpotato (33,333 plants ha$^{-1}$) + field bean at 66,667 plants ha$^{-1}$; and sweetpotato (33,333 plants ha$^{-1}$) + field bean at 33,333 plants ha$^{-1}$] were compared in a randomized complete block design, replicated four times.

In this study, monocropped sweetpotato (33,333 plants ha$^{-1}$) gave the highest tuber yield (34.1 t ha$^{-1}$) but was not significantly different from the lowest yield (28.9 t ha$^{-1}$) from sweetpotato intercropped with 100,000 plants ha$^{-1}$ of field beans. When the combined yield of field beans and sweetpotatoes was considered as indicated by Land Equivalent Ratios (LERs), there was a yield advantage of 56 to 79% greater than monoculture. This study, concerning the effect of intercropping sweetpotato with various field bean population densities, clearly shows the advantages of intercropping on the Oxisol soils of Swaziland.

Mineral concentration of tubers was not significantly (0.05%) affected by monoculture or intercropping with various field bean densities. Most soil chemical properties tested were also found not to be affected by the cropping systems evaluated by this experiment.

Keywords: Sweetpotato, field bean, Land Equivalent Ratio, intercropping, mineral concentration, soil chemical properties

## INTRODUCTION

The most dominant cropping system used by small-scale farmers in the humid tropics is mixed cropping (Ruthernberg, 1980; Gomez and Gomez, 1983; Vandermeer, 1992; Sullivan, 2000). Sullivan (2003) reported that in Central America, farmers traditionally mix-cropped corn, beans and squash. Intercropping is differentiated from mixedcropping in that in the former, the component crops in the mixture have a definite spacing and are arranged in definite rows whereas in the latter, no specific row arrangement is involved but farmers plant the crops at any convenient spacing (Ruthernberg, 1980). Intercropping is more commonly used in agricultural research stations and other institutions that might be interested in investigating crop associations. Typical crop associations can involve grain legumes and sweetpotato (Ossom et al., 2005), but cassava (*Manihot esculenta* Cranz), yams (*Dioscorea* spp.), cereals and legumes, sugarcane, maize and grain legumes (Zwane, 2003) have also been intercropped.

Sweetpotato is the most important storage root or root tuber crop in Swaziland. This crop, and recently cassava, are the two main storage root crops that are grown in Swaziland. But the importance of sweetpotato as a food security crop has only recently been realized as a result of changes in the physical and socio-economic environments brought about by persistent drought and increases in input prices largely caused by diminishing strength of the Swaziland currency (Lilangeni) since the 1990's (MoAC, 2003). Field bean, commonly known as sugar bean in Swaziland, is the second most important pulse after peanut (Thwala and Ossom, 2004).

While farmers use mixedcropping as an insurance against the risk of crop failure, and as a pest-control measure (Karel, 1993), the proponents of monocropping typically emphasize reduced crop yields under mixed cropping as the greatest disadvantages of crop associations, and hardly mention the benefits of mixed cropping and intercropping. Walker and Jodha (1986) explained that risk reduction in intercropping originates from the ability of at least one crop in the system to compensate for the failure or low yield of another crop. Compensation would not be possible in pure stands, because all plants would be affected in the same way. But planting crops in combination has stood the test of time, as this cropping system has been practiced in many tropical regions for many centuries (Ruthernberg, 1980; Vandermeer, 1992; Wolfe, 2000). Recent investigations in the tropics (Ossom et al., 2005) employing the concept of land equivalent ratio (LER) have demonstrated the advantage of intercropping on yield. Farmers do plant major crops (such as sweetpotato) with companion crops (such as grain legumes) in various combinations and spatial arrangements, not knowing which specific plant population densities to sow in order to obtain the best advantages. This investigation was undertaken to determine the influence of different field bean population densities on intercropped sweetpotato yields when the latter is planted at a constant density, LER, mineral concentration in sweetpotato tubers and chemical properties of the soil.

## METHODS

### Experimental site and design

This field investigation was conducted in the University of Swaziland, Crop Production Department Farm in Luyengo (26°34'S, 31°12'E; 750 m above sea level; mean annual temperature, 18°C; annual rainfall, 800 mm) on an Oxisol (Murdoch, 1968). Soil test values at the beginning of the experiment, measured using procedures described by the University of Missouri Extension (1998), were: pH, 5.32; N, 0.13%; P, 4.54 ppm; K, 4.10 meq 100 $g^{-1}$; exchangeable acidity, 0.29 meq 100 $g^{-1}$; and organic matter, 2.40%.

The investigation was done from October 2005 to April 2006. A randomized complete block design with five population treatments was replicated four times. The treatments and their respective plant populations were: $T_1$, monocropped sweetpotato at 33,333 plants $ha^{-1}$ – 30 cm within rows x 100 cm between rows; $T_2$, monocropped field bean at 100,000 plants $ha^{-1}$ - 10 cm within rows x 100 cm between rows; $T_3$, sweetpotato (33,333 plants $ha^{-1}$) + field bean at 100,000 plants $ha^{-1}$ – 10 cm within rows x 100 cm between rows; $T_4$, sweetpotato (33,333 plants $ha^{-1}$) + field bean at 66,667 plants $ha^{-1}$ – 15 cm within rows x 100 cm between rows; and $T_5$, sweetpotato (33,333 plants $ha^{-1}$) + field bean at 33,333 plants $ha^{-1}$ – 30 cm within rows x 100 cm between rows. Plot sizes were 5.1 m x 6.0 m; plots were spaced 100 cm apart. There were 7 ridges/plot.

### Soil amendments and planting

On the day of planting, dolomitic lime was broadcast on the ridges and worked into the soil at the rate of 2 t/ha (Anon., 1991). Thereafter, compound fertilizer [N:P:K, 2:3:2 (22)] that also contained 0.5% Zn, was applied at the rate of 350 kg $ha^{-1}$ (Anon., 1991). Single superphosphate was also applied at the rate of 50 kg $ha^{-1}$ to only plots of monocropped sweetpotato or sweetpotato with field beans, but was not applied to monocropped field bean. The method of application was banding and incorporation, 10 cm away from the planting rows. All crops were planted on 1.0-m ridges as recommended for the main crop, sweetpotato (Anon., 1991). Vines that were 30 cm in length were used as planting materials for sweetpotato. At six weeks after planting (WAP), a side dressing of 10 parts urea and 50 parts KCl was applied at the rate of 120 kg/ha only to plots of pure sweetpotato or sweetpotato with field beans, but none was applied to pure field bean as recommended by Anon. (1991). The variety of sweetpotato planted was 'Kenya' and that of field bean was 'PAN 159'; both were obtained from Malkerns Research Station.

### Management, harvesting and sampling

The crop was routinely managed as recommended by Anon. (1991). No pesticides were applied as there was no pest infestation that warranted any control measures. At 12 WAP, field beans were harvested by hand picking. At 24 WAP, sweetpotato was harvested using garden forks to dig up the tubers from the ridges. After harvest, five soil samples (15-cm depth) were collected from each experimental row; all samples from each plot were mixed together to obtain a composite sample for that plot. Whole tuber samples were obtained and washed to remove any adhering soil. Samples (300-400 g) were sliced to facilitate drying. The samples were dried in a hot air oven (Tafaj et al., 2006). All samples were analyzed for chemical properties including macro- and micronutrients at A & L Great Lakes Laboratories, Inc., Fort Wayne, IN, using methods outlined in Recommended Chemical Soil Test Procedures for the North Central Region (University of Missouri Extension, 1998).

### Calculation of Land Equivalent Ratio

Land equivalent ratio is a useful concept for comparison of the yield of intercropping to that of a pure stand (Sullivan, 2000; Ossom et al., 2005). LER was calculated as follows:

$$\text{LER} = \frac{\text{yield of crop A in intercrop mixture}}{\text{yield of pure crop A}} + \frac{\text{yield of crop B in intercrop mixture}}{\text{yield of pure crop B}}$$

## DATA ANALYSIS

Data were analyzed using MSTAT-C statistical software, version 1.3 (Nissen, 1983). The least significant difference (LSD) test was used for mean separation at $P \leq 0.05$, unless otherwise stated.

## RESULTS AND DISCUSSION

### Tuber and pod yields

Table 1 shows the effect of field bean population density on tuber yield of sweetpotato and pod yield of field bean. Interestingly, there was no significant difference in sweetpotato tuber yield at the 5% level when comparing a pure culture of sweetpotato with intercropped sweetpotato at a constant population density with the three population densities of field bean. However, highest tuber yield was obtained with pure culture (34.1 t ha$^{-1}$) and lowest tuber yield (28.9 t ha$^{-1}$) at the highest plant density of field bean.

As also shown in Table 1, field bean pod yields were significantly affected (0.05) by field bean plant density and intercropping with sweetpotato. Pure field bean yielded 3,192.5 kg ha$^{-1}$ while intercropped field bean at 33,333 plant ha$^{-1}$ with sweetpotato yielded only 2000 kg ha$^{-1}$. Field bean pod yields were not significantly reduced by intercropping with sweetpotato at a field bean population density of 66,667 or 100,000 plants ha$^{-1}$. Apparently, 33,333 plants ha$^{-1}$ of field bean plant density was insufficient when intercropped with sweetpotato to produce a yield comparable to a field bean monoculture. Expressing field bean yield as pod yields (Thwala and Ossom, 2004; Ossom and Nxumalo, 2003) appears to be important to livestock farmers for the reason that the family can eat the grain whereas the pods are fed to livestock.

### Field bean pods per plant, seeds per pod, and weight of 100 seeds

Data in Table 1 also indicate that field bean density and intercropping with sweetpotato significantly affected the number of pods per field bean plant as well as the number of seeds per pod. Intercropping sweetpotato (33,333 plants ha$^{-1}$) with field bean at field bean population densities of 33,333 and 66,667 plants ha$^{-1}$ significantly reduced the number of pods per plant. The number of field bean seeds per pod was significantly reduced at the 33,333 plants ha$^{-1}$ when intercropped with sweetpotato.

The weight of field bean seeds was unaffected by cropping system.

### Land Equivalent Ratio (LER)

It is readily apparent from the data presented in Table 1 that intercropping results in considerably greater yield per ha. LER for intercropped sweetpotato and field bean ranged from a low of 1.56 for sweetpotato (33,333 plants $ha^{-1}$) intercropped with a field bean plant density 33,333 plants $ha^{-1}$ to a high of 1.79 for intercropped sweetpotato and field bean plant density at 66,667 plants $ha^{-1}$. This means that a combined yield increase of 79% was obtained by intercropping sweetpotato planted at 33,333 plants $ha^{-1}$ and field bean at a plant density of 66,667 plants $ha^{-1}$. Our results were in agreement with a previous investigation (Ossom and Nxumalo, 2003) in which an LER of 1.79 was obtained in sweetpotato-peanut intercropping, and 1.48 in sweetpotato-field bean association, both results confirming the advantages of sweetpotato intercropping. Other researchers (Spio, 1996; Fininsa, 1997) concluded that based on LERs, intercropping was superior to sole cropping if the same level of crop management in terms of labor utilization, land and other inputs concerned were applied to both.

### Tuber mineral concentrations

As seen in Tables 2 and 3, there were no significant differences in mineral concentrations among the cropping systems.

### Soil chemical properties

Table 4 shows the influence of field bean population on the concentration of soil mineral nutrients in sweetpotato plots. There were no significant differences among these soil chemical properties, except Ca concentration that was significantly ($P < 0.05$) higher in monocropped field bean soils than when sweetpotato was intercropped with 33,333 plants $ha^{-1}$ of field bean. Table 5 shows the effects of different field bean populations on the base saturation and micronutrient concentrations in intercropped sweetpotato. Only Mg, Ca, and H base saturations showed significant differences among the treatments.

The optimum soil pH for field bean ranges from 5.5 to 7.0 (Norman, 1992). If the pH of the soil is less than 5.5, liming is recommended because field beans are sensitive to high concentrations of aluminum and manganese (Norman, 1992). LSU (2003) recommended that for sweetpotato, if the soil pH was below 5.2, liming would be required, and advised that liming sweetpotato could reduce soil acidity, improve fertilizer use efficiency and improve decomposition of crop residues. It is most probable that the advantages observed in the crop combination could be associated with the beneficial influence of nitrogen-fixing bacteria in field bean.

## CONCLUSIONS AND RECOMMENDATIONS

This study, concerning the effect of intercropping sweetpotato with various field bean population densities, clearly shows the advantage of intercropping on the Oxisol soils of Swaziland. Although a monoculture of sweetpotato produced highest yields, the intercropping of sweetpotato with field bean populations of 33,333, 66,667, and 100,000 plants $ha^{-1}$ resulted in a yield increase of 56 to 79% as determined by LERs. The 79% increase was obtained by intercropping sweetpotato with a field bean population density of 66,667 plants $ha^{-1}$. Therefore, Swaziland producers are encouraged to intercrop field beans and sweetpotatoes at plant population densities of 66,667 field bean plants $ha^{-1}$ and 33,333 sweetpotato plants $ha^{-1}$.

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Table 1. Yield and Land Equivalent Ration (LER) response to varying field bean densities intercropped with sweetpotato.

| Cropping system | LER | Tuber | Field Bean | | | |
|---|---|---|---|---|---|---|
| | | Yield (t ha$^{-1}$) | Pod yield (kg ha$^{-1}$) | Number of pods per plant | Number of seeds per pod | 100–seed mass (g) |
| Pure field bean at 100,000 plants ha$^{-1}$ | NA | NA | 3,192.5 | 13.7 | 6.1 | 32.2 |
| Pure sweetpotato at 33,333 plants ha$^{-1}$ | NA | 34.1 | NA | NA | NA | NA |
| Sweetpotato + field bean at 100,000 plants ha$^{-1}$ | 1.69 | 28.9 | 2,682.5 | 10.2 | 5.3 | 27.6 |
| Sweetpotato + field bean at 67,667 plants ha$^{-1}$ | 1.79 | 31.3 | 2,762.5 | 8.5 | 5.3 | 27.3 |
| Sweetpotato + field bean at 33,333 plants ha$^{-1}$ | 1.56 | 31.7 | 2,000.0 | 7.2 | 4.0 | 28.9 |
| Mean | | 31.5 | 2,659.4 | 9.9 | 5.2 | 29.0 |
| LSD$^1$ $_{(0.05)}$ | | 9.88 | 847.06 | 3.74 | 1.61 | 5.54 |
| Significance | | Ns | * | * | * | Ns |

[1] Least significant difference; NA, not applicable; NS, not significant at P > 0.05.

Table 2. Concentrations of macronutrients (%) in sweetpotato tubers intercropped under different field bean population densities.

| Cropping system | N | P | K | Mg | Ca | S | Na |
|---|---|---|---|---|---|---|---|
| Pure sweetpotato at 33,333 plants/ha | 0.455 | 0.147 | 1.087 | 0.062 | 0.055 | 0.053 | 0.090 |
| Sweetpotato + field bean at 100,000 plants/ha | 0.372 | 0.152 | 1.105 | 0.070 | 0.065 | 0.053 | 0.060 |
| Sweetpotato + field bean at 66,667 plants/ha | 0.422 | 0.145 | 0.902 | 0.070 | 0.060 | 0.050 | 0.108 |
| Sweetpotato + field bean at 33,333 plants/ha | 0.395 | 0.135 | 1.015 | 0.070 | 0.063 | 0.053 | 0.080 |
| Mean | 0.412 | 0.145 | 1.028 | 0.068 | 0.061 | 0.052 | 0.084 |
| LSD[1] $_{(0.05)}$ | 0.122 | 0.040 | 0.297 | 0.029 | 0.038 | 0.009 | 0.055 |
| Significance | Ns | Ns | Ns | Ns | Ns | Ns | Ns |
| Correlation coefficient with tuber yield | -0.388 | - 0.392 | - 0.443 | 0.060 | 0.504 | 0.126 | - 0.106 |

[1] Least significant difference; NA, Not applicable; Ns, not significant at $P > 0.05$.

Table 3. Concentrations of micronutrients (ppm) in sweetpotato tubers intercropped under different field bean population densities.

| Cropping system | B | Zn | Mn | Fe | Cu | Al |
|---|---|---|---|---|---|---|
| Pure sweetpotato at 33,333 plants/ha | 3.500 | 6.750 | 5.000 | 30.500 | 3.250 | 15.000 |
| Sweetpotato + field bean at 100,000 plants/ha | 4.500 | 7.750 | 6.750 | 32.500 | 3.000 | 23.000 |
| Sweetpotato + field bean at 66,667 plants/ha | 3.750 | 9.000 | 6.000 | 42.000 | 3.000 | 27.500 |
| Sweetpotato + field bean at 33,333 plants/ha | 4.000 | 9.700 | 5.000 | 36.000 | 2.750 | 28.000 |
| Mean | 3.938 | 8.313 | 5.688 | 35.250 | 3.000 | 23.375 |
| LSD[1] $_{(0.05)}$ | 0.933 | 4.859 | 2.533 | 22.020 | 0.998 | 22.195 |
| Significance | Ns | Ns | Ns | Ns | Ns | Ns |
| Correlation coefficient with tuber yield | - 0.425 | 0.028 | 0.103 | 0.103 | 0.032 | - 0.026 |

[1] Least significant difference; NA, Not applicable; Ns, not significant at $P > 0.05$.

Table 4. Influence of field bean population densities on concentration of soil mineral nutrients in sweetpotato plots.

| Cropping system | % | | Parts per million | | | | | | | pH | CEC[1] (meq/100 g) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Organic matter | Total N | Nitrate N | P | K | Mg | Ca | Sulfur | Exchangeable Al | | |
| Pure sweetpotato at 33,333 plants/ha | 3.20 | 0.112 | 3.25 | 11.75 | 70.00 | 161.25 | 650.00 | 15.25 | 7.00 | 5.73 | 6.88 |
| Pure field bean at 100,000 plants/ha | 3.43 | 0.131 | 2.50 | 13.50 | 108.25 | 178.75 | 762.50 | 15.00 | 6.50 | 5.85 | 7.40 |
| Sweet-potato + field bean at 100,000 plants/ha | 3.38 | 0.117 | 3.50 | 13.00 | 87.00 | 172.50 | 637.50 | 14.75 | 4.25 | 5.80 | 6.65 |
| Sweetpotato + field bean at 66,667 plants/ha | 3.53 | 0.113 | 4.00 | 15.25 | 72.50 | 167.50 | 625.00 | 14.75 | 4.75 | 5.75 | 6.20 |
| Sweetpotato + field bean at 33,333 plants/ha | 3.13 | 0.120 | 3.50 | 14.00 | 66.75 | 158.75 | 437.50 | 15.25 | 6.00 | 5.73 | 4.85 |
| Mean | 3.33 | 0.118 | 3.35 | 13.50 | 80.90 | 167.75 | 622.50 | 15.00 | 5.70 | 5.77 | 6.40 |
| LSD[1] $_{(0.05)}$ | 0.432 | 0.019 | 1.59 | 5.88 | 41.61 | 27.43 | 183.78 | 1.92 | 3.05 | 0.110 | 1.66 |
| Significance | Ns | Ns | Ns | Ns | Ns | Ns | * | Ns | Ns | Ns | * |

[1] Least significant difference; * significant at $P < 0.05$; Ns, not significant at $P > 0.05$.

Table 5. Base saturation and micronutrient concentrations in soil grown to sweetpotato and different field bean population densities.

| | Base saturation (%) | | | | Parts per million | | | |
|---|---|---|---|---|---|---|---|---|
| | K | Mg | Ca | H | Zn | Mn | Cu | B |
| Pure sweetpotato at 33,333 plants/ha | 2.73 | 20.93 | 47.43 | 28.95 | 2.83 | 29.75 | 1.28 | 0.40 |
| Pure field bean at 100,000 plants/ha | 3.70 | 20.75 | 51.70 | 23.83 | 2.85 | 30.75 | 1.23 | 0.40 |
| Sweet-potato + field bean at 100,000 plants/ha | 3.50 | 22.43 | 47.60 | 26.48 | 2.75 | 29.75 | 1.20 | 0.43 |
| Sweetpotato + field bean at 66,667 plants/ha | 3.13 | 23.28 | 50.00 | 23.60 | 2.93 | 30.00 | 1.25 | 0.40 |
| Sweetpotato + field bean at 33,333 plants/ha | 3.45 | 27.15 | 44.65 | 24.78 | 3.00 | 30.00 | 1.23 | 0.40 |
| Mean | 3.30 | 22.91 | 48.28 | 25.53 | 2.87 | 30.05 | 1.24 | 0.41 |
| LSD[1] $_{(0.05)}$ | 1.32 | 5.57 | 4.02 | 4.28 | 0.56 | 3.09 | 0.14 | 0.07 |
| Significance | Ns | * | * | * | Ns | Ns | Ns | Ns |

[1] Least significant difference; * significant at $P < 0.05$; Ns, not significant at $P > 0.05$.

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# Forming Partnerships With Overseas Colleagues

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## ABSTRACT

Thanks to the internet, developing world educators and researchers can now undertake collaborative projects with industrial world colleagues and do so at little cash cost. Such partnerships can make critically needed contributions to agricultural development through technology transfer and adaptation, research, production of educational materials and publications. We, the authors of this paper, coming as we do from Swaziland, Poland, and the United States, have found our working partnership rewarding. In this paper we share insights gained from our experience with the hope that others may develop such informal partnerships.

Abbreviations list:

ASA: American Society of Agronomy
ASF: Agronomic Science Foundation
CSSA: Crop Science Society of America
LDC: less-developed country
NGO's: Non-Governmental Organizations
PVO's: Private Voluntary Organizations
SAGA: Strategies and Analysis for Growth and Access
SANREM CRSP: Sustainable Agriculture and Resource Management Collaborative Research Support Program
USAID: United States Agency for International Development

Keywords: Developing countries, collaborative research, international research, poverty, world hunger

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## INTRODUCTION

Two of the world's most renowned and respected agronomists, Nobel Laureate Dr. Norman Borloug and World Food Prize Laureate Dr. Pedro Sanchez, have stressed the need for greater emphasis on improving agricultural production in order to help reduce, and hopefully eliminate, world hunger, malnutrition and extreme poverty (Sanchez, 2002).

Dr. Jeffrey D. Sachs, Director of "The Earth Institute" at Columbia University and Special Advisor to United Nations Secretary-General, Kofi Annan, on the Millennium Development Goals states that one billion of the earth's inhabitants are classified as extreme poor and all live in developing countries (Sachs, 2005). Sachs also reports that over 90 percent of the extreme poor live in sub-Saharan Africa, East Asia and South Asia. Tragically, the numbers continue to increase in sub-Saharan Africa while numbers in East Asia and South Asia have greatly decreased. Sachs further emphasizes that nearly half of Africa's population is considered to live in extreme poverty. The immediate urgency of eliminating extreme poverty with the present world-wide threat of terrorism was brought to light recently by former Secretary of State Colin Powell as he stated "The war against terror is bound up in the war against poverty" (Sachs, 2005).

The involvement of U.S. Land Grant and other agricultural universities in international agricultural development has waned since the ending of the Cold War. This is due primarily to the fact that the U.S. Agency for International Development (USAID) has greatly reduced their involvement in international agricultural development and their thrust toward reducing world hunger, malnutrition and extreme poverty. The authors believe that with recent developments such as the emphasis on globalization and the availability of e-mail, that industrial countries' agricultural scientists and educators now have an excellent opportunity to independently and informally reverse this trend with a minimum of inputs other than a passion for making the world a better place.

The recent emphasis in the U.S. on globalization along with the ubiquitous use of electronic mail via the computer, enables agricultural professors and scientists throughout the world to easily become involved in informal cooperative international research and education projects. Electronic mail now provides a means for professors and scientists to freely, and instantaneously exchange ideas, plan and conduct cooperative research projects, write and edit manuscripts, and assist in teaching each other's classes in almost any college/university in the world (Molnar and Fields, 2004).

The purpose of this paper is to encourage colleagues around the world to participate in some form of mutually beneficial professional activity with a peer/colleague in another part of the world, especially in a developing country where this type of activity would be most welcomed and rewarding for all involved. As an example, we are sharing our international cooperative teaching, technology transfer, and research experience over a period of more than two decades.

## PARTNERSHIPS YIELD TANGIBLE RESULTS

Our partnering has produced numerous concrete results in our classrooms, research activities, and other scholarly activities. Our research projects enable us to discuss first-hand the results of our research in numerous tropical regions of the world. We have presented 15 joint scientific papers at various professional meetings and have published 17 refereed agricultural journal articles in numerous countries. We find Transactions of the Illinois State Academy of Science to be especially useful in disseminating research results because the journal is published on the internet and available from computers worldwide. Especially rewarding to us is the fact that the Indiana Academy of Science named Dr. Ekpo M. Ossom, of the University of Swaziland, a Fellow, in 2006 based upon our 13 papers presented at their annual meetings along with five published abstracts and eight refereed journal articles.

We have found that the translation and printing of textbooks can be a very inexpensive method of making the most up-to-date technology more widely available. For this to work, the author(s) must grant permission for the translation and printing royalty free. One of us (Charles L. Rhykerd) was involved in an Andrew Mellon Foundation-supported agricultural development project in Poland during the early to mid-nineties. We recognized that some of the latest forage production and utilization technology in the United States would be helpful if made available to Polish farmers. Consequently, permission was obtained from the authors and publishers of "Southern Forages" (Ball, et. al., 1991) to translate their textbook to Polish royalty free.

Three Polish agricultural professors, with collaborator Czeslaw Nowak taking the leadership, translated "Southern Forages" to Polish. The U.S. publisher of "Southern Forages" donated sufficient funds to publish 500 copies of the Polish edition for distribution to libraries, agricultural extension service offices, and agricultural schools. As a result of the success of this project, a second edition (Ball, et. al., 1996 & 1997) was later published which contained several chapters authored by Czeslaw Nowak. These chapters contained the latest forage research results obtained in ongoing investigations in Poland.

Recently, the authors of "Southern Forages" presented a forage production and utilization workshop in China. As was the case in Poland, Chinese scientists and farmers found the discussion of modern forage technology useful in their situation. Based on the success of their Polish translation, the authors authorized the translation of "Southern Forages" to Chinese, again, royalty free. In both Poland and China four-way collaboration was worked out. Scientists and educators in their respective developing countries through collaboration recognized the value of the technologies described in the book. The authors generously agreed to permit translation, royalty free. The publishers, private sector partners, supported the undertaking and the whole endeavor was triggered through the collaborative inquiries and exchanges of scientists from less developed countries (LDC) and the U.S.

## COLLABORATION PRODUCES MUTUAL BENEFITS

Based on our experience and that of others over the last several decades, collaborative endeavors enable us:

- To exchange ideas about each other's culture, public policies, economics, education, religion, sports, etc.
- To broaden our knowledge of diverse environments, agricultural systems, soils, crops, markets, etc.
- To become more constructively involved in the reduction of malnutrition and poverty through transfer and adaptation of technology to the needs of developing countries.
- To become active participants in international education and research.

- To share the benefits of literature search engines operating in the industrial nations that may not be available in developing countries.
- To generate opportunities to present professional papers internationally.
- To facilitate the publication of scientific papers internationally, which in turn, favors academic promotion/advancement. The "Literature Cited" contains a sampling of our publications (Ossom et al., 1987, 1991, 2001, 2003a, 2003b, 2006) that involved three developing countries: Nigeria, Papua New Guinea, and Swaziland.
- To become an active participant in international affairs and know individuals and families on a first name basis across international boundaries.
- To enhance the recruitment and placement of graduate students, post docs and individuals involved in exchange programs.

## INITIATING CONTACTS

The success of an international cooperative endeavor depends upon both parties wanting to become involved in a collaborative research and/or educational project. Such cooperation can be encouraged but not dictated. Much thought and careful planning is required before embarking on such a venture. Chances of developing a successful relationship are enhanced if the prospective collaborators already know each other – as perhaps in a professor-graduate student relationship, as members of an international committee, or through a mutual friend.

For prospective LDC collaborators, we offer these following suggestions. If you have obtained an advanced degree in an industrialized country, the obvious first choice is to approach your former major professor. Our team effort resulted from an exceptionally good major professor-graduate student relationship. This is ideal because each individual knows the other person well. If one's major professor is already over-committed, he/she may suggest colleagues who may be interested in a collaborative relationship. In the absence of a personal contact one may communicate directly with agricultural educators, deans and department heads to explore the possibility of establishing linkages. Additionally, professional organizations may be in a position to provide assistance. For example, in the case of agronomy, one might contact the American Society of Agronomy (ASA), the Crop Science Society of America (CSSA), or the Soil Science Society of Agronomy (SSSA).*

*The mailing address of each of these societies is: 677 South Segoe Road, Madison, WI USA 53711. The phone number is 608-273-8080. The society web pages are: www.agronomy.org, www.crops.org, www.soils.org.

## AGRONOMIC SOCIETIES OFFER REDUCED MEMBERSHIP FEES FOR LDC SCIENTISTS

To increase the availability of Society membership and journals to the best and brightest scientists around the world, regardless of need, agronomic societies have created a special international membership category. Scientists in lower tiers of LDCs as defined by the World Bank may qualify. If so, they may join ASA, CSSA, or SSSA at a reduced annual rate (other fees may apply). In addition, the Agronomic Science Foundation (ASF) has established the ASF International Member Fund to further reduce the annual membership fee by 50% to scientists with the greatest need. Additional information concerning these two programs is available at www.asa-cssa-sssa.org/membership and www.asa-cssa-sssa.org/membership/pdf/international_discount.pdf. We hope that other scientific organizations will follow the lead of ASA, CSSA, and SSSA.

## FINDING NEEDED FUNDING

A major obstacle to a productive, synergistic relationship may be funding. If the industrial country partner desires such a collaborative relationship badly enough, he/she may invest personal funds. Such an investment can be very rewarding. Real satisfaction comes from knowing that you have personally contributed to the well being of people in need.

Obtaining funding from major donors such as USAID and World Bank is difficult as the projects that they intend to fund require competitive bids from institutions or companies, not from individuals. Although USAID has greatly reduced their support of agricultural development in low-income countries, limited opportunities are still available. For example, The Sustainable Agriculture and Resource Management Collaborative Research Support Program (SANREM CRSP) is presently being managed by Virginia Polytechnic Institute and State University (Virginia Tech). Details are available at http://www.sanrem.uga. Agricultural economists may wish to contact Cornell and Clark Atlanta Universities concerning a grant supported by USAID entitled "Strategies and Analysis for Growth and Access (SAGA) Project". Logging into www.saga.cornell.edu would provide further details.

The embassy in the country of interest can be a valuable source of information on funding for projects from both private and public sources. Other potential funding sources include Private Voluntary Organizations (PVO's) and Non-Governmental Organizations (NGO's). And one can, with the backing of one's institution, approach private foundations which support development work.

## CONCLUSION

Based on our experience, partnering with overseas colleagues is not easy. Funding, if required, is especially difficult. However, with present-day, virtually costless electronic communications, partnerships can be launched more easily than ever before. Our collaborative projects have proven to be both personally and professionally rewarding. We think that others may also find that establishing a collaborative relationship may bring many rewards to the participants.

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# Tree Species Diversity and Composition in Relation to Forest Borders in Two Old-Field Successional Stands at Allerton Park, Piatt County, Illinois USA

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## ABSTRACT

Two successional forest stands developed on pastureland abandoned during the 1930's at Allerton Park, Piatt County, Illinois USA were examined for patterns of tree species diversity and composition. After pastures were abandoned the subsequent successional processes were not altered by tree cutting, mowing, or grazing, which usually occur in the region. The most frequent species in both stands were *Quercus imbricaria* Michx., *Ulmus americana* L., *Ulmus rubra* Mühl., and *Juglans nigra* L. The Shannon index of diversity and Simpson index of dominance were calculated for both stands using the jack-knifing procedure. A regression equation using the jack-knifed values quantified a significant decrease in diversity with distance from forest border for the wider old-field stand. The other stand with a higher percentage of forest perimeter and a narrower configuration was more diverse. The $R^2$ value for the relationships with distance to forest border in the wider stand were 0.30 for diversity, 0.32 for density, 0.34 for basal area, and 0.32 for importance value for species having seed dispersed primarily by animals. These values indicate that factors associated with seed dispersal probably influence the variation of forest composition and structure more than is commonly suggested. Proximity to forest vegetation seems to be important as a determinant of species diversity and composition during old-field succession at this location. The wider tract had more wind and bird dispersed tree species and relatively fewer animal dispersed species. *Quercus imbricaria* was the dominant tree species among oaks and other species in this study, perhaps due to preference of its small acorns by the blue jay, which carries and caches acorns in soil and under litter.

Keywords: Old-field succession; tree species diversity; *Quercus imbricaria*; forest regeneration

## INTRODUCTION

In agricultural regions of the Midwest there are few examples of uninterrupted succession from old-field to forest. Mowing, grazing, and tree cutting practices during forest succession are common and alter successional processes in these stands. At Allerton Park in Piatt County Illinois, old agricultural fields set aside as nature reserves in the 1930's have reverted to forest without direct subsequent disturbance. The configurations and proximity to surrounding forest permitted examination and comparison of the composition and diversity of two old-field successional stands.

Adjacent vegetation influences tree invasion during old-field succession (Bazzaz, 1968; Vankat, 1991; Myster, 1993) and species found invading old-fields are often found in proximal forest stands (Ashby and Weaver, 1970; Buell et al., 1971; Crowder and Harmsen, 1998). The ability of tree species to disperse seed might be as important as other factors, such as competition and herbivory, in determining tree species composition in old-fields (De Steven, 1991a; 1991b). Near a forested border, tree density during succession is greater (Myster and Pickett, 1992) and small fields exhibit greater species richness (Crowder and Harmsen, 1998). Differing seed dispersal mechanisms in upland forests (wind, bird, or mammal) are important in determining the ability of trees to invade an old-field. Seed dispersal affects the timing of invasion and distribution of individual species (Bard, 1952; Buell et al., 1971; Connell and Slatyer, 1977; Oliver, 1981; McDonnell and Stiles, 1983; Christensen and Peet, 1984; Burton, 1989; Myster and Pickett, 1992) and can influence species composition by limiting the number of species that successfully establish at greater distances from seed sources.

If proximity to forest border influences the species composition and densities of successional forests on old-fields, then differing amounts of forest border along the perimeter of old-fields and the extent to which the forest surrounds an old-field should also have an effect on tree species composition and diversity of successional forests. At Allerton Park, we studied two forest stands with differing original amounts of forest border that developed on pastureland abandoned in the 1930's. We hypothesized that a forest stand that developed on a narrow field with 92 percent forest border would have greater species diversity than a forest stand that developed on a wider field with only a 50 percent forest border. We further hypothesized that species diversity and the abundance of mammal dispersed tree species would decrease with increasing distance from forest borders. In the present study we test these hypotheses and describe the species composition and structure of the two successional forest stands.

## STUDY SITE

The study location was Robert Allerton Park in east-central Illinois (N39° 59.9′; W88° 38.7′), along the Sangamon River in Piatt County, Illinois. Allerton Park was established in 1946 and is owned by the University of Illinois at Urbana-Champaign, which maintains it as a reserve for research and education. Robert Allerton, a wealthy benefactor, had established an estate and gardens at the site, prior to donating it to the University of Illinois. Most of the 600 ha of the park are rolling terrain and floodplain with both old-growth and second growth upland and bottomland forests. Robert Allerton set aside this land as a nature reserve. The park is located in the Prairie Peninsula of the oak-hickory forest region in the central United States (Braun, 1950). Allerton Park is located in the Grand Prairie Natural Division of Illinois (Schwegman, 1973).

Two separate upland forest tracts used as pasture prior to the 1930's were selected as study sites. Stand 1 is located in the southwestern portion of the park and is approximately 15.4 ha in size. The portion sampled is at least 4.5 m above the floodplain of the Sangamon River and not subject to periodic flooding. Slopes range from 0 to 7 percent. The soils consist of Miami (Oxyaquic Hapludalf) loams and Xenia (Aquic Hapludalf) and Russell (Typic Hapludalf) silt loams. They range from moderately well drained (Xenia) to well drained (Miami and Russell). These soils were formed under forest vegetation on till plain in loess, other silty material, and the underlying calcareous loam glacial till (Martin, 1991).

Stand 2 is approximately 16.2 hectares in size and is located in the eastern part of the park directly south of the Sangamon River approximately 1200 m northeast of stand 1. Slopes range from 0 to 7 percent. The soil types are the same as those of stand 1 with additional minor areas (less than 20 percent of total stand area) of Sunbury (Aquollic Hapludalf) silt loam, which is somewhat poorly drained and was formed in loess and underlying calcareous loam glacial till under forest vegetation (Martin, 1991). The stand is at least 6 m above the floodplain of the Sangamon River, but can occasionally have standing water in depressions associated with Sunbury silt loam. Variability of soil properties, including percent moisture and bulk density, for these and other upland forest soils at Allerton Park is low (David and Wang, 1989). A preliminary principal components analysis showed no relationship between tree species composition and soil types (unpublished data).

The critical differences between the stands for the purposes of this study are the amount of surrounding forest at the time of abandonment and the configuration of the fields. Stand 1 has a long and narrow configuration (Figure 1) and was almost completely surrounded by mature forest, having 92 percent of its perimeter contiguous with original forest. Stand 2 had 50 percent of its border forested along its northern boundary. Its remaining border was adjacent to abandoned pasture that was converted to tallgrass prairie. This recreated prairie is burned periodically to favor prairie and eliminate trees. Stand 2 has a wider configuration than stand 1 (Figure 1).

*Quercus alba* L. and *Quercus velutina* Lam. were the two most important species in an old-growth upland community located immediately west of stand 1 (Boggess and Geis, 1967). In this study *Ulmus rubra* Mühl. and *Ulmus americana* L. were ranked 3 and 6, respectively, due to a high number of stems in small diameter classes. The species composition of the portion of Allerton Park northeast of stand 2 has also been well documented (Bell, 1974; Johnson and Bell, 1975; Bell, 1980). *Quercus alba* dominated the upland forest and the second most dominant oak species was *Q. velutina*. Small *Ulmus* spp. were present in high densities. In the transitional zone between the uplands and floodplains, which is subject to minor flooding, *Quercus imbricaria* Michx. and *Celtis occidentalis* L. were the most important species. The floodplains were dominated by *Acer saccharinum* L. The majority of the forest presently bordering both stands is upland, with small percentages of riparian forest border. However, the north side of Stand 2 is within 30 m of the main floodplain and transitional forests of the Sangamon River (Figure 1).

Although separated by an upland forest similar in composition to the forest surrounding Stand 1, stand 2 has greater proximity to floodplain and transitional forest seed sources than Stand 1.

Records indicate that both study stands were cleared in the late 1800's and subsequently used for cattle grazing (Foster, 1981). Aerial photographs and maps show that both stands were originally grassy pastures with scattered trees (Holmberg Air Mapping Company, 1936; University of Illinois, 1948). Dykstra (1999) indicates that stand 1 was a secondary forest and stand 2 was an abandoned field in 1940. Both stands were described as successional forest in 1976 (Jones and Bell, 1976). These observations indicate that both stands began succession from pasture to forest in the mid to late 1930's. These stands have been allowed to succeed naturally without direct anthropogenic disturbance since 1946.

## METHODS

Aerial photographs from 1936 and maps from 1948 were used to describe site history and to delineate stands. Both stands were sampled using 0.081 ha circular plots systematically located 63.3 m apart along cardinal azimuths. There were 38 plots in stand 1 and 40 plots in stand 2. All woody stems greater than 6 cm in diameter at breast height (dbh) (Root et al., 1971; Boggess and Geis, 1967; Johnson et al., 1978; Edgington, 1991) within a plot were recorded by species to the nearest cm dbh, and dead standing trees were also recorded. Field work was conducted in the summer and fall of 1998 and 1999. For each stand the number of stems per ha (density), basal area ($m^2$) per ha, and frequency were estimated for tree species. Species importance values (IV) were calculated using a sum of relative density, relative basal area, and relative frequency, were scaled to 100 by dividing by 3, and are referred to hereafter as IVa. Importance values were also calculated for each individual plot using only relative density and relative basal area. These were also scaled to 100 and are referred to hereafter as IVb. Species were selected for comparisons based on two criteria: they were either one of the 10 most dominant species in either stand based on IVa or they were a species primarily dispersed by mammals. For the selected species, the mean plot values for density, basal area, and IVb were calculated for each stand. These means were used in t-tests to examine differences between stands in ecological values for the selected species. The distance to nearest forested border in 1936 was determined from aerial photographs, border forests being defined as those contiguous areas having at least 50 percent canopy closure. The upper soil horizons in both stands were examined for indicators of past agricultural use.

A Shannon index of diversity ($H'=-\Sigma p_i \ln p_i$ where $p_i$ equals the proportion of importance for the ith species) and Simpson index of dominance ($D=\Sigma p_i^2$ where $p_i$ equals the proportion of importance for the ith species) were calculated for each stand using the importance values from individual plots calculated with relative density and relative basal area. The Shannon index of diversity and the Simpson index of dominance are heterogeneity indices that combine information on both species richness and species evenness (Peet, 1974). The Shannon index is biased towards species richness, while the Simpson index is biased towards the abundance of the most common species (Magurran, 1988). Since the stands differed with respect to both of these attributes, both indices were used.

A jack-knifing procedure (Zahl, 1977) was used to calculate the indices for each stand. This re-sampling procedure calculates the index n times, where n is the number of plots. Each time the index is calculated, one plot is systematically removed from the sample. A series of jack-knife estimates (VJ) are created for each plot, and represent the diversity of the stand with an individual plot removed. A series of n pseudovalues (VP) are also created. The variance of the VP values is better than other estimates of H′ variance (Adams and McCune, 1979), making the VP values reliable for significance testing (Zahl, 1977). The mean of the VP values is the best estimate of the index. Jack-knifing an index of diversity allowed us to examine the influence of individual plots on the overall diversity of a stand without losing the overall diversity. Calculating an individual index value for each plot, and then an average, would not accurately reflect the true diversity of a stand because diversity is sensitive to sample size (Magurran, 1988). In accordance with our hypothesis, we expected plots close to the forest border to have a positive influence (greatest tree diversity), plots far from the border to have a negative influence (least tree diversity), and plots in between to have little influence (intermediate tree diversity) on the diversity of a stand. The two stands were tested for differences with t-tests using the VP values for both H′ and D. The VJ values from the jack-knifing procedure using H′ were examined for relationships with distance from forest border (m). In addition a linear regression analysis was used to statistically quantify the relationship of VJ with distance from forest border for the wider stand 2 which afforded sufficient width to do so. The values for tree density, basal area, and IVb for major mammal dispersed species were pooled by plot for stand 2. The values were pooled because many species were absent from a large number of the plots, making an analysis of individual species problematic. Regression analyses were performed with each pooled variable and distance from plots to forest border to examine relationships between the abundance of the mammal dispersed species and the distance to forest border.

## RESULTS

The soil examinations from both stands showed evidence of past grazing and in portions there were indications of plowing. Indicators of past agricultural use included an abrupt soil structure change (granular to subangular blocky) at depths of 13 cm to 25 cm, non-pedogenic mixing of the A and B horizons, and evidence of compaction in the lower A horizon.

The two stands had similar species composition (Tables 1 and 2). In stand 1 *Q. imbricaria* had the highest IVa, followed by *U. rubra* and *U. americana* (Table 1). *Ulmus rubra* and *U. americana* comprised about 30 percent of the stems in the smallest size class (6-10 cm). *Sassafras albidum* (Nutt.) Nees, *Q. imbricaria*, *Fraxinus americana* L., and *C. occidentalis* also had high numbers of stems in this size class. In the 11-20 cm size class *Ulmus* spp., *Q. imbricaria*, and *S. albidum* made up a major portion of the total stems, along with *F. americana* and *Juglans nigra* L. In the 21 to 30 cm dbh size class *Q. imbricaria* was the dominant tree. *Gleditsia triacanthos* L. also had values reflecting a high degree of dominance. *Quercus imbricaria* was the most common tree in the 31 to 40 cm diameter class. *Quercus velutina* and *Quercus rubra* L. had more stems than the *Ulmus* spp. in this size class. In the 41 cm and greater size class, *Q. velutina* and *Q. alba* outnumbered *Q. imbricaria*, the third most common species. The *Quercus* spp. combined made up almost 69 percent of the stems in this size class. *Juglans nigra* and *G. triacan-*

*thos* were also common. The total basal area for stand 1 was 24.0 $m^2$ per hectare, with 782 stems per hectare.

In stand 2, *Q. imbricaria* and *U. americana* had the highest IVa (Table 2). *Juglans nigra* was third, but had less than half the IVa of *U. americana*. The ranking of seventh in IVa for *A. saccharinum*, a floodplain species, on upland stand 2 is noteworthy. *Quercus imbricaria* and *U. americana* dominated the three smallest size classes in stand 2. *Sassafras albidum* had a large number of stems in the two smallest size classes. *Juglans nigra* represented a significant portion of the 21 to 30 cm size class. *Acer saccharinum* also had a large proportion of its total number of stems per ha in this size class. In the 31 to 40 cm size class, *Q. imbricaria* was the most common species, followed by *U. americana* and *J. nigra*. *Gleditsia triacanthos* had its highest density in this size class. The largest size class (41+ cm) was dominated by *Q. imbricaria*. *Ulmus americana* had a much lower percentage of the total stems per ha in this size class than in smaller size classes. There were 798 stems per ha having a total basal area of 21.1 $m^2$ per ha for stand 2.

The t-tests revealed significant differences between stands in density, basal area, and IVb for some of the selected tree species (Table 3). *Quercus imbricaria*, *U. americana*, *Prunus serotina* Ehrh., and *A. saccharinum* from stand 2 had significantly higher values for the three variables than in stand 1. *Quercus velutina*, *F. americana*, *Q. alba*, *Carya glabra (Mill.) Sweet*, *Quercus macrocarpa Michx.*, *Carya ovata (Mill.) K. Koch*, and *Carya tomentosa (Poir.) Nutt.* from stand 2 had significantly lower values for all three variables. Also in stand 2 *Gleditsia triacanthos* had significantly lower density and *Carya cordiformis (Wangenh.) K. Koch.* had significantly lower IVb and basal area relative to stand 1. *Quercus rubra* was the only oak species that was not significantly different for any of the three variables. *Juglans nigra* also did not differ significantly in mean values for any of the variables between stands. *Quercus imbricaria* was the only oak species that had a significantly higher density, basal area, and IVb in stand 2.

The estimate of H′, which is the mean of the VP values, is 2.99 for stand 1, the narrow stand with 92 percent original forest border. The estimate of H′ for stand 2, the wide stand with only 50 percent original forest border, is 2.44. The H′ values are significantly different (df=75; p-value<0.0001) indicating that stand 1 is more diverse than stand 2. The estimate of D for stand 1 is 0.06; the estimate of D for stand 2 is 0.13. The D values are also significantly different (df=49; p-value<0.0001). This indicates that the most common species are more dominant in stand 2 than in stand 1.

There was an apparent relationship between the VJ values of H′ and distance from original forest border (m) in stand 2. When stand 2 plots that were close to the forest border were removed from diversity calculations during the jack-knifing procedure, diversity decreased. When plots far from the border were removed, diversity increased. This indicates plots closer to forested border positively influenced the H′ value for stand 2 and plots far from the border negatively influenced the H′ value. In stand 2 diversity was highest close to the forest border and decreased as distance from the forest border increased. The results of the linear regression analysis, where VJ=2.41+0.00011*Distance (m), showed a significant relationship with distance from the forest border (df=39; p-value<0.001). The $R^2$ value was 0.30, suggesting that distance to original forest border was an important factor contributing to the variance in diversity among the plots.

The species with seeds primarily dispersed by mammals from stand 2, for which the density, basal area, and IVb values were pooled, were *J. nigra*, *Q. velutina*, *Q. rubra*, *Q. macrocarpa*, *C. cordiformis*, *C. ovata*, *C. tomentosa*, and *C. glabra*. The regression analyses between pooled values of density, basal area, and IVb and the distance to forest border were all significant (df=39; p-value<0.001). For density, the relationship was Density=16.59-0.0831*Distance (m), with an $R^2$ value of 0.32. The relationship for basal area was Basal Area=0.76-0.0040*Distance (m), with an $R^2$ value of 0.34. For IVb, it was IVb=32.06-0.1564*Distance (m), with and $R^2$ value of 0.32.

## DISCUSSION

The greater percentage of border perimeter shared with forest during succession and a narrower configuration of stand 1 with respect to stand 2, most likely contributed to the greater diversity of stand 1 by providing a proximal seed source during colonization and old-field succession.

Small fields have been shown to have higher species richness closer to a forest border (Crowder and Harmsen, 1998). A significant increase in diversity with proximity to original forest border was evident only for stand 2. This relationship was likely not seen in stand 1 because of its narrow configuration and higher percentage of forested border. No plots in the narrow stand were far enough from the forest border to decrease seed dispersal of any tree species in a way that significantly influenced stand diversity. The average and maximum distance from a plot to forest border for stand 1 were 47 m and 99 m, respectively, as opposed to average distance of 103 m and maximum distance of 204 m for stand 2.

During early succession to forest, tree density is usually highest near forest borders. As succession progresses, tree density begins to increase further from the forest border until eventually the entire field is stocked (Myster and Pickett, 1992). At greater distances from the nearby forest, tree species with longer seed dispersal ranges could establish earlier during succession, affording them a competitive advantage. Close to the forest border, where a greater number of species could successfully disperse their seeds, greater diversity would be expected. Wind-dispersed species, followed closely by bird-dispersed species, often invade old fields in advance of mammal-dispersed species (Bard, 1952; Buell et al., 1971; Smith, 1975; Christensen and Peet, 1984; Myster and Pickett, 1992; Myster, 1993).

The reduced abundance in stand 2 for most of the *Quercus* and *Carya* spp. (Table 3) suggests their ability to invade the stand was reduced with increasing distance from a forest border. The notable exception was the greater abundance of *Q. imbricaria* in stand 2. Considering that the seeds of oak and hickory species are commonly distributed by mammals and gravity, more surrounding forest cover with seed and associated dispersal agents seemed to increase the chances for these species to successfully disperse into the site. In stand 2, the significant reduction in the IVb, density, and basal area with greater distance from forest border for species primarily dispersed by mammals is consistent with this idea. Similarly, *Quercus and Carya* spp. were absent in southern Illinois old-fields less than 25 years old (Bazzaz, 1968; 1975).

Less forest border and the greater width of stand 2 probably favored wind-dispersed species compared to mammal-dispersed species. For example, *A. saccharinum* and *U. americana* had greater abundance in this stand (Table 3). *Acer saccharinum*, a floodplain species able to tolerate wet soils, was most common on, but not restricted to, the Sunbury silt loam, a somewhat poorly drained soil found in upland depressions. Its lower abundance in stand 1 might have been due to the absence of this poorly drained soil type, which would favor the flood tolerant species noted above. *Ulmus* spp. were distributed throughout the stand, not solely on the poorly drained Sunbury silt loam, indicating a greater ecological amplitude for this species with respect to soil moisture conditions. Elsewhere at Allerton Park and along the Sangamon River, small diameter *Ulmus* spp. were common across the entire hydrological gradient while *A. saccharinum* dominated the floodplain forests and poorly drained soils (Boggess and Geis, 1967; Root et al., 1971; Bell, 1974; Johnson and Bell, 1975; Johnson et al., 1978).

*Quercus imbricaria*'s natural habitat is wooded floodplains, especially the margins of floodplains, but it occurs more frequently as a pioneer species in the disturbed or agricultural landscape (Wagner and Schoen, 1976). Besides the successional stands, at Allerton Park and other forests along the Sangamon River in central Illinois *Q. imbricaria* had its greatest importance in transition zones between floodplain and upland forests; it was not as common as other *Quercus* spp. in undisturbed upland forests (Boggess and Geis, 1967; Root et al., 1971; Bell, 1974; 1980). *Quercus imbricaria* is an important *Quercus* sp. in other old-field stands in Illinois (Bazzaz, 1968; Jokela and Sawtelle, 1985). *Quercus imbricaria* is also drought tolerant (McCarthy and Dawson, 1990), an attribute of early successional species (Bazzaz, 1979). The greater mass of *Q. imbricaria* and other *Quercus* spp. acorns relative to the seed mass of wind dispersed species may afford the *Quercus* spp. seeds an advantage in penetrating through grassland plant communities (Jokela and Sawtelle, 1985; Fowler, 1986; Hamrick and Lee, 1987). In addition, *Quercus imbricaria* may be primarily dispersed by the blue jay (*Cyanocitta cristata* L.) (Darley-Hill and Johnson, 1981; Harrison and Werner, 1984; Johnson and Webb, 1989; Johnson et al., 1993; Johnson et al., 1997) which prefers small acorns (Scarlett and Smith, 1991) and is known to take the small *Q. imbricaria* acorns (Hermes, 1991). Seed dispersal by the blue jay, which, unlike most birds, caches acorns in the soil and under litter, could explain *Q. imbricaria's* dominance in both stands and its greater abundance in stand 2 than in stand 1. Most other *Quercus* spp. were less abundant in stand 2 than in narrow stand 1. *Prunus serotina*, the seed of which is also commonly dispersed by birds, was more abundant in stand 2 (Table 3).

Mature pasture trees could have provided a seed source within the field. Observations on the ground reveal that two of the seven large pasture trees identified in the 1936 photograph of stand 2 could have been *Q. imbricaria*. These two trees were less than 40 m from the forest border and by themselves could not likely have contributed to the differences observed between stands in this study through seed or sprouts. *Quercus imbricaria* sprouts (Dolan, 1994), and sprouting from root systems of seedlings that developed during the pasture phase might explain *Q. imbricaria's* dominance. It is unlikely, however, that there were many residual sprouts from root systems of pasture trees at the time of agricultural abandonment because cattle browsing usually eliminates sprouts and clearing the forest for crops typically entailed the removal of large tree roots and stumps.

The large number of *U. americana* stems in the smaller size classes (Tables 1 and 2) and its intermediate shade tolerance (Bey, 1990) suggest that existing elm trees may not have been initial colonizers. *Ulmus americana*, however, comprised 9 percent of the stems in the 41 cm and greater size class in stand 2. Recruitment into larger size classes is likely limited due to Dutch elm disease mortality, which Bell (1997) found to be highest in trees with a dbh greater than 26 cm. *Ulmus* spp. currently represent 18.4 percent of the density and 30.2 percent of the basal area of dead standing trees in stand 1, and 28.3 percent of the density and 53.7 percent of the basal area of dead standing trees in stand 2. *Ulmus americana* has been found to be an initial invader (Briggs and Gibson, 1992; Crow et al., 1994; Crowder and Harmsen, 1998) and a dominant early to mid-successional species in northern Illinois (Bell and del Moral, 1977; Bell, 1997). *Ulmus rubra* was codominant in 90 year old successional stands in Ohio (Vankat and Snyder, 1991), and an early to mid-successional species in other parts of central Illinois (McClain and Ebinger, 1968).

This study is unique for several reasons. While the jack-knifing procedure has been used previously to estimate and test the Shannon and Simpson indices, and has been shown to provide superior accuracy, to our knowledge the technique has not previously been applied to assess the influence of individual plots in studies of forest succession. The procedure allowed us to examine the influence of individual plots on overall stand level diversity, making it possible to quantify the diversity of a single plot while still permitting a comparison of diversity between stands. Calculating the diversity of each plot separately and using the mean to quantify stand diversity is problematic because it is possible for two plots to have identical values for diversity yet be composed of completely different species. Also the study site is unique in that areas of undisturbed succession in central Illinois are rare because of the typical history of both timber harvesting and grazing in secondary forests.

In the old-field successional forest stands examined in this study, proximity to forest border was significantly associated with increased tree species diversity and differences in species composition. The $R^2$ values of 0.30 for the relationship between distance to forest and diversity and 0.32, 0.34, and 0.32 for the relationships between distance to forest and density, basal area, and IVb, respectively, for species whose seed is dispersed primarily by mammals indicate that seed dispersal mechanisms influence the variation of stand composition, diversity and structure more than is commonly suggested. Many studies focus exclusively on site characteristics, resource availability, and competition as important determinants of forest successional patterns (Kimmins, 1997). The importance of seed dispersal is often noted, but with no quantification of the variability associated with seed sources. Proximity to surrounding forest vegetation has been shown in the present study to be important as a determinant of species diversity and composition during old-field succession. Reduced forest border and increased distance from forest stands increases establishment of wind and bird dispersed tree species over mammal dispersed species. *Quercus imbricaria* was the most dominant tree species in the successional forests of this study, and preference of its small acorns by the blue jay, which caches acorns in soil and under litter, might be a primary factor in its ability to more successfully invade old-field successional stands than other oaks and mammal-dispersed tree species.

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Table 1. Density (number of trees per hectare), basal area (BA, m$^2$ per hectare), frequency (number of plots in which species occurred / total number of plots), and importance value (IV, (relative density + relative BA + relative frequency) / 3) by size classes (dbh in cm) for stand 1.

| | Density | | | | | | BA | Freq | IVa |
|---|---|---|---|---|---|---|---|---|---|
| Species | 6-10 cm | 11-20cm | 21-30 cm | 31-40 cm | 41+ cm | >6 cm | >6 cm | >6 cm | >6 cm |
| *Quercus imbricaria* Michx. | 27.6 | 27.6 | 14.6 | 12.7 | 6.5 | 89.1 | 3.67 | 76.3 | 11.0 |
| *Ulmus rubra* Mühl. | 54.6 | 32.5 | 7.2 | 1.0 | 0.0 | 95.3 | 1.25 | 84.2 | 8.2 |
| *Ulmus americana* L. | 49.7 | 28.3 | 5.2 | 1.6 | 0.0 | 84.9 | 1.03 | 92.1 | 7.7 |
| *Quercus velutina* Lam. | 9.4 | 12.4 | 7.2 | 5.5 | 7.5 | 41.9 | 2.66 | 60.5 | 7.2 |
| *Fraxinus americana* L. | 22.8 | 23.1 | 8.5 | 4.9 | 1.0 | 60.1 | 1.57 | 78.9 | 7.0 |
| *Juglans nigra* L. | 8.5 | 20.5 | 7.8 | 3.9 | 5.2 | 45.8 | 2.38 | 60.5 | 7.0 |
| *Quercus alba* L. | 4.6 | 6.8 | 3.6 | 1.6 | 7.5 | 24.1 | 2.70 | 42.1 | 6.0 |
| *Sassafras albidum* (Nutt.) Nees | 35.8 | 26.3 | 4.9 | 0.0 | 0.0 | 67.0 | 0.82 | 57.9 | 5.6 |
| *Gleditsia triacanthos* L. | 1.3 | 7.8 | 10.7 | 5.2 | 2.9 | 28.0 | 1.84 | 60.5 | 5.4 |
| *Celtis occidentalis* L. | 22.8 | 10.4 | 5.9 | 1.6 | 0.3 | 41.0 | 0.75 | 60.5 | 4.5 |
| *Prunus serotina* Ehrh. | 11.4 | 8.5 | 7.8 | 0.7 | 0.3 | 28.6 | 0.66 | 68.4 | 4.1 |
| *Quercus rubra* L. | 7.2 | 6.5 | 4.2 | 2.0 | 1.3 | 21.1 | 0.79 | 57.9 | 3.6 |
| *Quercus macrocarpa* Michx. | 4.9 | 2.6 | 1.3 | 0.7 | 2.3 | 11.7 | 0.80 | 36.8 | 2.6 |
| *Cercis canadensis* L. | 15.9 | 8.1 | 0.0 | 0.0 | 0.0 | 24.1 | 0.19 | 39.5 | 2.4 |
| *Carya ovata* (Mill.) K. Koch | 6.2 | 4.9 | 2.9 | 2.0 | 0.0 | 15.9 | 0.42 | 39.5 | 2.4 |
| *Carya glabra* (Mill.) Sweet | 0.7 | 6.8 | 4.2 | 3.3 | 0.3 | 15.3 | 0.76 | 21.1 | 2.3 |
| *Acer saccharum* Marsh | 7.8 | 3.6 | 0.7 | 0.0 | 0.0 | 12.0 | 0.12 | 36.8 | 1.7 |
| *Tilia americana* L. | 5.2 | 3.9 | 0.7 | 1.0 | 0.0 | 10.7 | 0.23 | 31.6 | 1.7 |
| *Juniperus virginiana* L. | 10.4 | 7.8 | 0.3 | 0.0 | 0.0 | 18.5 | 0.18 | 21.1 | 1.6 |
| *Carya cordiformis* (Wangenh.) K. Koch. | 3.9 | 2.3 | 2.6 | 0.7 | 0.0 | 9.4 | 0.26 | 28.9 | 1.6 |
| *Carya tomentosa* (Poir.) Nutt. | 2.9 | 2.0 | 1.3 | 1.0 | 0.0 | 7.2 | 0.21 | 34.2 | 1.6 |
| *Acer saccharinum* L. | 1.0 | 1.3 | 0.7 | 0.0 | 0.3 | 3.3 | 0.16 | 18.4 | 0.9 |
| *Viburnum prunifolium* L. | 3.3 | 0.0 | 0.0 | 0.0 | 0.0 | 3.3 | 0.01 | 18.4 | 0.7 |
| *Platanus occidentalis* L. | 0.0 | 0.7 | 0.3 | 0.7 | 1.0 | 2.6 | 0.22 | 7.9 | 0.6 |
| *Crataegus spp.* L. | 3.3 | 2.9 | 0.0 | 0.0 | 0.0 | 6.2 | 0.05 | 10.5 | 0.6 |
| *Morus rubra* L. | 0.7 | 0.7 | 1.3 | 0.0 | 0.0 | 2.6 | 0.07 | 10.5 | 0.5 |
| *Acer negundo* L. | 2.9 | 2.3 | 0.0 | 0.0 | 0.0 | 5.2 | 0.05 | 5.3 | 0.4 |
| *Fraxinus quadrangulata* Michx. | 2.9 | 0.0 | 0.0 | 0.0 | 0.0 | 2.9 | 0.01 | 5.3 | 0.3 |
| *Fraxinus pennsylvanica* Marsh. | 0.0 | 0.0 | 0.3 | 0.3 | 0.0 | 0.7 | 0.05 | 5.3 | 0.2 |
| *Robinia pseudoacacia* L. | 0.0 | 0.0 | 0.3 | 0.7 | 0.0 | 1.0 | 0.08 | 2.6 | 0.2 |
| *Maclura pomifera* (Raf.) C. K. Schneid. | 0.0 | 1.0 | 0.7 | 0.0 | 0.0 | 1.6 | 0.05 | 2.6 | 0.2 |
| *Prunus spp.* L. | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 | 0.3 | 0.00 | 2.6 | 0.1 |
| *Cornus spp.* L. | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 0.00 | 2.6 | 0.1 |
| Total | 327.7 | 261.7 | 105.0 | 50.7 | 36.4 | 781.6 | 24.0 | 1181.6 | 100 |

Table 2. Density (number of trees per hectare), basal area (BA, m$^2$ per hectare), frequency (number of plots in which species occurred / total number of plots), and importance value (IV, (relative density + relative BA + relative frequency) / 3) by size classes (dbh in cm) for stand 2.

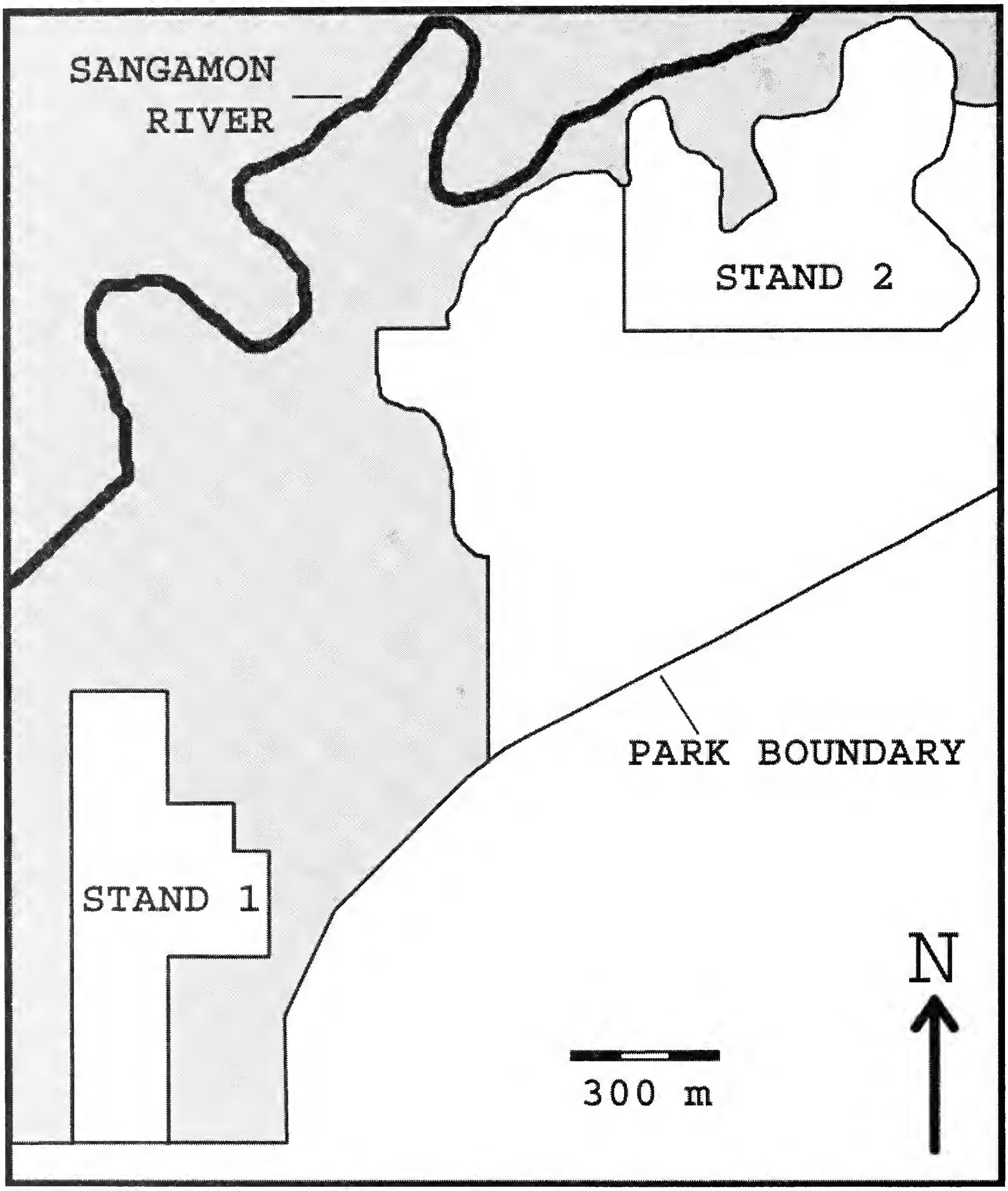
| | Density | | | | | | BA | Freq | IVa |
|---|---|---|---|---|---|---|---|---|---|
| Species | 6-10 cm | 11-20cm | 21-30 cm | 31-40 cm | 41+ cm | >6 cm | >6 cm | >6 cm | >6 cm |
| *Quercus imbricaria* Michx. | 65.2 | 68.3 | 22.2 | 9.9 | 11.4 | 177.0 | 5.86 | 100.0 | 20.0 |
| *Ulmus americana* L. | 79.1 | 66.7 | 24.7 | 5.9 | 2.2 | 178.5 | 3.73 | 100.0 | 16.7 |
| *Juglans nigra* L. | 7.4 | 19.8 | 14.5 | 5.3 | 1.2 | 48.2 | 1.85 | 82.5 | 7.7 |
| *Sassafras albidum* (Nutt.) Nees | 38.9 | 39.5 | 5.3 | 1.2 | 0.3 | 85.2 | 1.24 | 60.0 | 7.5 |
| *Prunus serotina* Ehrh. | 12.0 | 20.1 | 8.6 | 3.7 | 1.5 | 46.0 | 1.40 | 80.0 | 6.8 |
| *Ulmus rubra* Mühl. | 31.8 | 22.9 | 5.6 | 0.9 | 0.3 | 61.5 | 0.96 | 75.0 | 6.6 |
| *Acer saccharinum* L. | 7.1 | 15.4 | 10.5 | 1.9 | 0.9 | 35.8 | 1.18 | 47.5 | 4.9 |
| *Quercus velutina* Lam. | 3.1 | 6.2 | 4.9 | 1.5 | 3.1 | 18.8 | 1.24 | 65.0 | 4.9 |
| *Celtis occidentalis* L. | 13.6 | 9.9 | 4.0 | 0.6 | 0.3 | 28.4 | 0.54 | 65.0 | 4.2 |
| *Gleditsia triacanthos* L. | 0.3 | 3.1 | 1.9 | 4.0 | 3.1 | 12.4 | 1.22 | 35.0 | 3.6 |
| *Crataegus spp.* L. | 18.2 | 5.3 | 0.0 | 0.0 | 0.0 | 23.5 | 0.15 | 65.0 | 3.4 |
| *Quercus rubra* L. | 3.1 | 4.6 | 3.4 | 1.9 | 0.9 | 13.9 | 0.65 | 20.0 | 2.3 |
| *Fraxinus americana* L. | 6.2 | 5.3 | 0.6 | 0.0 | 0.0 | 12.0 | 0.15 | 35.0 | 1.9 |
| *Malus spp.* Mill. | 12.7 | 1.5 | 0.0 | 0.0 | 0.0 | 14.2 | 0.08 | 32.5 | 1.8 |
| *Cercis canadensis* L. | 8.0 | 3.1 | 0.6 | 0.0 | 0.0 | 11.7 | 0.11 | 30.0 | 1.7 |
| *Quercus macrocarpa* Michx. | 1.2 | 1.9 | 1.5 | 0.6 | 0.0 | 5.3 | 0.19 | 15.0 | 1.0 |
| *Acer negundo* L. | 3.4 | 1.9 | 0.0 | 0.6 | 0.0 | 5.9 | 0.10 | 17.5 | 1.0 |
| *Carya cordiformis* (Wangenh.) K. Koch. | 3.1 | 1.2 | 0.6 | 0.0 | 0.0 | 4.9 | 0.06 | 20.0 | 1.0 |
| *Tilia americana* L. | 1.2 | 1.5 | 0.6 | 0.0 | 0.0 | 3.4 | 0.08 | 15.0 | 0.8 |
| *Carya ovata* (Mill.) K. Koch | 2.2 | 1.2 | 0.6 | 0.3 | 0.0 | 4.3 | 0.09 | 7.5 | 0.6 |
| *Quercus alba* L. | 0.6 | 0.6 | 0.3 | 0.6 | 0.3 | 2.5 | 0.13 | 7.5 | 0.6 |
| *Acer saccharum* Marsh | 0.9 | 0.0 | 0.3 | 0.0 | 0.0 | 1.2 | 0.01 | 10.0 | 0.4 |
| *Carya tomentosa* (Poir.) Nutt. | 0.3 | 0.6 | 0.0 | 0.0 | 0.0 | 0.9 | 0.02 | 5.0 | 0.2 |
| *Viburnum prunifolium* L. | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.6 | 0.00 | 5.0 | 0.2 |
| *Carya glabra* (Mill.) Sweet | 0.0 | 0.6 | 0.0 | 0.0 | 0.0 | 0.6 | 0.01 | 2.5 | 0.1 |
| *Maclura pomifera* (Raf.) C. K. Schneid. | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 0.00 | 2.5 | 0.1 |
| *Morus rubra* L. | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 0.00 | 2.5 | 0.1 |
| *Cornus spp.* L. | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 0.00 | 2.5 | 0.1 |
| *Quercus imbricaria* Michx. | 65.2 | 68.3 | 22.2 | 9.9 | 11.4 | 177.0 | 5.86 | 100.0 | 20.0 |
| *Ulmus americana* L. | 79.1 | 66.7 | 24.7 | 5.9 | 2.2 | 178.5 | 3.73 | 100.0 | 16.7 |
| *Juglans nigra* L. | 7.4 | 19.8 | 14.5 | 5.3 | 1.2 | 48.2 | 1.85 | 82.5 | 7.7 |
| *Sassafras albidum* (Nutt.) Nees | 38.9 | 39.5 | 5.3 | 1.2 | 0.3 | 85.2 | 1.24 | 60.0 | 7.5 |
| *Prunus serotina* Ehrh. | 12.0 | 20.1 | 8.6 | 3.7 | 1.5 | 46.0 | 1.40 | 80.0 | 6.8 |
| Total | 321.2 | 301.1 | 110.9 | 38.9 | 25.6 | 797.8 | 21.1 | 1005.0 | 100 |

Table 3. Plot means for importance value b (IVb), density, and basal area (BA) in m$^2$, for selected species. Stand 1 was narrower and had a greater percentage of its perimeter bordered by forest at the time of agricultural abandonment.

| | IVb | | | Density | | | BA | | |
|---|---|---|---|---|---|---|---|---|---|
| Species | Stand 1 | | Stand 2 | Stand 1 | | Stand 2 | Stand 1 | | Stand 2 |
| *Quercus imbricaria* Michx. | 12.60 | * | 24.91 | 7.21 | * | 14.33 | 0.30 | * | 0.47 |
| *Juglans nigra* L. | 8.88 | | 7.61 | 3.71 | | 3.90 | 0.19 | | 0.15 |
| *Ulmus rubra* Mühl. | 8.35 | | 5.86 | 7.71 | | 4.98 | 0.10 | | 0.08 |
| *Quercus velutina* Lam. | 8.05 | * | 3.92 | 3.39 | * | 1.53 | 0.21 | * | 0.10 |
| *Ulmus americana* L. | 7.72 | * | 20.41 | 6.87 | * | 14.45 | 0.08 | * | 0.30 |
| *Fraxinus americana* L. | 7.22 | * | 1.04 | 4.87 | * | 0.98 | 0.13 | * | 0.01 |
| *Quercus alba* L. | 6.28 | * | 0.42 | 1.95 | * | 0.20 | 0.22 | * | 0.01 |
| *Sassafras albidum* (Nutt.) Nees | 5.66 | | 7.75 | 5.42 | | 6.90 | 0.07 | | 0.10 |
| *Gleditsia triacanthos* L. | 5.54 | | 3.35 | 2.26 | * | 1.00 | 0.15 | | 0.10 |
| *Celtis occidentalis* L. | 4.42 | | 3.51 | 3.32 | | 2.30 | 0.06 | | 0.04 |
| *Prunus serotina* Ehrh. | 3.31 | * | 6.39 | 2.32 | * | 3.73 | 0.05 | * | 0.11 |
| *Quercus rubra* L. | 2.96 | | 2.21 | 1.71 | | 1.13 | 0.06 | | 0.05 |
| *Carya glabra* (Mill.) Sweet | 2.81 | * | 0.05 | 1.24 | * | 0.05 | 0.06 | * | 0.00 |
| *Quercus macrocarpa* Michx. | 2.54 | * | 0.71 | 0.95 | | 0.43 | 0.06 | * | 0.02 |
| *Carya ovata* (Mill.) K. Koch | 2.07 | * | 0.52 | 1.29 | * | 0.35 | 0.03 | * | 0.01 |
| *Carya cordiformis* (Wangenh.) K. Koch. | 1.08 | * | 0.43 | 0.76 | | 0.40 | 0.02 | * | 0.00 |
| *Carya tomentosa* (Poir.) Nutt. | 0.96 | * | 0.09 | 0.58 | * | 0.08 | 0.02 | * | 0.00 |
| *Acer saccharinum* L. | 0.73 | * | 5.48 | 0.26 | * | 2.90 | 0.01 | * | 0.10 |

* Significantly different (probability <0.05)

Figure 1. Allerton Park circa 1936 showing stands 1 and 2. Shaded areas indicated forest cover; non-shaded areas indicate pasture. Adapted from: Jones and Bell (1976)



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# Floodplain Forest Response to Large-Scale Flood Disturbance

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## ABSTRACT

Flood disturbance is the principal factor influencing species composition and distribution in floodplain forests. It has been widely assumed that these floodplain species have developed the ability to survive different magnitudes of flooding. However, research on the effects of large-scale flooding is lacking. Floodplain forests on Pool 26 of the Upper Mississippi River System, suffered high mortality following a 1993 flood disturbance. The degree of mortality was dependent upon tree species, forest community and tree size. Mixed forests suffered greater mortality in trees and saplings than did the maple-ash and oak forests studied. *Celtis occidentalis* and *Quercus palustris* were largely flood intolerant while *Fraxinus pennsylvanica* and *Acer saccharinum* were more tolerant. Larger diameter trees had better flood survivorship than did smaller diameter trees. Tree seedlings and lianos were intolerant of the flood event. Seedling regeneration was forest community and species dependent. Maple-ash forests had a seedling density of 365,700 seedlings/hectare while mixed and oak forests were significantly less (144,012 and 95,545 seedlings/hectare, respectively). *Acer saccharinum*, *F. pennsylvanica* and *Ulmus americana* were the dominant seedlings of the three forests communities. High canopy, overstory and understory covers reduced seedling density. Openings in the canopy and silt deposition initiated a tremendous response in the herbaceous strata. Annual forbs, grasses and grass-like plants responded favorably to the flood event, whereas, biennial and perennial forbs were largely lacking. *Bidens aritosa* was the dominant herbaceous plant occurring in over 75% of the quadrats sampled and having an average cover of 36%.

Key Words: flood disturbance; floodplain forest; seedling regeneration, Upper Mississippi River, LTRMP

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## INTRODUCTION

Periodic flooding is the most common disturbance event on floodplains and often determines the distribution of forest species and communities (Bedringer, 1978; Metzler and

Damman, 1985; Streng et al., 1989; Hughes, 1990; Oliveira-Filho et al., 1994). The degree of disturbance is dependent upon flooding frequency, duration, intensity, and timing as well as the stage of successional development in the forest community (Hosner and Boyce, 1962; Gill, 1970; Bell and Johnson, 1974; Bedringer, 1978). Most floodplain trees are adapted to survive moderate frequency, moderate intensity and short duration flooding when it occurs between late summer and early spring during plant dormancy (Johnson and Bell, 1976; Bedringer, 1978; Harms et al., 1980; Taylor et al., 1990). However, tree mortality increases with flood frequency, intensity, or duration and when flooding occurs during the growing season (Hosner and Boyce, 1962; Kozlowski, 1984; Yin et al., 1994; Yin, 1998). Infrequent, "large-scale" flooding is generally considered natural and may actually be a driving force of organism, community and landscape successional patterns (Hupp, 1983; Hupp and Osterkamp, 1985; Duncan, 1993; Michener et al., 1998). However, knowledge of forest community and individual tree species response to large-scale flooding is poorly understood due to the infrequency.

In 1993, a long duration, high intensity flood inundated floodplain forests along Reach 26 of the Upper Mississippi River System (UMRS) during much of the growing season (US Army Corps of Engineers, 1994) (Figure 1). This was the largest flood event on record in the vicinity of St. Louis, MO, and is considered to have exceeded the 100-year recurrence interval (Scientific Assessment and Strategy Team, 1994; Bhowmik et al., 1994). Our study 1) describes the impact of the 1993 flood on forest communities, community size classes, and individual species, 2) identifies tree seedling, herbaceous, and woody liano response to canopy gap openings caused by tree and sapling mortality, and 3) discusses changes in forest community composition as a result of the 1993 flood.

## METHODS

### Study Area

The UMRS includes the stretch of the Mississippi River from the confluence with the Ohio River near Cairo, Illinois, northward to the headwaters at Lake Itasca, Minnesota (Upper Mississippi River Basin Commission, 1981). It also includes the Illinois River, which merges with the Mississippi River approximately 218 miles upriver from the Mississippi-Ohio Rivers confluence. The Upper Mississippi and Illinois Rivers still retains approximately 50% (1,038,000 ha) of the original floodplain as unleveed (Delaney and Craig, 1997).

The study area included floodplain forests along the upper Mississippi River from Lock and Dam 25 to Lock and Dam 26 (Reach 26) and the lower Illinois River from the confluence to Illinois River mile 12 (Figure 2). There are four major floodplain forest communities on this reach of the UMRS: cottonwood-willow, maple-ash, mixed, and oak (Barclay, 1924; Hosner and Minckler, 1960, 1963; Eyre, 1980; Galatowitsch and McAdams, 1994; Yin et al., 1997). Cottonwood-willow forest communities occupy recent riverine sediment deposits and are subject to annual flooding. Maple-ash forest communities occupy areas subject to prolonged periods of anaerobic conditions and to annual flooding. Oak forest communities occupy the higher elevations (second bottoms) on the floodplain and are subject to flooding rarely or for short periods of time. These forest communities may be more dependent upon small gap creation from windfall or fire for community replacement than flood disturbance. Transition from a maple-ash to an oak forest community may occur with only a meter change in elevation. Mixed forests are an advanced successional stage that develops through lack of severe flood disturbance in maple-ash forest communities and tree-fall disturbance in oak forest communities.

Reach 26 of the Mississippi and Illinois Rivers is mostly unrestricted bordered by bluffs and the Missouri River floodplain. Low man-made and natural levees do occur along some stretches of the Mississippi and Illinois Rivers and along the tributaries. Natural levees and barrier bars along the Illinois River rise as much as 1.2 to 3.0 meters above the floodplain (Butzer, 1977). This approximates the crest elevations of the mean annual flood levels of the 1800's prior to impoundment. Sloughs and tributaries are scattered throughout the floodplain and numerous islands are present. The combination of barrier bars, levees, islands, and isolated water bodies has created a myriad of vegetative communities distributed according to slight changes in elevation and soil hydrology (Hupp and Osterkamp, 1985; Galatowitsch and McAdams, 1994). Forests occupy most of the lower elevation floodplains and islands with herbaceous wetland communities occupying a thin band near the waters edge. Although most of the higher elevation floodplain forest and wetlands have been converted to farmland, some of the higher elevation floodplain forests have been preserved in hunting clubs. The flood of 1993 inundated most of the floodplain resulting in almost continuous flooding from bluff to bluff along the Illinois, Mississippi and Missouri Rivers.

## Sampling Methods

### Experimental Design and Forest Community Delineation

Fourty-five sites were randomly selected using a geographic information system (GIS) (ArcView, ESRI, Inc., Redlands, CA), land coverage. An additional 15 sites were randomly selected from forest communities known to be oak. A global positioning system (GPS) was utilized to locate sites in the field during the summer of 1995. At each site a 314 $m^2$ (10 meter radius) circular plot was established. We recorded the taxonomic name (Mohlenbrock, 1986), measured the diameter at breast height (dbh) and identified the vigor of each tree (dbh greater than 10 cm) and sapling (dbh greater than 2.5 cm and less than 10 cm). We defined vigor as dead prior to 1993, dead after 1993, and currently living.

Species importance values (IV) were used to determine the forest community type at each site. IV's were calculated by summing species relative density and relative dominance (Whittaker, 1967; Bell, 1974). Sites were classified as either an oak or maple-ash forest community if the total IV for all *Quercus spp.* (oak) trees combined or *Acer saccharinum* (silver maple), *Acer negundo* (box elder) and *Fraxinus pennsylvanica* (green ash) trees combined was greater than 100. If the site could not be classified as an oak or maple-ash forest community, it was classified as a mixed forest (dominated by *Celtis occidentalis* and *Ulmus americana*). Sites with a combined IV greater than 100 for *Populus deltoides* (cottonwood) and *Salix nigra* (black willow) and were removed from the study because there were not enough of the cottonwood/willow forest types represented (dropped two sites). Mortality rates and changes in species importance values were used to describe forest community and species response to the 1993 flood event. Regression analysis ($\alpha$=.05) was used to identify the significance of the relationship between tree dbh and percent mortality.

Canopy Gaps

Stratum cover was visually estimated at each subplot to determine canopy and subcanopy gaps. The strata included canopy (trees), subcanopy (saplings), overstory (combination of trees and saplings), understory (combination of seedling and herbaceous cover), and total (combination of all strata) cover estimates. Differences in strata cover between forest communities were determined using Tukey's W multiple comparison procedure (parametric, $\alpha$=.05). We calculated the relationship between understory, overstory and seedling density by utilizing a General Linear Model ($\alpha$=.05) by forest community.

Seedling and Herbaceous Measures

Within each plot, ten .25 $m^2$ (.5 m x .5 m) subplots were randomly established. Within each subplot, we identified each seedling (Mohlenbrock, 1986) and estimated its age. We defined a seedling as woody, non-vine, vegetation less than 2.5 cm in diameter. Herbaceous species were also identified (Mohlenbrock, 1986; Hitchcock, 1971) and ocular cover estimates were made. IV's were used to describe seedling composition among forest communities by combining relative frequency and relative density. We also used IV's to describe herbaceous composition (sum of relative cover and relative frequency). A General Linear Model ($\alpha$=.05) was utilized to describe the relationship between seedling density and forest community.

## RESULTS

### Response of the Tree and Sapling Strata

Tree and sapling mortality, resulting from the 1993 flood, varied according to tree species, tree size and forest community. Prior to 1993, trees with the highest IV's in Pool 26 were *A. saccharinum*, *Q. palustris*, *F. pennsylvanica*, *U. americana*, and *Celtis occidentalis* (IV's of 58, 35, 25, 17, and 12 respectively) (Table 1). Following the flood of 1993 the IV's of *Celtis occidentalis*, *Q. palustris*, *P. deltoide*s, and *U. americana* trees decreased due to high mortality (91%, 57%, 57% and 49%, respectively). *Q. lyrata* and *F. pennsylvanica* trees had better survivorship (mortalities of 19% and 23%, respectively). *Acer saccharinum* trees also experienced high mortalities following the flood. However, relative to other species, the post-flood importance value of *A. saccharinum* increased due to high mortality in other tree species. Prior to flooding, the sapling cohort was dominated by *Celtis occidentalis*, *U. americana*, *A. saccharinum*, and *F. acuminata* (IV's of 42, 37, 37, and 36, respectively) (Table 1). *Acer negundo*, *A. saccharinum* and *Celtis occidentalis* saplings suffered high mortalities (100%, 96%, and 75%, respectively). Although, *F. acuminata*, *D. virginiana*, *Cornus spp.*, *F. pennsylvanica*, and *U. americana* also suffered high mortalities (57%, 36%, 0%, 48%, and 66%, respectively), these species emerged as dominants in the post-flood sapling cohorts of Pool 26.

Across all forest communities, trees had lower mortality rates than did saplings (Table 2 and 3). Regression analysis utilizing tree dbh explained almost 66% of the variation (p = 0.0001, F = 3663.15) in percent mortality (Figure 3). Some outliers do appear to have high mortalities at large dbh's. These points represent large *P. deltoides* and indicate a species relationship.

The degree of tree and sapling mortality varied among forest communities. Mixed forests suffered greater tree mortality (60%) than maple-ash (41%) and oak (42%) forests due to high mortalities in all of the dominant tree species (Table 2). Oak forests had better sapling survivorship (mortality of 56%) than did maple-ash (80% mortality) and mixed (80% mortality) forests (Table 3). This may be related to the slightly higher elevation where these oak communities occurred, which decreased the length of flood disturbance.

Individual tree and sapling species mortality varied among forest communities. *Celtis occidentalis* and *Q. palustris* trees experienced very high mortalities in maple-ash forests (100 and 80%, respecitively) lower degrees of mortality in mixed (94 and 73%, respectively) and oak forests (74 and 54%, respectively) (Table 2). *Acer saccharinum*, *U. americana* and *F. pennsylvanica* trees experienced the greatest mortality in mixed forests (64, 60 and 36 % mortality, respectively) (Table 2). Other than *A. negundo*, all tree species experienced lower mortality in oak forests. Lower mortality rates on oak forests may be related to differences in elevation.

### Canopy Gap Responses

The creation and size of gaps was highly variable (Table 4). Some forest communities showed little sign of flood disturbance while other similar communities were denuded of forest. Canopy (tree) cover was significantly different across forest communities (Table 4 and 5). Maple-ash forest communities had the largest mean canopy cover followed by oak and mixed forest. Oak forest communities had significantly greater subcanopy (sapling) coverage than the maple-ash and mixed forests (Table 5). This is related to the lower mortality rates in saplings exhibited by the oak forests. Overstory cover estimates were significantly different across all forest types (Table 5). Maple-ash forests had higher overstory cover than the oak or mixed forests. Mixed forest understory cover was significantly greater than that of oak and maple-ash forests (Table 5). This is the result of higher mortalities in both the trees and saplings in mixed forests. There was no significant difference in total cover between the three forest communities.

There was a relationship between the creation of gaps and response of the understory. The overstory explained 40% of the variation ($r^2 = 0.4$, $F = 106.55$, $p = 0.0001$) of understory cover for oak forests. Overstory explained significantly less of the variation in understory for maple-ash ($r^2 = 0.07$, $F = 19.80$, $p = 0.0001$) and mixed forests ($r^2 = 0.03$, $F = 4.27$, $p = 0.04$). This result may be related to the high cover of shade tolerant herbaceous vegetation and seedling germination. In many instances, a forest community may have had little disturbance and mortality in the tree cohort, but received several centimeters to several meters of newly deposited sediment. This initiated tremendous herbaceous and tree seedling germination.

### Forest Regeneration and Woody Liano and Herbaceous Response

Following the flood of 1993, the floodplain seedling bank was essentially eliminated. Although care was taken to account for re-sprouts, none were identified and the mean age for all seedlings was between 1 and 2 years (Table 6). *Acer saccharinum* dominated the seedling bank of Pool 26 with a density of 146,502 seedlings/ha and occurred in 48% of the quadrats sampled. *Fraxinus pennsylvanica* and *U. americana* were codominant members of the post-flood seedling cohort (IVs of 30 and 21, respectively).
There was a significant relationship ($p = 0.0003$, $F = 9.65$) between seedling density and forest community. Maple-ash forests had a higher seedling density (365,700 seedlings/ha) than mixed and oak forests (144,012 seedlings/ha and 95,545 seedlings/ha, respectively).

Canopy, overstory, and understory cover were also significant predictors of seedling density (p = 0.0001, F = 48.08; p = 0.0019, F = 9.71; p = 0.0001, F = 32.97; respectively). Seedling density decreased as percent cover increased. However, with a low $r^2$ (0.14), other variables are more likely to influence seedling density.

There were 55 herbaceous and woody liano plant species identified in this study. Herbaceous and woody liano species composition following the 1993 flood was similar among forest communities (Table 9). However, there was variation in cover estimates by species (Table 7). This is the result of the heterogeneous flood disturbance and creation of canopy/subcanopy gaps. *Bidens aritosa* was the dominant species occurring in over 73% of the quadrats sampled and having an average cover of 36%. Percent cover of *B. aritosa* was considerably less on maple-ash forest communities, however this species still had a high frequency because of its ability to assume a dwarved physical stature in a low light environment. *Polygonum spp.*, unknown forbs, *Leersia oryzoides*, *Carex spp.*, unknown grasses, *Urtica dioica*, *Xanthium spp.*, *Bidens cernua*, *Ipomoea pandurata*, *Campsis radicans*, and *Vitis spp.* were co-dominants (Table 7). Much of the herbaceous vegetation was represented by rosettes and seedlings resulting in the creation and dominance of unknown forbs and unknown grasses categories.

## DISCUSSION

### Forest Response

The perception that floodplain forests are resilient to flood disturbance may be erroneous and highly dependent upon the degree of disturbance. Results of this study indicate that the 1993 flood was a large-scale disturbance event that inflicted high mortality in all tree species. However, the rate of mortality was species, forest community and size specific. We identified *Celtis occidentalis*, *Q. palustris*, *P. deltoides*, and *U. americana* to be large-scale flood intolerant, while *Q. lyrata*, *F. pennsylvanica*, *Q. macrocarpa*, and *A. saccharinum* were more tolerant. These results are consistent with the findings of other studies of permanent inundation and large-scale flooding on the UMRS (Turner, 1930; Green, 1947; Yeager, 1949; Yin et al., 1994). Variations in species response to flooding are related to a species ability to avoid or tolerate a flood event (Kozlowski, 1984, 1997). With high mortality in species thought to be flood tolerant, the 1993 flood may be labeled as a rare disturbance event that compromised most means of flood avoidance and tolerance in tree species.

The relationship of tree mortality and forest community was one of ‘successional stage’ (disturbance gradient) and floodplain elevation. Mixed forests are an advanced stage in the successional pattern of floodplain forests of the UMRS (Hosner and Minckler, 1960; Galatowitsch and McAdams, 1994). Shade tolerant species abound in this forest community but appear to be moderately- to non-tolerant to a flood disturbance of this magnitude. Oak forests are also composed of species non-tolerant to large-scale flooding. However, the slightly higher elevation that these forests occupied may have lessened the effects of the 1993 flood. Maple-ash forests are composed of species that are considered flood tolerant. Nevertheless, the magnitude of the flood inflicted high mortality in even these species and eliminated the shade tolerant species that were present.

We found that tree mortality generally increased as diameter decreased. This supports the findings of previous studies (Harms *et al.*, 1980; Yin *et al.*, 1994). Harms *et al.* (1980) indicated that the relationship of higher survival of flooding with increased diameter as being related to tree vigor and root surface available to produce adventitious roots. Nonetheless, mortality was high in some species regardless of size (*Celtis occidentalis* and large *P. deltoides*) due to lack or compromise of physiological adaptations that promote flood survivorship.

The dominance of *U. americana* and *Celtis occidentalis* in the sapling cohort of maple-ash and oak forest communities, prior to the 1993 flood, indicate that these two forest communities on Reach 26 of the UMRS were experiencing a shift in species composition towards mixed forest communities. The dominance of *U. americana* and *Celtis occidentalis* in the sapling and tree cohorts of the mixed forests indicate that under the past hydric regime, a mixed forest community will persist for a considerable length of time until a disturbance event occurs. Large-scale flooding maybe that driving force increasing species diversity and landscape heterogeneity on the floodplain.

### Seedling Response

Following a disturbance event, a suppressed seedling and seed bank often respond to canopy gap creation by germinating and or growing vigorously (Marshall,1927; Hosner and Minckler, 1960; Norton, 1983; Kohyama, 1984; Streng et al., 1989; Peterson and Pickett, 1995). This study determined that the pre-flood seedling bank was eliminated and that no seedlings greater than two years of age were found in 1995. This is consistent with the concept that seedlings are susceptible to high mortality if flooding occurs during the growing season over a prolonged period of time (McDermott, 1954; Hosner, 1958, 1959, 1960; Broadfoot and Williston, 1973; Peterson and Bazzaz, 1984; Jones et al., 1989). Nonetheless, there was astonishing seed germination and seedling development immediately following the flood disturbance (average density of 239,000 seedlings/ha and mean age of 1.8). Seedling densities identified by this study are 8 to 10 times greater than those reported for similar bottomland forests located near the confluence of the Mississippi and Ohio rivers in southern Illinois and central Ohio (Hosner and Minckler, 1960; Robertson et al., 1978; Boerner and Brinkman, 1996). The magnitude of the disturbance event and recentness of sampling following the 1993 flood would explain the vast differences between this study and that of Hosner and Minckler (1960), Robertson et al. (1978), and Boerner and Brinkman (1996). The increase in seedling densities following disturbance indicates the important role that these events play in forest reorganization, community succession and species composition.

Current knowledge of UMRS floodplain forest reorganization, would have predicted that *P. deltoides* and *Salix nigra* (pioneer species) would dominate the seedling cohort of all forests communities following the 1993 flood disturbance (Hupp, 1992; Galatowitsch and McAdams, 1994; Hodges, 1994; Yin et al., 1997; Rood et al., 1998). This widely accepted theory inclined Galatowitsch and McAdams (1994) to write, "After extreme flood episodes, as occurred in 1993, cottonwood-willow communities will increase in extent because they will form pioneer communities in the annual floodplain and on higher terrain as well". However, these species played a minor role in the composition of the post-flood seedling bank of the most flood-impacted Reach of the UMRS. A factor influencing *P. deltoides* and *S. nigra* recruitment is an optimum seed-bed. Low litter depth, low herbaceous and overstory cover and dry soil conditions for part of the year are necessary for *P. deltoides* and *S. nigra* regeneration (Hosner and Minckler, 1960). High herbaceous cover following the 1993 flood event and an anthropogenically created and maintained high water table may have inhibited these two early pioneers species from regenerating.

*Acer saccharinum*, *F. pennsylvanica*, and *U. americana* (mid to late successional species) dominated the seedling bank of Reach 26 following the 1993 flood. The dominance of these three species is in agreement with other studies of floodplain forests of this region (Hosner and Minckler, 1960; Lindsey et al., 1961; Boerner and Brinkman; 1996). *Acer saccharinum*, *F. pennsylvanica*, and *U. americana* produce many seeds that are widely dispersed (wind and water) and capable of germinating in herbaceous cover and under anaerobic soil conditions (Hosner and Minckler, 1960; Young and Young, 1992). In addition to long dispersal distances, these species had high densities of surviving parent trees to facilitate regeneration. Early germination and establishment by these species will ensure a competitive advantage over seeds germinating later and may present little change in composition in the near future (Hibbs, 1983; Brokaw, 1985; Connel, 1989; Streng et al., 1989; Jones et al., 1994, 1997).

*Celtis occidentalis* and *Q. palustris* were poorly represented in the post-flood seedling bank, which we attribute to the relatively low number of seeds produced, short dispersal distances and low number of surviving adult trees. *Celtis occidentalis* is a slow growing, shade tolerant species and *Q. palustris* is a species that relies upon treefall or low intensity fire disturbance to release short-lived seedlings (Shelford, 1954; Minckler, 1957; Aust et al., 1985; Galatowitsch and McAdams, 1994). Both species rely upon gravity and frugivores for dispersal resulting in short dispersal distances and a large number of seedlings germinating under conspecific adults (Hoppes, 1988; Schupp, 1993; Steele et al., 1993; Steele and Smallwood, 1994). The requirement of a closed canopy to establish in, short dispersal distances, very slow growth, and high tree and sapling mortality, indicates that it may be several hundred years before *Celtis occidentalis* will re-establish at densities and sizes equal to that of pre-flood. *Quercus palustris* relies primarily upon gravity, small mammals (squirrels) and birds (blue jay) as dispersal agents. The larger seeds would indicate shorter dispersal distances than even *Celtis occidentalis*. However, lower tree mortality than *Celtis occidentalis* and establishment in gaps would indicate that the time frame for re-organization of *Q. palustris* would be substantially less.

Seedlings were more numerous in maple-ash than mixed or oak forest communities and in gaps than under canopy cover. The higher seedling densities identified in maple-ash forest communities is related to seed dispersal and location of conspecific adults. Although *A. saccharinum*, *F. pennsylvanica*, and *U. americana* produce light seeds that have high dispersal distances, a majority of the seedfall still occurs near the conspecific adults. An increase in seedling density with the formation of gaps is in agreement with other findings (Maguire and Forman, 1983; Boerner and Brinkman, 1996; Dunn, 1986; Molofsky and Augspurger, 1992). However, we found that it was a weak relationship. *Acer saccharinum*, *U. americana* and *F. pennsylvanica* had high germination and seedling densities in large gaps and in dense canopy cover. We observed that gaps were commonly over grown with herbaceous vegetation and vines attaining heights of approximately 2 meters. Sites with dense tree canopy also had high herbaceous and vine cover, although nowhere near that of the gaps. The light regime that these seedlings were exposed to in the summer of 1995 probably did not vary significantly from a densely forested site to a large gap due to the dense herbaceous cover. However, there may be an improved light environment in the long run for those seedlings in the gaps if they are able to capitalize on improved light conditions in the early spring or late fall when the herbaceous vegetation is less prevalent and if these seedlings can tolerate very low light levels and high root competition throughout the rest of the year. Also, reduced predation and fungal attack is likely to occur in gaps further increasing the chances of survival (Augspurger, 1984; Terborgh et al., 1993; Schupp, 1995; Wada et al., 2000; Wenny, 2000).

### Herbaceous and Liano Vegetation Response

The creation of gaps in the forest canopy initiates a response from suppressed seedlings and herbaceous vegetation. Without continued disturbance, tree species eventually replace the herbaceous vegetation. However, the time frame involved is dependent upon the tree species ability to quickly grow above the herbaceous vegetation or survive extreme shading. Consequently, the herbaceous understory dictates what tree species are likely to regenerate into the immediate forest (Siccama et al., 1970; Maguire and Forman, 1983; Gilliam et al., 1995). Compared with other studies of the UMRS, species composition did change as a result of the 1993 flood event (Hus, 1908; Hosner and Minckler, 1960; Linsey et al., 1961; Eyre, 1980; Galatowitsch and McAdams, 1994). Annual plant species became more prevalent than grasses, grass-like plants and perennials. Annual life-forms are very well adapted to pulsed flood events (Hall et al., 1946; Lindsey et al., 1961; Menges and Waller, 1983; Galatowitsch and McAdams, 1994) by tolerating these extreme anaerobic conditions as a seed. In addition, the annual flood events disperse the seeds, deposit them with nutrient rich sediment and bury or inhibit competitors. The annual plant (such as *B. aritosa*) can then complete its life-cycle in a very short period of time before the next flood event occurs.

Creation of canopy gaps should allow for an increase in understory cover due to increased PAR and decreased competition for water and nutrients (Hosner and Minckler, 1960; Moore and Vankat, 1986; Perison et al., 1997). Consequently, many of the dominant understory species identified by this study have been classified as high-light specialists or light generalists (Menges and Waller, 1983; Galatowitsch and McAdams, 1994). However, our results were inconclusive in describing the relationship between overstory and understory cover. We believe that this is related to high herbaceous cover of shade tolerants (*Urtica dioica*) in low-impacted areas. We found that herbaceous cover was high in gaps and in the understory. This may be attributed to slightly increased levels of PAR with subcanopy gap formation and a rich sediment deposition.

The UMRS floodplain forest is characterized by a high abundance and diversity of woody vines (Hus, 1908; Shelford, 1954; Lindsey et al., 1961; Galatowitsch and McAdams, 1994). Following disturbance and gap creation in the forest canopy, vines commonly increase in biomass and abundance and may delay forest reorganization for an extended period of time (Shelford, 1954; Allen et al., 2005). Vines grow rapidly, survive moderate canopy, and through structural adaptations (tendrils) can grow up and on top of the herbaceous and seedling strata effectively shading competitors. However, for many species effective trellises must be available to facilitate this. Large-scale disturbances remove support structures (trellis) making it difficult for large woody vines to become established (Putz, 1984; Allen et al., 1997; Allen et al., 2005). Loss of hosts in large gaps may promote smaller statured vine species until larger trees can regenerate and act as effective trellis. We observed that woody vine abundance, biomass and diversity may have been reduced by the 1993 flood. *Vitis spp.*, *Campsis radicans*, and *Toxicodendron radicans* were the only woody vines that were abundant and were restricted to the understory.

**Implications**

Floodplain forests provide valuable habitat for many species of wildlife (both residential and migratory) (Wiener et al., 1998; Knutson et al., 1999; Smith and Twedt, 1999), provide organic input into the aquatic system (Polit and Brown, 1996), and reduce bank erosion (Wiener et al., 1998). Over the past 200 years, floodplain forests have undergone significant anthropogenic modifications resulting in altered floodplain hydrology, altered river geomorphology, separation from the flood regime, and extensive forest clearing (Peck and Smart, 1986; Sparks, 1995; Wlosinski et al., 1995; Yin and Nelson, 1995; Yin et al. 1997; Sparks et al., 1998; Giedeman, 1999). These modifications have resulted in a change in the species composition of the floodplain forests with an increase in the dominance of *Acer spp.* and *Fraxinus spp.* and a decline in *Celtis occidentalis*, *Ulmus americana*, *Carya illinoensis*, *Quercus palustris*, *Populus deltoides*, and *Salix spp.* (Hus, 1908; Yeager, 1949; Everitt, 1968; Nelson *et al.*, 1994; Yin and Nelson, 1995; Knutson and Klaas, 1998; Nelson and Sparks, 1998; Giedeman, 1999).

The 1993 flood event has further accentuated a shift towards a maple-ash dominated forest community. Interestingly, the trend of *Acer spp.* and *Fraxinus spp.* replacing *Quercus spp.* and *Carya spp.* has been reported for floodplain and upland forests worldwide and is generally related to river regulation (changes in the flooding regime) and lack of disturbance (Bragg and Tatschl, 1977; Lorimer, 1993; Chester et al., 1995; Neumeister et al., 1997; Abrams, 1998; Foster et al., 1998; Abrams et al., 1999; Huddle and Pallardy, 1999; Tinner, *et al.*, 1999; Dey and Guyette, 2000; McCarthy and Evans, 2000).

The further decline in hard-mast and soft-mast tree species will likely result in a decrease in wildlife diversity, individual species density, and quality of habitat. Further research is necessary to understand the complex dynamics of seed production and dispersal and seedling germination and survivorship in floodplain forests of the UMRS. A more complete understanding of these processes will provide natural resource managers with the necessary information to improve and protect floodplain forests in the future.

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Figure 1. Mean annual post-dam (1940-1993) hydrograph and 1993 flood hydrograph at the confluence of the Upper Mississippi and Illinois Rivers (Mississippi River Mile 218, Grafton, IL).

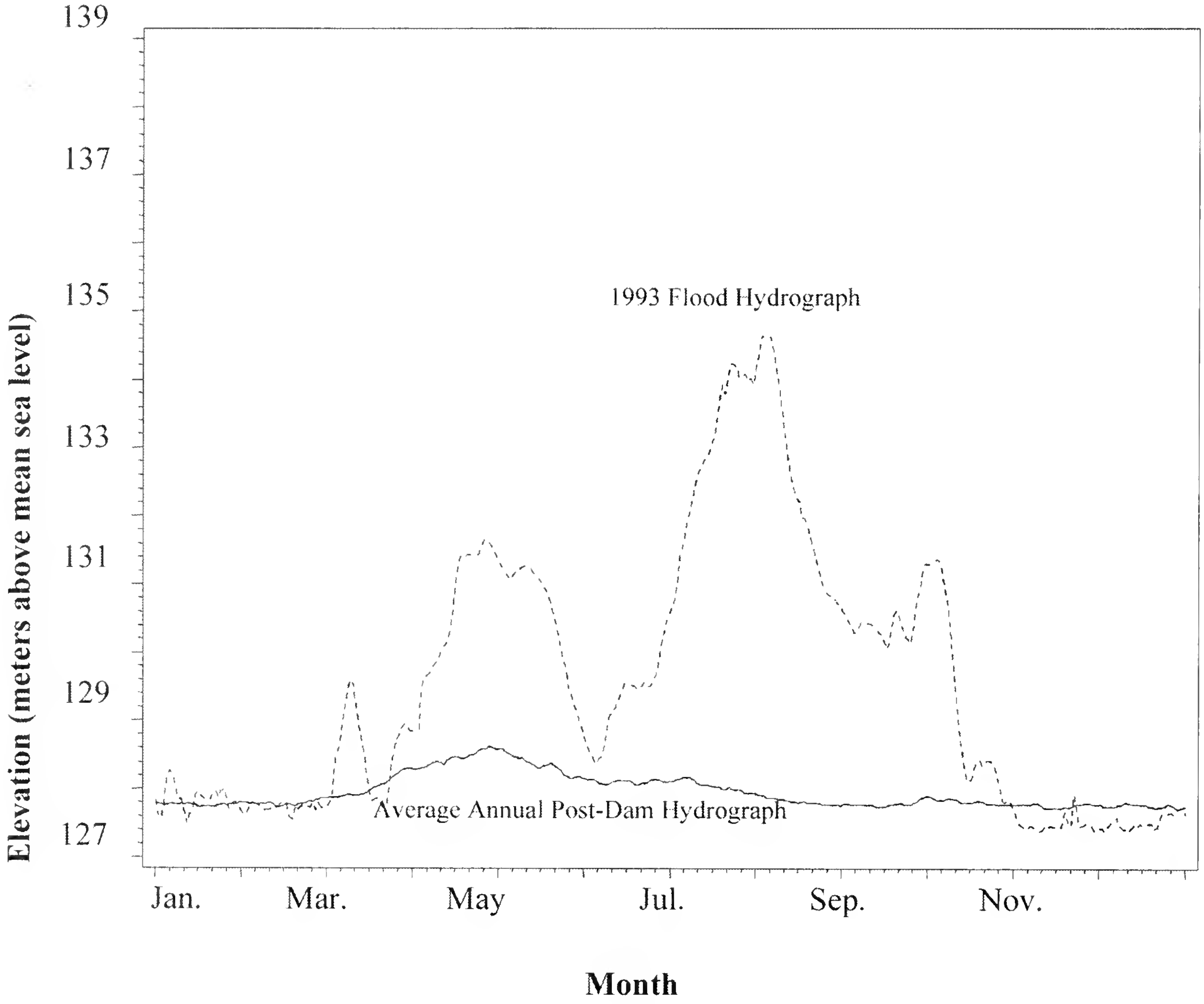

Figure 2.
Reach 26 study area showing the confluence of the Mississippi, Illinois, and Missouri Rivers.

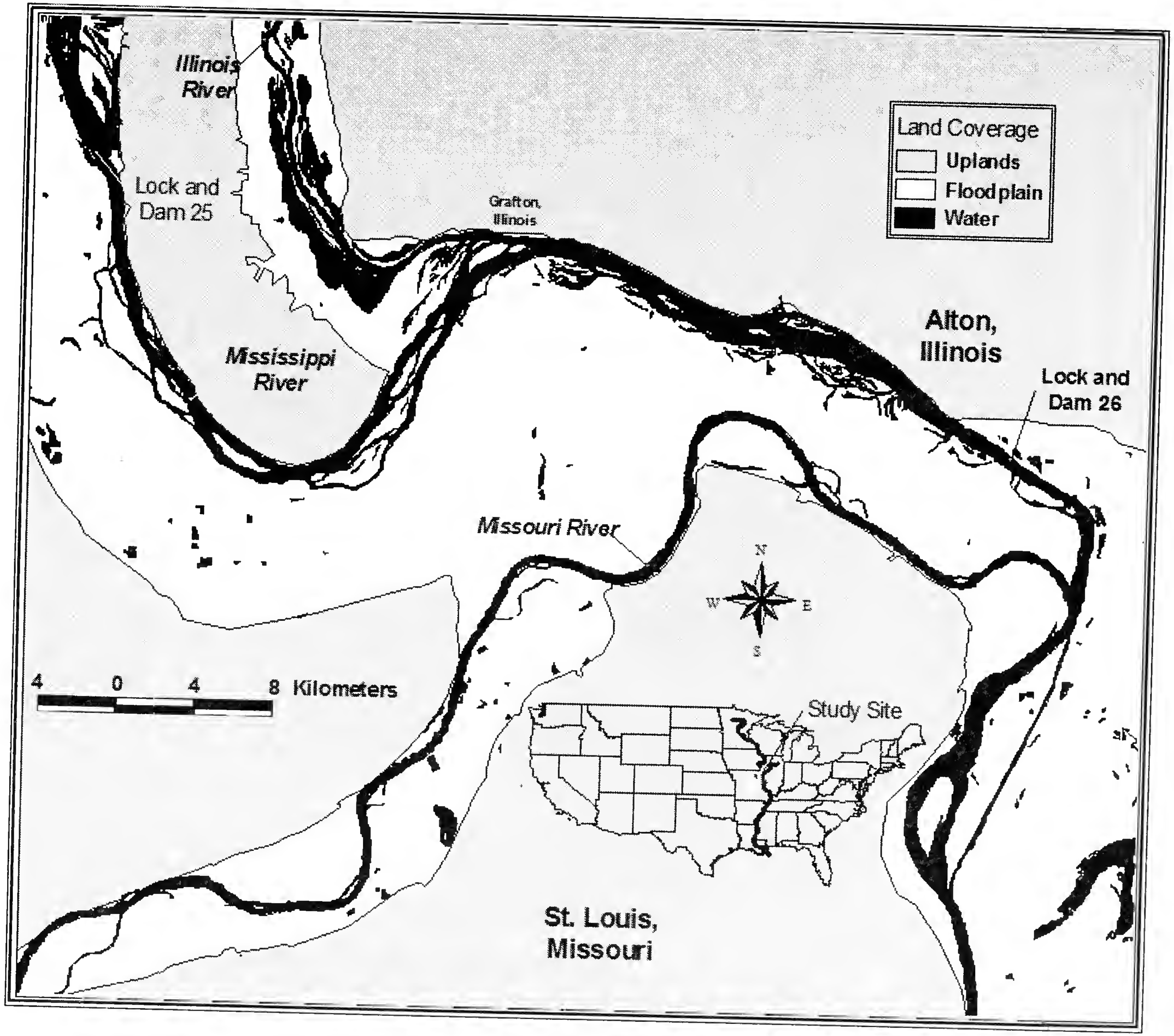

Figure 3. Percent mortality by diameter at breast height (dbh).

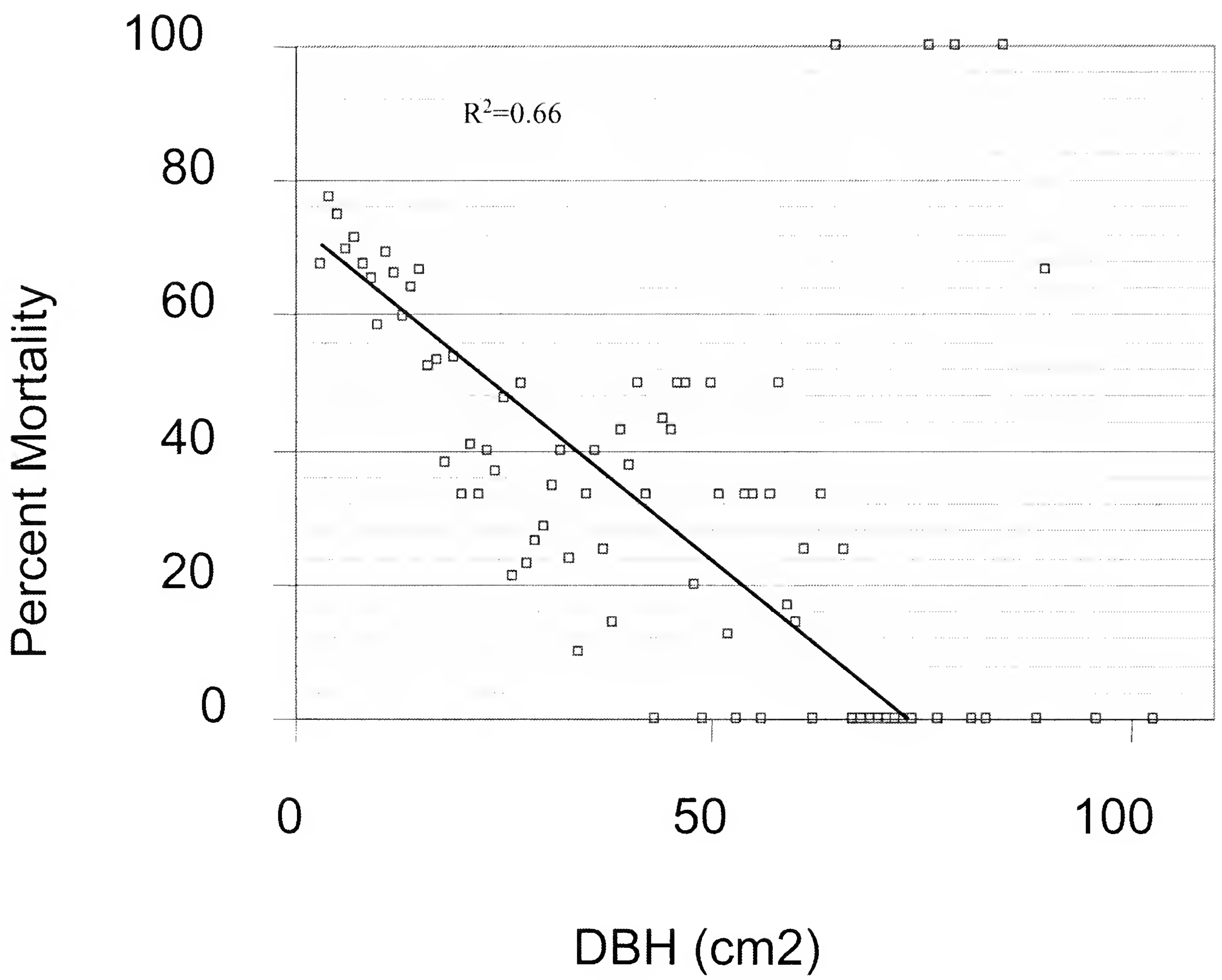

Table 1. Response of trees and saplings to the 1993 flood.

| | Pool 26 Pre-1993 Flood | | Pool 26 Post-1993 Flood | | | |
|---|---|---|---|---|---|---|
| Species (n) | Density/ Hectare | Importance Value | Mortality (%) | Density/ Hectare | Importance Value | **Change in Importance Value** |
| **Tree** | | | | | | |
| *Acer negundo (50)* | 27.9 | 10.4 | 42.0 | 16.2 | 10.9 | **0.5** |
| *Acer saccharinum (283)* | 158.1 | 58.3 | 42.4 | 91.1 | 63.8 | **5.5** |
| *Celtis occidentalis (84)* | 46.9 | 11.6 | 90.5 | 4.5 | 2.2 | **-9.4** |
| *Fraxinus pennsylvanica (123)* | 68.7 | 25.3 | 22.8 | 53.1 | 33.0 | **7.7** |
| *Populus deltoides (23)* | 12.9 | 10.0 | 56.5 | 5.6 | 8.0 | **-2.0** |
| *Quercus lyrata (62)* | 34.6 | 10.7 | 19.3 | 28.0 | 15.5 | **4.8** |
| *Quercus macrocarpa (13)* | 7.3 | 4.3 | 30.8 | 5.0 | 5.9 | **1.6** |
| *Quercus palustris (145)* | 81.0 | 34.8 | 57.3 | 34.6 | 26.9 | **-7.9** |
| *Ulmus americana (122)* | 68.2 | 16.7 | 49.2 | 34.6 | 14.7 | **-2.0** |
| Other (95) | 53.1 | 18.0 | 41.1 | 31.3 | 18.9 | **0.9** |
| **Total (1000)** | **558.7** | **200.0** | **45.6** | **303.9** | **200.0** | ------- |
| **Sapling** | | | | | | |
| *Acer negundo (40)* | 22.4 | 8.9 | 100.0 | 0.0 | 0.0 | **-8.9** |
| *Acer saccharinum (162)* | 90.5 | 36.6 | 96.3 | 3.4 | 6.3 | **-30.4** |
| *Celtis occidentalis (199)* | 111.2 | 42.2 | 74.9 | 27.9 | 31.1 | **-11.1** |
| *Cornus spp. (13)* | 7.3 | 1.7 | 0.0 | 7.3 | 7.0 | **5.2** |
| *Crataegus spp. (26)* | 14.5 | 6.6 | 50.0 | 7.3 | 11.0 | **4.4** |
| *Diospyros virginiana (33)* | 18.4 | 7.4 | 36.4 | 11.7 | 14.0 | **6.6** |
| *Forestiera acuminata (202)* | 112.9 | 35.7 | 56.9 | 48.6 | 51.2 | **15.5** |
| *Fraxinus pennsylvanica (31)* | 17.3 | 7.2 | 48.4 | 8.9 | 12.1 | **4.9** |
| *Ulmus americana (148)* | 82.7 | 36.6 | 66.2 | 28.0 | 41.1 | **4.5** |
| Other (61) | 34.1 | 17.7 | 91.7 | 3.4 | 26.3 | **8.6** |
| **Total (915)** | **511.3** | **200.7** | **72.1** | **146.4** | **200.0** | ------- |

Table 2. Tree response by forest community response to the 1993 flood.

| Tree Species (n) | Pool 26 Pre-1993 Flood | | | Pool 26 Post-1993 Flood | | |
|---|---|---|---|---|---|---|
| | Density/ Hectare | Importance Value | Mortality (%) | Density/ Hectare | Importance Value | **Change in Importance Value** |
| **Maple-Ash** | | | | | | |
| *Acer negundo (22)* | 25.0 | 10.0 | 31.8 | 17.1 | 11.2 | **1.2** |
| *Acer saccharinum (249)* | 283.2 | 103.8 | 41.8 | 164.8 | 103.1 | **-0.7** |
| *Celtis occidentalis (25)* | 28.4 | 6.6 | 100.0 | 0.0 | 0.0 | **-6.6** |
| *Fraxinus pennsylvanica (83)* | 94.4 | 37.1 | 20.5 | 75.1 | 44.0 | **6.8** |
| *Populus deltoides (8)* | 9.1 | 7.5 | 37.5 | 5.7 | 8.2 | **0.7** |
| *Quercus lyrata (5)* | 5.7 | 1.7 | 20.0 | 4.6 | 2.3 | **0.5** |
| *Quercus macrocarpa (0)* | ------- | ------- | ------- | ------- | ------- | **-------** |
| *Quercus palustris (10)* | 81.0 | 3.7 | 80.0 | 2.3 | 1.8 | **-1.9** |
| *Ulmus americana (46)* | 68.2 | 12.7 | 41.3 | 30.7 | 12.2 | **-0.5** |
| *Other (39) | 53.1 | 16.8 | 38.4 | 27.3 | 17.3 | **0.4** |
| **Total (487)** | **558.7** | **200.0** | **41.1** | **327.5** | **200.0** | **------** |
| **Mixed** | | | | | | |
| *Acer negundo (23)* | 56.3 | 20.9 | 47.8 | 29.4 | 25.5 | **4.7** |
| *Acer saccharinum (22)* | 53.9 | 19.9 | 63.6 | 19.6 | 25.3 | **5.4** |
| *Celtis occidentalis (36)* | 88.2 | 24.5 | 94.4 | 4.9 | 4.8 | **-19.7** |
| *Fraxinus pennsylvanica (22)* | 53.9 | 19.3 | 36.4 | 34.3 | 31.5 | **12.3** |
| *Populus deltoides (15)* | 36.8 | 27.4 | 66.7 | 12.2 | 19.9 | **-7.4** |
| *Quercus lyrata (0)* | ------- | ------- | ------- | ------- | ------- | **-------** |
| *Quercus macrocarpa (2)* | 4.9 | 2.3 | 0.0 | 4.9 | 5.0 | **2.7** |
| *Quercus palustris (11)* | 27.0 | 24.8 | 72.7 | 7.4 | 20.6 | **-4.2** |
| *Ulmus americana (50)* | 122.5 | 32.3 | 60.0 | 49.0 | 29.3 | **-3.1** |
| *Other (37) | 90.7 | 28.8 | 43.3 | 51.4 | 38.0 | **9.2** |
| **Total (218)** | **534.1** | **200.0** | **60.1** | **213.2** | **199.9** | **------** |
| **Oak** | | | | | | |
| *Acer negundo (5)* | 10.0 | 2.4 | 60.0 | 4.0 | 1.6 | -0.8 |
| *Acer saccharinum (12)* | 23.9 | 5.9 | 16.7 | 19.9 | 7.4 | 1.5 |
| *Celtis occidentalis (23)* | 45.8 | 10.0 | 73.9 | 12.0 | 4.7 | -5.4 |
| *Fraxinus pennsylvanica (18)* | 35.8 | 8.2 | 16.7 | 29.9 | 11.7 | 3.4 |
| *Populus deltoides (0)* | ------- | ------- | ------- | ------- | ------- | ------- |
| *Quercus lyrata (57)* | 113.5 | 35.7 | 19.3 | 91.6 | 50.3 | 14.6 |
| *Quercus macrocarpa (11)* | 21.9 | 14.3 | 36.4 | 13.9 | 19.4 | 5.2 |
| *Quercus palustris (124)* | 246.8 | 100.7 | 54.0 | 113.5 | 81.8 | -18.9 |
| *Ulmus americana (26)* | 51.8 | 11.4 | 42.3 | 29.9 | 11.5 | 0.1 |
| *Other (19) | 37.8 | 11.5 | 36.8 | 23.9 | 11.8 | 1.3 |
| **Total (295)** | **587.2** | **200.1** | **42.4** | **338.4** | **200.0** | **------** |

*Other includes: *Carya illinoensis*, *Carya spp.*, *Cercis canadensis*, *Crataegus spp.*, *Diospyros virginiana*, *Forestiera acuminata*, *Gleditsia aquatica*, *Gleditsia triacanthos*, *Morus spp.*, and *Salix nigra*.

Table 3. Sampling response by forest community to the 1993 flood event.

| | Pool 26 Pre-1993 Flood | | Pool 26 Post-1993 Flood | | | |
|---|---|---|---|---|---|---|
| SaplingSpecies (n) | Density/ Hectare | Importance Value | Mortality (%) | Density/ Hectare | Importance Value | **Change in Importance Value** |
| **Maple-Ash** | | | | | | |
| *Acer negundo (8)* | 9.1 | 4.2 | 100.0 | 0.0 | 0.0 | **-4.2** |
| *Acer saccharinum (132)* | 150.1 | 77.5 | 97.7 | 3.5 | 8.8 | **-68.8** |
| *Celtis occidentalis (44)* | 50.1 | 23.3 | 95.5 | 2.3 | 7.2 | **-16.0** |
| *Cornus spp. (0)* | ------- | ------- | ------- | ------- | ------- | **-------** |
| *Crataegus spp. (12)* | 13.7 | 8.3 | 58.3 | 5.7 | 20.3 | **12.0** |
| *Diospyros virginiana (9)* | 10.2 | 5.5 | 55.6 | 4.6 | 14.5 | **9.0** |
| *Forestiera acuminata (68)* | 77.3 | 32.1 | 52.9 | 36.4 | 72.5 | **40.4** |
| *Fraxinus pennsylvanica (8)* | 5.7 | 4.3 | 40.0 | 3.4 | 13.0 | **8.7** |
| *Ulmus americana (60)* | 68.2 | 35.8 | 66.7 | 22.7 | 63.7 | **27.9** |
| *Other (12) | 13.7 | 8.3 | 99.9 | 0.0 | 0.0 | **-8.3** |
| **Total (350)** | **398.1** | **199.3** | **80.3** | **78.5** | **200.0** | ------- |
| **Mixed** | | | | | | |
| *Acer negundo (27)* | 66.1 | 23.7 | 100.0 | 0.0 | 0.0 | **-23.7** |
| *Acer saccharinum (12)* | 29.4 | 10.1 | 100.0 | 0.0 | 0.0 | **-10.1** |
| *Celtis occidentalis (52)* | 127.4 | 43.0 | 100.0 | 0.0 | 0.0 | **-43.0** |
| *Cornus spp. (0)* | ------- | ------- | ------- | ------- | ------- | **-------** |
| *Crataegus spp. (4)* | 9.8 | 4.2 | 50.0 | 4.9 | 10.0 | **5.9** |
| *Diospyros virginiana (2)* | 4.9 | 3.6 | 50.0 | 2.5 | 7.8 | **4.1** |
| *Forestiera acuminata (62)* | 151.9 | 46.1 | 5.1 | 63.6 | 99.4 | **53.4** |
| *Fraxinus pennsylvanica (8)* | 19.6 | 7.3 | 75.0 | 4.9 | 10.0 | **2.7** |
| *Ulmus americana (44)* | 107.8 | 48.1 | 72.7 | 29.4 | 60.0 | **12.0** |
| *Other (15) | 36.8 | 14.3 | 92.9 | 4.9 | 12.8 | **-1.5** |
| **Total (226)** | **553.7** | **200.3** | **80.1** | **110.2** | **200.0** | ------- |
| **Oak** | | | | | | |
| *Acer negundo (5)* | 10.0 | 2.6 | 100.0 | 0.0 | 0.0 | **-2.6** |
| *Acer saccharinum (182)* | 35.8 | 9.9 | 83.3 | 6.0 | 7.2 | **-2.7** |
| *Celtis occidentalis (103)* | 205.0 | 58.8 | 53.4 | 95.5 | 57.9 | **-0.9** |
| *Cornus spp. (13)* | 25.9 | 6.1 | 0.0 | 25.9 | 13.9 | **7.7** |
| *Crataegus spp. (10)* | 19.9 | 6.4 | 40.0 | 11.9 | 9.2 | **2.8** |
| *Diospyros virginiana (22)* | 43.8 | 12.2 | 27.3 | 31.8 | 18.4 | **6.3** |
| *Forestiera acuminata (72)* | 143.3 | 33.7 | 59.7 | 57.8 | 34.9 | **1.1** |
| *Fraxinus pennsylvanica (18)* | 35.8 | 13.3 | 38.9 | 21.9 | 17.6 | **4.4** |
| *Ulmus americana (44)* | 87.6 | 31.2 | 59.1 | 35.8 | 30.0 | **-1.1** |
| *Other (34) | 67.7 | 25.9 | 85.3 | 10.0 | 11.0 | **-14.9** |
| **Total (339)** | **674.8** | **200.0** | **56.3** | **296.6** | **200.0** | ------- |

*Other includes: *Carya spp.*, *Cephalanthus occidentalis*, *Cercis canadensis*, *Gleditsia triacanthos*, *Maclura pomifera*, *Morus spp.*, *Quercus lyrata*, *Quercus macrocarpa*, and *Quercus palustris*.

Table 4. Cover response to the 1993 flood event.

| Stratified Cover (n) | Mean % cover | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|
| **Maple-Ash** | | | | |
| Canopy (279) | 54.4 | 33.1 | 5.0 | 100.0 |
| Subcanopy (279) | 18.1 | 24.9 | 5.0 | 95.0 |
| Overstory (279) | 60.5 | 32.3 | 5.0 | 100.0 |
| Understory (279) | 65.5 | 31.0 | 0.0 | 100.0 |
| Total (279) | 87.9 | 14.8 | 25.0 | 100.0 |
| **Mixed** | | | | |
| Canopy (130) | 28.7 | 27.8 | 5.0 | 95.0 |
| Subcanopy (130) | 21.9 | 26.3 | 5.0 | 95.0 |
| Overstory (130) | 40.7 | 31.0 | 5.0 | 95.0 |
| Understory (130) | 74.0 | 31.3 | 0.0 | 100.0 |
| Total (130) | 88.2 | 19.8 | 25.0 | 100.0 |
| **Oak** | | | | |
| Canopy (160) | 39.4 | 32.3 | 0.0 | 95.0 |
| Subcanopy (160) | 25.0 | 30.5 | 0.0 | 95.0 |
| Overstory (160) | 51.7 | 36.1 | 0.0 | 100.0 |

Table 5. Stratified cover differences by forest community. Forest types with Similar codes do not differ statistically ($p>0.05$) using Tukey's HSD (Honestly Significant Difference).

| Forest Community | Canopy | Subcanopy | Overstory | Understory | Total |
|---|---|---|---|---|---|
| Maple-Ash | A | A | A | A | A |
| Mixed | B | AB | B | B | A |
| Oak | C | B | C | A | A |

Table 6. Tree seedling response to the 1993 flood event.

| *Species (n)* | Frequency | Relative Frequency | Density/ Hectare | Relative Density | Importance Value | Mean Percent Cover | Mean Age |
|---|---|---|---|---|---|---|---|
| **Maple-Ash** | | | | | | | |
| *Acer negundo (155)* | 14.7 | 7.2 | 22219.4 | 6.1 | 13.3 | 2.5 | 1.9 |
| *Acer saccharinum (1804)* | 113.6 | 55.9 | 258599.3 | 70.7 | 126.6 | 2.8 | 1.7 |
| *Celtis occidentalis (13)* | 3.9 | 1.9 | 1860.9 | 0.5 | 2.5 | 8.7 | 1.9 |
| *Cephalanthus occidentalis (10)* | 3.6 | 1.8 | 1433.7 | 0.4 | 2.2 | 8.5 | 2.0 |
| *Diospyros virginiana (4)* | 1.1 | 0.5 | 572.0 | 0.2 | 0.7 | 0.8 | 1.0 |
| *Fraxinus pennsylvanica (171)* | 25.8 | 12.7 | 24567.7 | 6.7 | 19.4 | 5.0 | 1.9 |
| *Quercus palustris (7)* | 1.4 | 0.7 | 1003.6 | 0.3 | 1.0 | 3.0 | 2.0 |
| *Ulmus americana (299)* | 27.6 | 13.6 | 42833.0 | 11.7 | 25.3 | 1.8 | 1.9 |
| *Other (88)* | 11.5 | 5.6 | 12610.8 | 3.5 | 9.1 | 3.3 | 2.0 |
| **Total (2551)** | **203.2** | **100.0** | **365700.4** | **100.0** | **200.0** | **2.9** | **1.8** |
| **Mixed** | | | | | | | |
| *Acer negundo (10)* | 3.1 | 2.3 | 3076.9 | 2.1 | 4.5 | 1.3 | 1.3 |
| *Acer saccharinum (143)* | 70.0 | 53.2 | 74760.0 | 51.9 | 105.1 | 8.6 | 1.9 |
| *Celtis occidentalis (4)* | 3.1 | 2.3 | 1230.8 | 0.9 | 3.2 | 3.0 | 1.8 |
| *Cephalanthus occidentalis (9)* | 3.8 | 2.9 | 2769.2 | 1.9 | 4.9 | 12.2 | 1.8 |
| *Diospyros virginiana (2)* | 1.5 | 1.2 | 615.4 | 0.4 | 1.6 | 1.0 | 1.5 |
| *Fraxinus pennsylvanica (119)* | 16.9 | 12.9 | 36621.5 | 25.4 | 38.3 | 1.9 | 1.7 |
| *Quercus palustris (8)* | 2.3 | 1.8 | 2464.6 | 1.7 | 3.5 | 1.5 | 1.7 |
| *Ulmus americana (68)* | 27.7 | 21.1 | 20935.4 | 14.5 | 35.6 | 1.7 | 1.8 |
| *Other (5)* | 3.1 | 3.0 | 1538.5 | 1.1 | 4.1 | 0.8 | 1.5 |
| **Total (368)** | **131.5** | **100.7** | **144012.3** | **100.0** | **200.7** | **4.7** | **1.8** |
| **Oak** | | | | | | | |
| *Acer negundo (1)* | 0.6 | 0.6 | 250.0 | 0.3 | 0.8 | 1.0 | 1.0 |
| *Acer saccharinum (37)* | 18.1 | 16.9 | 9280.0 | 9.7 | 26.6 | 2.6 | 2.0 |
| *Celtis occidentalis (29)* | 9.4 | 8.7 | 7237.5 | 7.6 | 16.3 | 1.2 | 1.6 |
| *Cephalanthus occidentalis (71)* | 13.8 | 12.8 | 17765.0 | 18.6 | 31.4 | 7.6 | 2.0 |
| *Diospyros virginiana (26)* | 5.6 | 5.2 | 6502.5 | 6.8 | 12.0 | 1.0 | 1.3 |
| *Fraxinus pennsylvanica (23)* | 11.3 | 10.5 | 5760.0 | 6.0 | 16.5 | 4.1 | 1.9 |
| *Quercus palustris (41)* | 12.5 | 11.6 | 10250.0 | 10.7 | 22.4 | 3.0 | 2.0 |
| *Ulmus americana (102)* | 19.4 | 18.0 | 25497.5 | 26.7 | 44.7 | 1.6 | 1.8 |
| *Other (52)* | 16.9 | 16.9 | 13002.5 | 13.6 | 30.5 | 1.8 | 2.1 |
| **Total (382)** | **107.5** | **101.2** | **95545.0** | **100.0** | **201.2** | **3.1** | **1.9** |

Table 7. Herbaceous and liano response to the 1993 flood event.

| Species | Cover | Std. Dev. | Minimum | Maximum | Relative Cover | n | Frequency | Relative Frequency | IV |
|---|---|---|---|---|---|---|---|---|---|
| **Maple-Ash** | | | | | | | | | |
| *Bidens aritosa (191)* | 23.1 | 25.8 | 1.0 | 100.0 | 12.2 | 191.0 | 68.5 | 25.8 | 38.0 |
| *Bidens cernua (14)* | 5.0 | 4.6 | 1.0 | 15.0 | 2.6 | 14.0 | 5.0 | 1.9 | 4.5 |
| *Campsis radicans (22)* | 21.9 | 21.5 | 1.0 | 70.0 | 11.6 | 22.0 | 7.9 | 3.0 | 14.5 |
| *Carex spp. (47)* | 8.2 | 15.0 | 1.0 | 80.0 | 4.3 | 47.0 | 16.8 | 6.4 | 10.7 |
| *Ipomoea pandurata (56)* | 14.8 | 16.9 | 1.0 | 80.0 | 7.8 | 56.0 | 20.1 | 7.6 | 15.4 |
| *Leersia oryzoides (32)* | 15.0 | 25.4 | 1.0 | 90.0 | 7.9 | 32.0 | 11.5 | 4.3 | 12.3 |
| *Polygonum spp. (25)* | 30.3 | 29.8 | 1.0 | 88.0 | 16.0 | 25.0 | 9.0 | 3.4 | 19.4 |
| *Toxicodendron radicans (26)* | 15.9 | 19.0 | 1.0 | 70.0 | 8.4 | 26.0 | 9.3 | 3.5 | 11.9 |
| *Unknown Forbs (104)* | 9.1 | 16.0 | 1.0 | 75.0 | 4.8 | 104.0 | 37.3 | 14.1 | 18.9 |
| *Unknown Grasses (56)* | 4.0 | 6.7 | 1.0 | 45.0 | 2.1 | 56.0 | 20.1 | 7.6 | 9.7 |
| *Urtica dioica (88)* | 5.6 | 12.5 | 1.0 | 65.0 | 2.9 | 88.0 | 31.5 | 11.9 | 14.8 |
| *Vitis spp. (47)* | 15.0 | 21.4 | 1.0 | 100.0 | 7.9 | 47.0 | 16.8 | 6.4 | 14.3 |
| *Xanthium spp. (22)* | 13.7 | 17.7 | 1.0 | 73.0 | 7.2 | 22.0 | 7.9 | 3.0 | 10.2 |
| Other (10) | 8.0 | *** | *** | *** | 4.2 | 9.8 | 3.5 | 1.3 | 5.6 |
| **Total** | **189.5** | *** | *** | *** | **100.0** | **739.8** | **265.1** | **100.0** | **200.0** |
| | | | | | | | | | |
| **Mixed** | | | | | | | | | |
| *Bidens aritosa (106)* | 50.1 | 37.8 | 1.0 | 100.0 | 22.1 | 106.0 | 81.5 | 33.1 | 55.1 |
| *Bidens cernua (11)* | 19.0 | 17.2 | 5.0 | 63.0 | 8.4 | 11.0 | 8.5 | 3.4 | 11.8 |
| *Campsis radicans (9)* | 17.9 | 13.8 | 1.0 | 45.0 | 7.9 | 9.0 | 6.9 | 2.8 | 10.7 |
| *Carex spp. (17)* | 10.2 | 19.4 | 1.0 | 70.0 | 4.5 | 17.0 | 13.1 | 5.3 | 9.8 |
| *Ipomoea pandurata (16)* | 11.1 | 13.9 | 1.0 | 45.0 | 4.9 | 16.0 | 12.3 | 5.0 | 9.9 |
| *Leersia oryzoides (8)* | 3.5 | 2.1 | 1.0 | 5.0 | 1.5 | 8.0 | 6.2 | 2.5 | 4.0 |
| *Polygonum spp. (16)* | 23.4 | 27.3 | 1.0 | 90.0 | 10.3 | 16.0 | 12.3 | 5.0 | 15.3 |
| *Toxicodendron radicans (9)* | 11.3 | 8.3 | 1.0 | 25.0 | 5.0 | 9.0 | 6.9 | 2.8 | 7.8 |
| *Unknown Forbs (47)* | 7.8 | 11.0 | 1.0 | 70.0 | 3.4 | 47.0 | 36.2 | 14.7 | 18.1 |
| *Unknown Grasses (24)* | 15.5 | 23.8 | 1.0 | 95.0 | 6.9 | 24.0 | 18.5 | 7.5 | 14.3 |
| *Urtica dioica (32)* | 6.2 | 11.5 | 1.0 | 63.0 | 2.7 | 32.0 | 24.6 | 10.0 | 12.7 |
| *Vitis spp. (14)* | 15.7 | 24.1 | 1.0 | 80.0 | 6.9 | 14.0 | 10.8 | 4.4 | 11.3 |
| *Xanthium spp. (7)* | 22.6 | 15.2 | 5.0 | 45.0 | 9.9 | 7.0 | 5.4 | 2.2 | 12.1 |
| Other (5) | 12.4 | *** | *** | *** | 5.5 | 4.6 | 3.6 | 1.4 | 6.9 |
| **Total** | **226.8** | *** | *** | *** | **100.0** | **320.6** | **246.6** | **100.0** | **200.0** |
| | | | | | | | | | |
| **Oak** | | | | | | | | | |
| *Bidens aritosa (118)* | 42.7 | 36.3 | 1.0 | 100.0 | 22.3 | 118.0 | 73.8 | 25.1 | 47.4 |
| *Bidens cernua (25)* | 5.6 | 4.8 | 1.0 | 21.0 | 2.9 | 25.0 | 15.6 | 5.3 | 8.3 |
| *Campsis radicans (9)* | 8.2 | 5.9 | 1.0 | 20.0 | 4.3 | 9.0 | 5.6 | 1.9 | 6.2 |
| *Carex spp. (38)* | 16.0 | 20.2 | 1.0 | 80.0 | 8.3 | 38.0 | 23.8 | 8.1 | 16.4 |
| *Ipomoea pandurata (23)* | 9.5 | 16.6 | 1.0 | 80.0 | 4.9 | 23.0 | 14.4 | 4.9 | 9.8 |
| *Leersia oryzoides (45)* | 15.7 | 20.0 | 1.0 | 90.0 | 8.2 | 45.0 | 28.1 | 9.6 | 17.7 |
| *Polygonum spp. (33)* | 31.8 | 35.3 | 1.0 | 100.0 | 16.6 | 33.0 | 20.6 | 7.0 | 23.6 |
| *Toxicodendron radicans (21)* | 16.5 | 24.4 | 1.0 | 90.0 | 8.6 | 21.0 | 13.1 | 4.5 | 13.1 |
| *Unknown Forbs (49)* | 3.9 | 4.9 | 1.0 | 23.0 | 2.0 | 49.0 | 30.6 | 10.4 | 12.5 |
| *Unknown Grasses (25)* | 8.8 | 13.0 | 1.0 | 40.0 | 4.6 | 25.0 | 15.6 | 5.3 | 9.9 |
| *Urtica dioica (35)* | 3.9 | 10.7 | 1.0 | 63.0 | 2.0 | 35.0 | 21.9 | 7.4 | 9.5 |
| *Vitis spp. (25)* | 3.2 | 3.5 | 1.0 | 15.0 | 1.7 | 25.0 | 15.6 | 5.3 | 7.0 |
| *Xanthium spp. (18)* | 21.8 | 29.0 | 1.0 | 98.0 | 11.4 | 18.0 | 11.3 | 3.8 | 15.2 |
| Other (6) | 4.2 | *** | *** | *** | 2.2 | 6.3 | 3.9 | 1.3 | 3.5 |
| **Total** | **191.8** | *** | *** | *** | **100.0** | **470.3** | **293.9** | **100.0** | **200.0** |

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# A Case Study in Reuse: An XML-Editing Component and Contract Editor

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## I. INTRODUCTION AND OVERVIEW

Many decades ago, Bill Joy developed the first full-screen editor for UNIX, **vi**. Users could edit files on ASCII terminals by moving the cursor up, down, backwards and forwards with the **h**, **j**, **k**, **l** keys (the home keys) and press other sequences to delete lines, words, sentences and insert text. On a slow connection on an ASCII terminal, a few lines might be displayed; if one enjoyed a relatively high speed connection, one would be able to edit using a full screen. Note that this was before "WIMP" interfaces, such as the Xerox Star, Macintosh, and Windows, were widely available.

This worked using the "escape codes" on the terminal. When a computer program sent a sequence of characters to the terminal, it might move the cursor, clear the screen, delete a line or ring the bell. Unfortunately, this was different for each brand of terminal. So Bill Joy "abstracted" the problem. A file named **termcap** contained the sequences needed for each operation. The users would set an environment variable to indicate which terminal they were using. **vi** would read the **termcap** file and issue the correct sequence of escape codes to implement the user's editing request. (Gaughan, 2003) This was called optimal cursor movement, as the logic in vi will determine the sequence of escape codes with the fewest, or close to the fewest, number of characters needed to change the display.

Ken Arnold created a library called **curses** by "simply lifting nearly intact" the routines to implement "optimal cursor movement" from Bill Joy's editor. (Arnold), (Arnold and Amir). This was used for many full-screen programs, most notably, an "adventure game" called Rogue (Wichman, 1997). Wichman indicated that his group, which originally implemented Rogue, simply used it after "it made the rounds to other Universities." Some web sites, however, including (die.net) (Foldoc, 1993), indicate that **curses** was developed specifically to support games.

In this article, we report an analogous sequence, over two decades later. Mr. Go Eguchi developed a Graphical User Interface (GUI) to create rule-base for transforming XML files (Eguchi and Leff, 2002) (Tong, et. al., 2005). Those works define two expert systems that would examine XML files. It would match this information against the XML appearing in the left-hand side of the rule. These expert systems would then generate the XML designated by the right-hand side of the rule, transferring information from the input. The standard (Leff, 2002) also defined additions to the XML so that when the expert system is run, information that was in the input file being matched is transferred

into the output XML. The goal of the editor was to allow the rule-writer or user to create the XML defining the transformations to occur.

That editor's user interface had two panes, a menu bar and three sets of buttons. The user, or rule writer, develops the XML rule-base in the right-hand pane. The rule-writer loads samples of the XML to be transformed in the left-hand pane. They use the left-hand set of arrow buttons to move within that XML. Then, using the right-hand set of arrow buttons, the rule-writer moves within the rule-base to indicate which rule to create or modify. In the middle set of buttons, there is a "Move From Sample" button. The user presses this to set up the example. Then, the user has to modify the XML moved to the left hand set of the rules to add the special markup. The rule writer moves within the rule-base (again with the right set of buttons) and inserts the special markup to indicate how to recognize the inputs that are considered similar. Lastly, the user loads a sample of the XML to be produced when the input is recognized, and similarly, they move some of the XML to the "right hand side" of the rule. The reader of this paper does not have to be concerned with the above detail; only to realize that Mr. Eguchi implemented code to allow transformation of XML for the specific purpose of implementing the above-described system, and he embedded that within his system without planning for any reusability.

The first author extracted this into a Java Swing "component" for general use. Swing is a package, provided by Sun, which programmers use to develop GUIs using the Java programming language. The items on one of these implemented GUIs which includes other panels, edit boxes, buttons, sliders, and menus are all components (Walrath and Campione, 1998) derived from the class **Component** (Java, 2004). The programmer sets up a "containment hierarchy" in their GUI; for example, a main screen might contain several panels, some of which may have buttons or edit boxes.

The XML-Editing **Component** which is the subject of this report contains a panel in which XML is displayed with a set of four arrow buttons; the user uses these to navigate the XML. One element or "tag" is always highlighted in red. That is, when the user clicks the left arrow, the containing tag is highlighted; when the user clicks the right arrow, the highlight changes from the current tag to the immediate child on which the mouse is selected. The Up and Down arrows move the cursor from the current tag to the subsequent, or previous tag at the same level.

The programmer creates the XML editing component using its constructor and adds it to the frame or another panel using the **add** method of the frame. This is precisely how they would add an ordinary built-in edit box or button. Then they can use **setParser** to load an XML file, which is displayed. The programmer can retrieve a **parser** object. This allows the user to add or otherwise manipulate elements. It also supports the operation **getPointer** so the programmer can get the node that the user has highlighted. For example, assume the user selected an element that represents an "if," and selected a button to add a "then" part. The logic for a button would use the **getPointer** method to get a pointer to this element and then use the XML manipulation methods that are part of the packages that come with the Java programming language to add the new information.

The senior author developed an XML standard for legal contracts (Leff, 2000). It was proposed to the Legal XML standards organization. A legal contract can be viewed as a

series of obligations. This is a use of deontic logic which includes the modelling of obligations, prohibitions, and permissions (Boulmakoul, 2002). In a simple contract to purchase pizza, the pizza company has an obligation to deliver the agreed-upon number of boxes of and type of pizza to the purchaser. Conversely, the purchaser has an obligation to pay the amount. Some of these contracts may be obligations which may be conditional (Boulmakoul, 2002). For example, the purchaser might state that the pizza is only to be delivered if it was not raining. One application of deontic contract languages and logic is the monitoring of contract compliance, particularly in complex situations such as quality-of-service agreements (Neal, et. al., 2003). The Distributed Systems Technology Centre at the University of Queensland has developed contract monitoring systems based upon Business Contract Language (Neal, et. al., 2003) (Meyer, 2005).

The first author used the component in a contract editor. It allowed the user to create the contract interactively. She used the **getPointer** method to determine which clause that the user selected. Then, the user could issue commands to add new conditional elements to that clause.

## II. SETTING: SOFTWARE REUSE

The idea of reusing programs, software knowledge and software "artifacts" such as documentation or test plans was mentioned in the famous 1968 NATO Software Engineering Conference that is considered the birth place of software engineering and is the subject of several books and articles, as reviewed in (Krueger, 1992). Several reports show that large organizations that develop software make good use of reuse techniques and report productivity gains (Lim, 1994) (Mili, et. al., 2001) (Poulin, 1997). (Krueger, 1992) recognizes that "many programmers" copy contiguous blocks of code. In many cases, no effort is made to repackage the software copied so it can be be easily used a third or later time. The programmer simply copies the code to solve the immediate problem (Caldiera and Basili, 1991). Arnold's work, (Pant, et. al., 1996), and this case report cover cases where the code is extracted for the purpose of reuse. (Pant, et. al., 1996) had developers implement three systems: a matrix class, a name and phone manager, and an inventory manager. Then, the programmers identified potentially reusable classes and prepared a class library of thirteen reusable components. They found that generalization increased the average number of lines of code per module from 226 to 264 lines, with similar increases in other measures of complexity. They found that the time to perform the generalization was 55% of the original development effort.

(Laubile and Visaggio, 1997) applied a concept called "program slicing" to help identify reusable software. However, the senior author was unable to find a report that this technique extracted a reusable software module from previously-written code.

## III. SETTING: XML AND THE CONTRACT STANDARD

XML has angle brackets and tags that makes it superficially similar to HTML—both come from Standard Generalized Markup Language (SGML). See Figure Three at the end of the article for an example of XML. However, each type of XML document uses its own tags, often defined by a standards organization. For example, Common Business Language (xcbl.org, 2004), RosettaNet, and the Open Application Group develop standards for purchase orders. Thus, many different organizations needing to purchase supplies could use a common XML, even if they use different software to manage their accounts receivable, accounts payable, and delivery management (Cooke, 2001). These tags describe and mark up the text contained within them. Techniques such as DOM processing allow a programmer to implement software to easily find the tags representing the desired information item and retrieve it (Maruyama et. al., 1999).

| | Functions | Mr. Eguchi's Program | My Contract Editor | Hypothetical Editor for MathML |
|---|---|---|---|---|
| Commonality | The traversing buttons that allow user to move around | User can move across both the sample XML document and the rule-based XML document being formed | User moves to select a clause to receive a new **Then** or **Implication** | User moves to select an expression to be modified or evaluated |
| | Visually shows the selected and non-selected part of the XML clearly | Part to be moved from sample document is displayed in red. Part to be edited in rule-based document is also marked in red | Anything that is newly added or selected is displayed in red. New party, clause to receive, new **Then** or **Implication** | Anything that is added or selected is displayed in red. |
| Variability | The editing buttons that allow user to create or manipulate the XML document | Replace text with variables etc. | Add a new party, clause to receive, new **Then** or **Implication** | Evaluate a sub expression. Modify subexpression by introducing a number, variable, operator, indentifie structure etc |

LegalXML's aim is to standardize XML used for exchange among the entities participating in the legal system; it is a collection of Technical Committees. In 2002, it joined with the Organization for the Advancement of Structured Information Standards (OASIS) (Mountain, D., 2003). One of the Technical Committees is the eContracts Technical Committee. The contract proposal mentioned in Section I. was submitted originally to Legal XML in August 2000 and it is now on the OASIS web-site in the eContracts Technical Committee documents section. The hope is that different organizations would be able to exchange contracts as they are negotiating them, but would need to use the same schema (Meyer, 2005). In addition, XML would allow the reuse of contract clauses or boiler plate, called "precedent documents," and the exchange of information with and between systems developed by contract management vendors.

## IV. REUSING THE XML NAVIGATION AND DISPLAY CODE

As mentioned in Section I, we started with Mr. Go Eguchi's XML editor which had two panes. And, we created a reusable Java Swing Component, **ComponentForXml**. In creating a reusable class for a domain, one must locate a set of applications that have commonality, but identify those areas that would vary for each application (Frakes and Isoda, 1994) (Fayad, et. al., 1999).

This is best explained for **ComponentForXML**, by identifying two different application domains. One is an editor for contracts, for which it was successfully used. The other is a hypothetical editor for MathML. MathML is a W3C standard that can be embedded in web pages for the display of mathematical equations and to allow exchange of information between mathematical programs, e. g., between symbolic mathematics systems such as Mathematica, Macsyma and Maple (Topping, 1998).

As mentioned in Section I, Mr. Go Eguchi developed a Graphical User Interface for XML rules whose main file was **GuiForXml.java**. This contained the front end that interacted with a rule-writer for XML transformation. **GuiForXml.java** contained 1833 lines of code (LOC). Of these, 334 lines represented interacting with the user to traverse the XML and displaying in red the part selected. **GuiForXML** also created and displayed the panels to contain the XML and the arrows and supported two DOM trees (as **DomParserPart**) for the sample XML and the rule-based file being created.

Thus, the first author simplified this to only one panel and one DOM Tree for **ComponentForXML**. The 334 lines were revised slightly giving 322 lines in this component representing reused code.

Three smaller class files were used with no change, **DomParserPart** (281 LOC), **ApplicationPanel** (47 LOC), and **ALine.java** (22 LOC). The first contained the recursive routine that converted the XML, represented as a DOM tree, into an array of ALine objects. The other two represented the panel on which the user saw the representation of the XML and a single line, as displayed in the panel, respectively.

However, in order to make a reusable **Component**, several facilities needed to be generalized for the programmer. Consistent with standard practice in developing object-oriented code, we implemented a "getter" method to retrieve the **DomParserPart**. Also, the first author added three other methods. The programmer uses these to implement loading a new file into the display area. For example, the programmer would use this when coding the action to be performed when the user does "File" and "Open" from the menu. (Mr. Eguchi hard coded the menu and these functions into his program, so we set up the code to allow the programmer using the component to access this capability.) These four methods were 90 LOC added.

The **DomParserPart** also supported an important method, **getPointer** which got a pointer in the DOM tree to the XML that the user selected and currently sees highlighted in red. The **DOMParserPart** also had a "getter" method to retrieve the DOM model representing the XML argument. From this, the programmer would invoke methods (Maruyama, et. al., 1999) (Java, 2004) for such purposes as adding an attribute to it or adding a tag below it. This was used in the contract editor, described in other sections, to add an implication to the currently selected clause.

Thus, we reused 672 LOC from Mr. Eguchi's rule editor and added 90 LOC which is an 11% addition to make a reusable class. This is low compared to that reported by (Pant et. al., 1996) to make code implemented for a specific purpose into a reusable object.

Unfortunately, we did not keep a record of the number of hours spent by Mr. Eguchi or the first author of this article. Both completed Masters degrees at Western Illinois University doing the work as a final project or thesis, but neither had a prior degree in a computer-related field. However, the first author of this paper started her project very early in her career at WIU. Thus, even if they had records of the number of hours spent on their respective projects, they would not be comparable. Thus, all we can observe regarding time is that the first author wrote the code that was reused as well as an application and the second author made it into a reusable component and used it in a different application in a time frame consistent with a Masters project or Masters thesis.

## V. THE CONTRACT EDITOR

As mentioned in Section I, the first author implemented an editor for legal contracts that are represented in XML based upon a suggested standard for the OASIS eContracts Technical Committee.

A legal contract contains a list of the parties to the contract (Harrop, 2004). Corresponding to this, our contract editor has buttons to prepare the XML containing a list of the parties and their addresses. Each party has a unique PartyID by which it is referenced in the clauses.

Then, the contract editor's user creates clauses using the "Add Clause" button. A dialogue pops up, and the user enters the Clause ID (which must be unique) and one of the PartyID's for the "Clause From" and "Clause To" These would indicate the party who owed the obligation and the party to whom they owed the obligation.

Many clauses just contain text such as "deliver ten boxes of pizza." However, most interesting are the implications. They indicate that the obligation only exists when something else happens. Sometimes, this is text. For example, if the pizza was for a picnic, the parties might agree that the pizza would only be delivered it was not raining on that day. Alternatively, one obligation only is in force if a prior action to which the parties agreed occurs. For example, the buyer is only obligated to make a payment after the product was delivered.

The user will often use the contract editor to replace an ordinary clause, created as indicated above, by an implication. Here (Figure One), the user used the arrow buttons to traverse to the clause containing "Deliver Ten Boxes of Pizza." Then, the user selected **Add Implication** and the dialogue you see popped up. The user entered the text of the condition that it not be raining.

Now, the user must indicate what would happen if it was not raining on the indicated day. In this case (Figure Two), that means that Acme Pizza would deliver the pizza to the first party. The user traversed to the "Then" part of the clause and selected **Add Clause to Then**. In the resulting dialogue, the user provides a new clause id and selects the parties from whom and to whom the obligation is owed. They also enter the text of the clause, which in this case is a repeat of what was already in the clause.

Then, the user will create a new implication in a similar manner. However, the user will select Clause ID C002 in the "Add Implication" dialogue instead of entering "Condition Text." In the "Add Clause to Then," the user would enter text for the obligation which would be to pay money, and the "Clause From" would be P001 for the buyer. The resulting XML Contract after all of these steps is shown in Figure Three.

## VI. RESULTS AND CONCLUSIONS

The senior author did a search for "code scavenging." Then, a citation search was done on the relevant articles—which articles cited them. This was done in both citeseer.IST, the Scientific Literature Digital Library started by the NEC, now run by Pennsylvania State University and sponsored by Microsoft Research, the National Science Foundation, NASA and the ACM. That author also searched for citations to Arnold's work on **curses**, as well as (Pant, et. al., 1996). Thus, although (Kruger, 1992) reported that code scavenging was widely used in practice, (Pant, et. al., 1996) was the only article found that reported on specific experience extracting a reusable component, class or library subroutine from preexisting code not intended for reuse. Thus, this modest contribution to the literature.

(Meyer, 2005) discusses the difficulties in authoring contracts in XML. (Lauritsen, 1992) reports little analysis or empirical analysis of what happens when one authors a legal document. We acknowledge concerns[1] that it might not be easy for individuals to work with an XML representation. (An alternative would be a natural language representation of the contract that would be updated interactively as the user activated certain buttons.) However, we note Van Enger's work on representation methods for tax legislation. The system that the users most preferred turned out to be the one in which they made the most errors in comprehension (van Engers, et. al., 2002). The best user interface for the structured creation of contracts can only be resolved by empirical work, which is "further work" not only for this editor but for all systems and ideas for generating legal discourse, documents and representation (Lauritsen, 1992)[2].

So, we make this modest contribution by demonstrating one more interface style for deontic logic in specific, and XML manipulation for contracts. It is now available as an open source project, http://sourceforge.net/projects/amina.

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[1] Some came from the members of the first author's Masters Thesis Committee. Others came when a version of this work was submitted and rejected by a conference.

[2] This was confirmed by later research by the senior author and by a personal communication from Peter Meyer in 2005.

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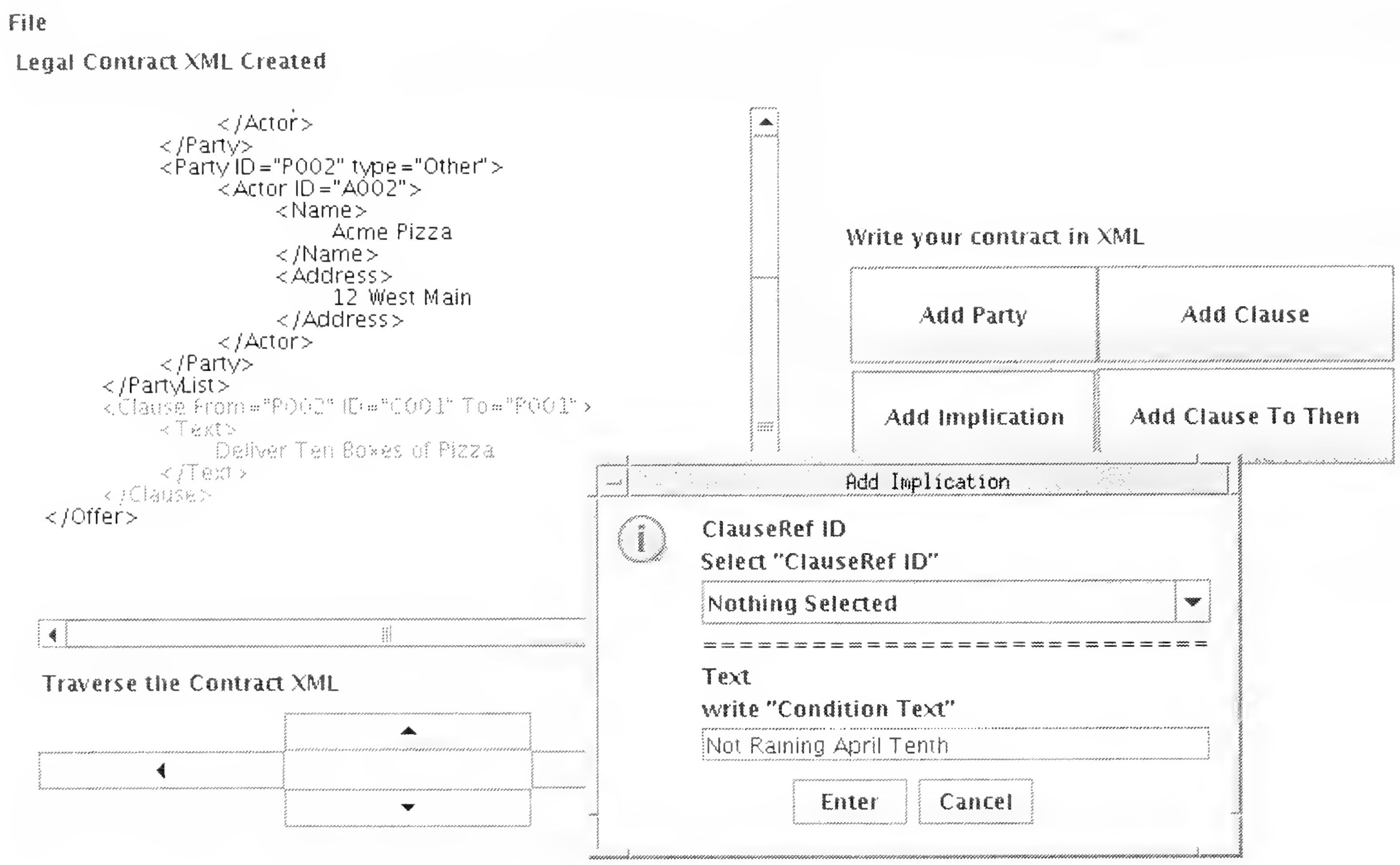
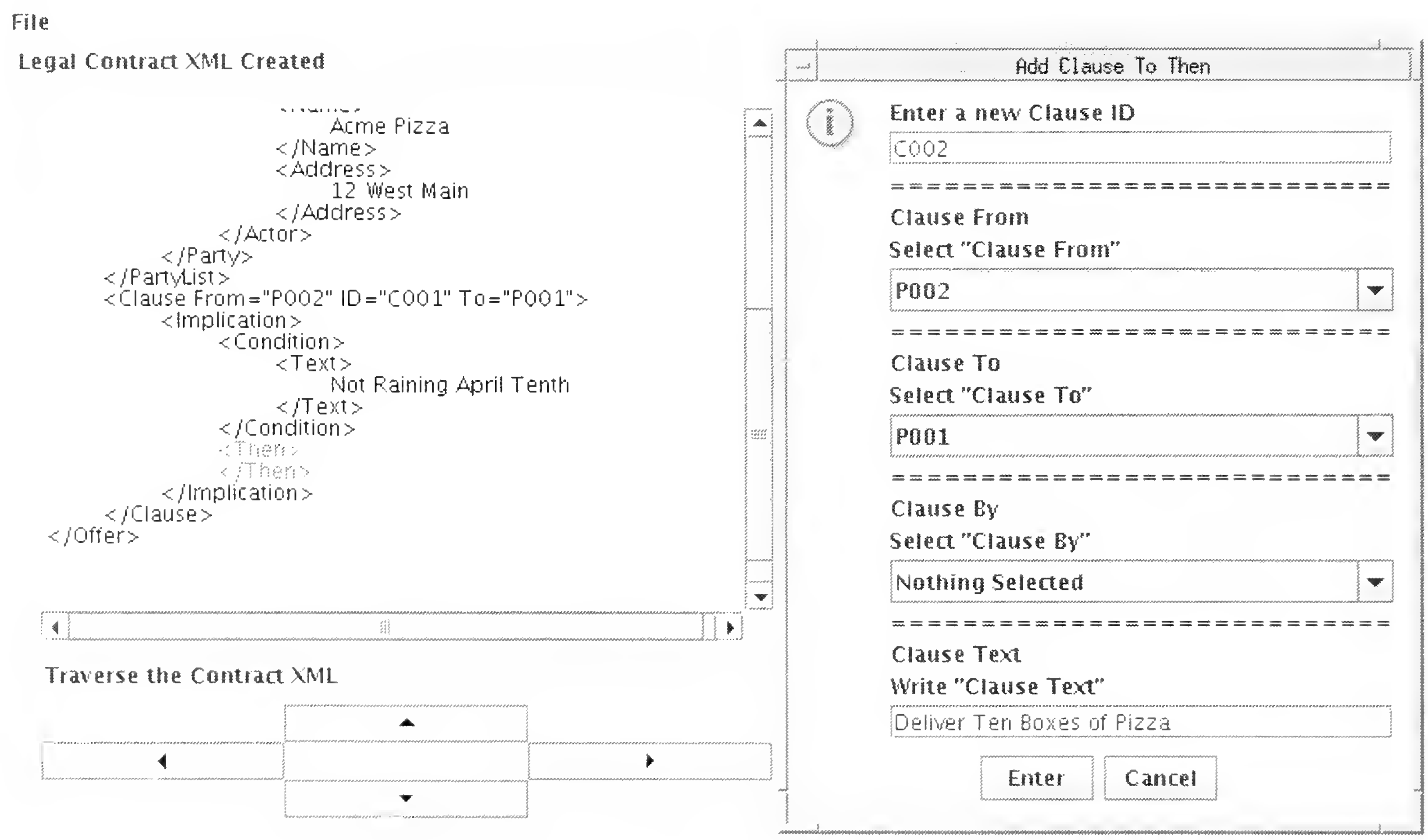
Figure 1. Adding an Implication to Replace a Clause



```
            </Actor>
        </Party>
        <Party ID="P002" type="Other">
            <Actor ID="A002">
                <Name>
                    Acme Pizza
                </Name>
                <Address>
                    12 West Main
                </Address>
            </Actor>
        </Party>
    </PartyList>
    <Clause From="P002" ID="C001" To="P001">
        <Text>
            Deliver Ten Boxes of Pizza
        </Text>
    </Clause>
</Offer>
```

ClauseRef ID
Select "ClauseRef ID"
Nothing Selected
==========================
Text
write "Condition Text"
Not Raining April Tenth

Figure 2. Add Clause to Then Dialogue.



```
                    Acme Pizza
                </Name>
                <Address>
                    12 West Main
                </Address>
            </Actor>
        </Party>
    </PartyList>
    <Clause From="P002" ID="C001" To="P001">
        <Implication>
            <Condition>
                <Text>
                    Not Raining April Tenth
                </Text>
            </Condition>
            <Then>
            </Then>
        </Implication>
    </Clause>
</Offer>
```

Enter a new Clause ID
C002
==========================
Clause From
Select "Clause From"
P002
==========================
Clause To
Select "Clause To"
P001
==========================
Clause By
Select "Clause By"
Nothing Selected
==========================
Clause Text
Write "Clause Text"
Deliver Ten Boxes of Pizza

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# Unique Severe Storms Struck Illinois in March 2006

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## ABSTRACT

During the night of March 12-13, 2006, a series of severe thunderstorms crossed central and northern Illinois, producing nine tornadoes, damaging hail, heavy rains, and very high winds. These conditions caused great property damage, totaling $37 million, and 38 persons were injured. Seven days later the weather made a dramatic shift, and a massive winter storm moved across central Illinois accompanied by high winds causing blizzard conditions, snowfall totaling 10 inches, sleet, and freezing rains. Thousands of vehicle accidents resulted with 89 persons injured. These two storms were unique in that collectively they produced every type of severe storm that occurs in Illinois. Other weather oddities of note included the winter storm occurring after the summer type storm, and the fact they were separated by only seven days. Furthermore, the most extensive damage occurred in the same area, west-central Illinois and in and near Springfield. Fortunately, no one was killed in Illinois, an outcome likely related to the timely and accurate storm forecasts .

---

## INTRODUCTION

The continental climate of Illinois produces a very wide variety of weather conditions with major changes occurring hourly, daily, monthly, and yearly (Changnon et al., 2004). As a result of the wide differences in air masses that cross the state, Illinois experiences almost every known form of severe storm (except for damaging hurricanes), and storms occur in every month of the year. Tornadoes are most frequent in the spring but occur in all 12 months (Angel, 2002). Hail occurs often in spring and early summer (Huff and Changnon, 1959) , and thunderstorms, which maximize in summer, also occur in every month of the year (Changnon, 2001). Lightning and thunder sometimes occur during a heavy Illinois snowstorm (Changnon, 1964). High damaging winds occur in all months (Changnon, 1980), and intense, heavy rains occur in all seasons but are most frequent in the warm season (Huff and Angel, 1989). The cold season sees major snowstorms, blizzards, sleet, and ice storms (Changnon, 1969).

An 8-day period in March 2006 experienced all forms of warm season and cold season severe storms across central Illinois, often Illinois' home to such diverse extremes. The night of March 12-13 had nine tornadoes, numerous severe thunderstorms, damaging hailstorms, dangerous lightning, heavy rains, and record-setting, non-tornadic high winds. Afterwards, weather conditions took a dramatic turn. Seven days later, instead of more hail, tornadoes, and high winds, nature provided a rare March winter storm that blanketed parts of Illinois with heavy snow on the official first day of spring, March 21. Such greatly different forms of severe weather have occurred infrequently in past spring seasons, and the vastly different March 2006 storms occurring within a few days was very unusual, particularly with the winter season storm following the warm season event. This shift was observed by many as a highly unusual event (Farm Week, 2006).

March has more volatile weather than any other month. One day can be summer-like and then winter-like conditions develop in a matter of hours, last several days, and are then replaced with warm, spring-like conditions. These shifts often are accompanied by some form of severe weather.

March 2006 exhibited these highly volatile extremes that can occur in this month with highly changeable conditions.

## CONVECTIVE STORMS ON MARCH 12-13

By early afternoon on March 12, National Weather Service (NWS) forecasters had recognized the potential for severe storms across central Illinois, and they issued warnings for severe thunderstorms in 27 counties and tornado warnings for 24 other counties, all in central Illinois. A major storm complex originated in northeast Oklahoma at noon and tracked across Kansas and Missouri, reaching Illinois in late evening. This massive storm system ultimately produced 110 tornadoes in this 4-state area (NWS, 2006). Across the nation's mid-section, the weekend of March 11-12, 2006, featured the wildest weather in recent years (Rippy, 2006). Nationally, there were 150 tornadoes, a new 2-day record for March.

A large supercell thunderstorm developed near Tulsa, and traveled across Missouri and into Illinois, creating an unusually long 400-mile track (NWS, 2006), a record exceeding the previous high of 366 miles set in April 2001 by a long-track, Kansas-to-Illinois, supercell hailstorm (Changnon and Burroughs, 2003). A supercell thunderstorm is a long-lasting and quite large storm because it has an internal organization that creates a single, quasi-steady rotating updraft with constantly available warm moist air to fuel the updraft, and the right atmospheric setting including the changes in wind speed and direction with height. Strong winds aloft greatly influence the structure of these storms. The March 2006 supercell produced considerable hail along its track. Hailstones measuring 2 inches in diameter fell west of Springfield and in southeastern Logan County, and hailstones with diameters of 2 to 3 inches fell at Fisher in northwestern Champaign County.

Figure 1 shows the tracks of the nine tornadoes that occurred in Illinois on March 12, all the result of the supercell storm. The longest track tornado (labeled #1) began at the Illinois River at 7:07 p.m. and moved 66 miles to the ENE, terminating in south-central Springfield at 8:26 p.m. This large storm with a F2 intensity rating and a path width varying from ¼ to ¾ mile, destroyed all 30 houses in Barrow and did major damage in Springfield's southwestern and southern sections. Another strong F2 tornado (#4 on Fig. 1) formed over central Springfield at 8:25 p.m. just as the first tornado was dissipating. This new tornado did great damage to the central and eastern parts of the city on its 4-mile track. City power lines were downed and power outages lasting 12 to 36 hours affected 25,000 Springfield homes. It took five days before all the power service was restored. Downed trees and power poles blocked most roads into Springfield on March 13, and debris blocked and closed a railroad line. The two Springfield tornadoes badly damaged 1,000 homes, two shopping centers, and two hotels, while 24 city residents were injured.

As shown on figure 1, the other seven tornadoes had tracks that were essentially parallel to the major storm. The three tornadoes in Logan County destroyed many power lines (Fig. 2), and toppled a 350-foot communication tower. The nine tornadoes were closely aligned in space and time and formed a "family of tornadoes," a condition often generated by a supercell (Fujita, 1974). The parallel tracks and temporal closeness of tornadoes 6-7 and 8-9 also suggest the presence of twin vortices.

Lightning started several fires along the huge thunderstorm's path, including a building near Watseka. High winds generated by the massive storm tore down power lines in Ford County, and did major damage in Elliott and to many farms in McLean, Dewitt and Ford counties. Another severe thunderstorm passed across central Illinois from 3 to 4 a.m., and produced large hail near Farmer City and wind damage at Saybrook in McLean County.

Other thunderstorms during the night created strong downbursts leading to damaging winds in the Quad City area and in certain suburbs of Chicago. Moline recorded a wind speed of 107 mph, a new station record and fastest speed to occur nationally during March 2006 (Rippy, 2006). Early morning (March 13) high winds near Bridgeview, a southwest suburb of Chicago, were estimated at 85 to 100 mph by NWS meteorologists, and caused considerable property damage in Bridgeview. Many parts of northwestern Illinois, from Moline to Freeport, received hail of ¾ to one inch in diameter. Large amounts of hail also fell from Knox County eastward along the Illinois River Valley from La Salle to Kankakee. Ottawa and Joliet had hailstones ranging from 1½ to 2 inches in diameter, a rare event (Huff and Changnon, 1959).

Heavy rains also occurred throughout most parts of central and northeastern Illinois, producing totals of 1 to 2.5 inches in a few hours. Rains were heaviest in Sangamon, Logan, and Dewitt counties where 2 to 2.5 inches fell. The area from Moline to Freeport and eastward to Waukegan also received 2 to 2.5 inches of rain. Flash flooding occurred in parts of central Illinois, including in Dewitt and Ford Counties, and in parts of Chicago and its northern suburbs.

The strong storm system also created high winds that continued through the morning hours of March 13 and caused structural damage in central and northeastern Illinois. Damaged buildings in Antioch led to three injuries, and the winds caused major damage to a shopping mall in Prospect Heights and to homes in parts of Evanston.

Illinois fortunately experienced no deaths due to this sizable storm system, although 37 persons were injured. More than 1,685 Illinois homes were badly damaged including many farm homes, those in Springfield, and in several other communities. The total storm damage estimate is $37 million. The Governor of Illinois declared seven counties (Ford, Greene, Logan, Morgan, Randolph, Sangamon, and Scott) as disaster areas. This provided state reimbursements for a portion of the local recovery costs. The federal government also provided disaster assistance to Sangamon, Greene, Logan, Morgan, and Scott counties.

## WINTER STORM ON MARCH 21

On March 20, a deep low pressure system with attendant cold front was moving east from the High Plains and developed a track along the Ohio River Valley, a perfect scenario for creating a major winter storm across the Midwest. Cold Arctic air behind the cold front prevailed over Kansas, Missouri, and Illinois, and the low's passage brought Gulf moisture that flowed up and over the cold air, creating heavy snow and sleet. The resulting significant snowstorm that developed in Kansas was moving eastward across Missouri on March 19-20 (Rippy, 2006).

On the morning of March 20 the NWS issued severe winter storm warnings for most central Illinois counties. The snowfall from the advancing storm began in the early hours of March 21, ironically the date that marks the official start of spring.

The storm system moved west-to-east across central Illinois during the early morning and afternoon of March 21. Snow was heaviest in a narrow belt 90 miles wide from Quincy to Pana in central Illinois with a secondary maximum near Paris in eastern Illinois (Fig. 3). High winds produced blizzard conditions across south-central Illinois, and the resulting poor visibility led to hundreds of auto and truck accidents. High winds also caused much drifting, while freezing rain and large quantities of sleet fell along the storm's southern edge, creating very slippery conditions and numerous vehicular accidents. Most of the snow ended by late afternoon as the large winter storm system moved into Indiana..

The resulting total snowfall pattern in Illinois (Fig. 3) shows three areas with 7 or more inches of snow, and the maximum was 10.5 inches at Winchester, which is located 40 miles west of Springfield. Springfield had 6 inches of snow, a new one-day record high value for March, and Peoria had 5 inches, also a new one-day record for March.

Due to the timely issuance of storm warnings, road crews were out early clearing the roads, but the high winds that accompanied the storm kept blowing snow back over the roads. Many rural roads along the storm track were closed on March 21, and all schools in the large snow region (Fig. 3) were closed. More than 2,450 vehicular accidents occurred, and traffic was blocked by accidents on several highways including Interstates 70, 55, and 57. Injuries occurred to 89 individuals but no one was killed.

## SUMMARY AND CONCLUSIONS

Although March experiences wider weather swings than occur in any other month in Illinois, the occurrence of the two massive March 2006 storms ranked as a weather-climate oddity for several reasons. Most importantly, the conditions produced by the two events included all forms of severe storms that occur in Illinois. Another oddity was having the winter storm occur after the spring storm. The temporal closeness of the two storms, just seven days apart, was another unusual outcome. The area with the most damage from both storms was west-central Illinois, in and near the Springfield area, an interesting outcome. An oddity that serves as a blessing is that neither storm resulted in any deaths, partly a result of the excellent, long-lead storm forecasts issued by the National Weather Service. Last but not least was the irony of having a major winter storm on the official first day of the spring season.

## ACKNOWLEDGMENTS

The reviews and comments of Jim Angel and Ken Kunkel are appreciated, and Linda Hascall prepared the illustrations. Portions of this work were supported by a grant from NOAA, as part of the Climate Change Enhanced Data Set Project, NA16GP1585.

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Figure 1. Tornadoes on March 12, 2006, and locations with damages (times are p.m.).

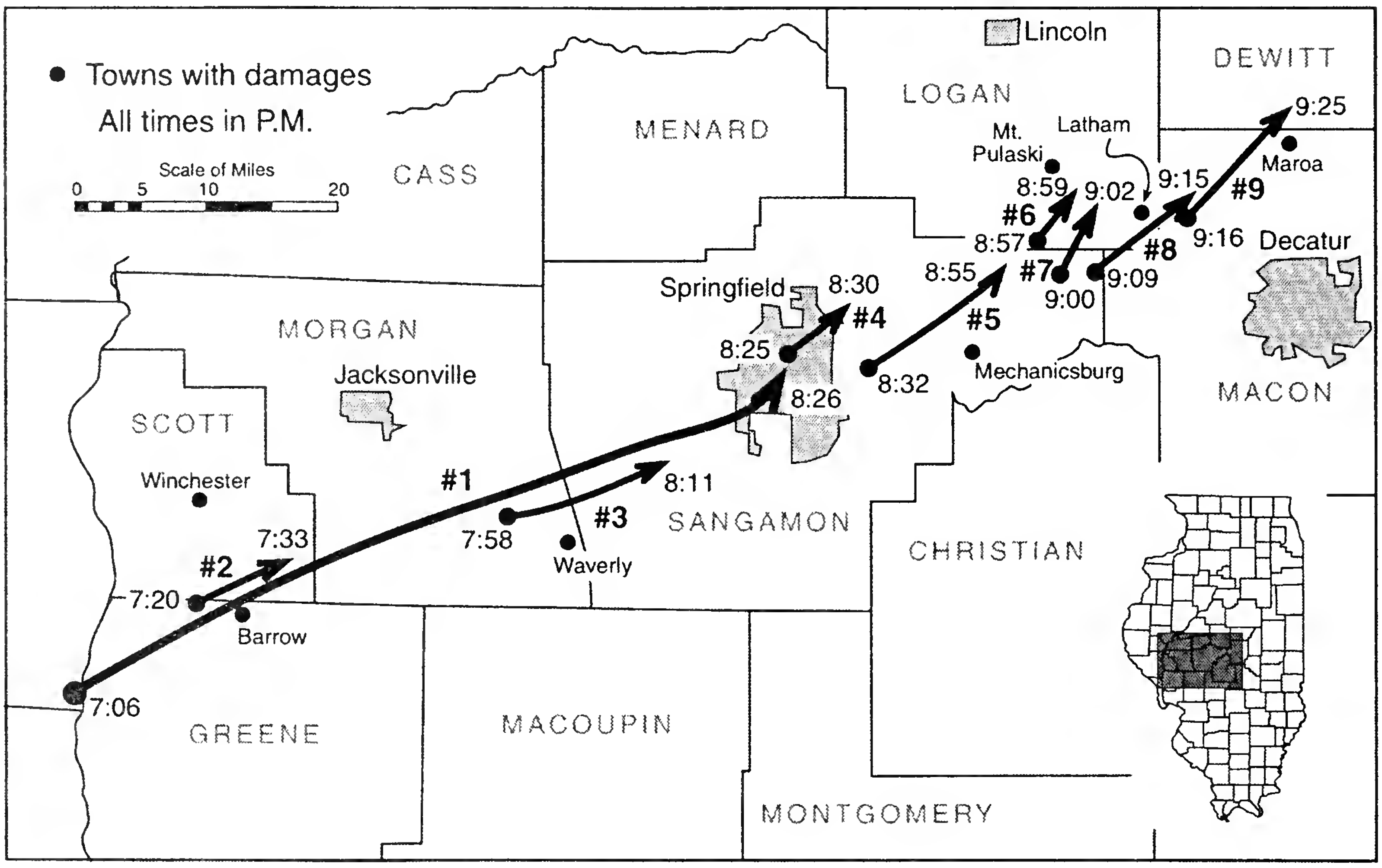


Figure 2. A country road near Mt. Pulaski with many power poles downed by a tornado on March 12. (Photo courtesy of Decatur Herald and Review, and taken by Kelly Huff).

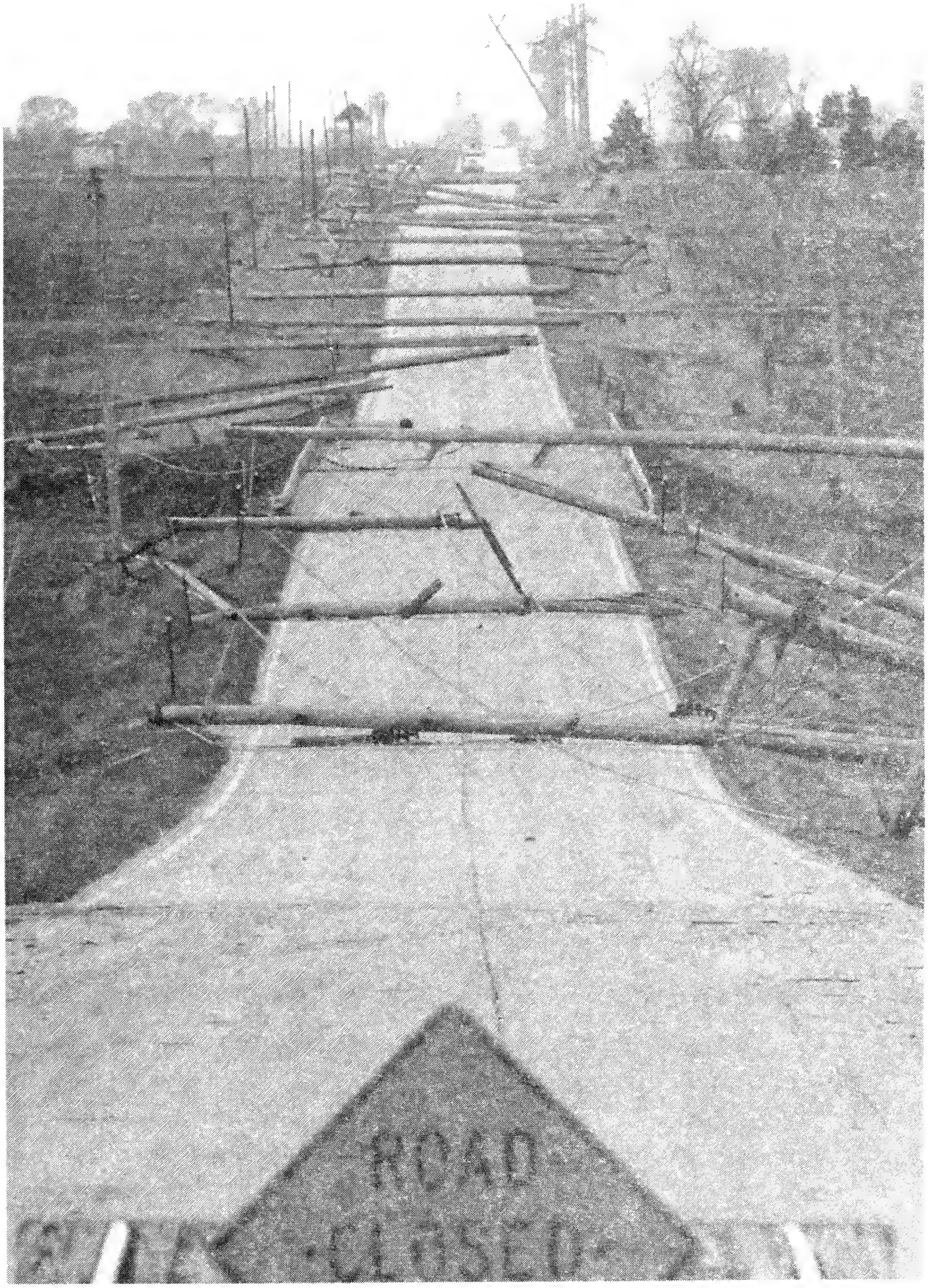
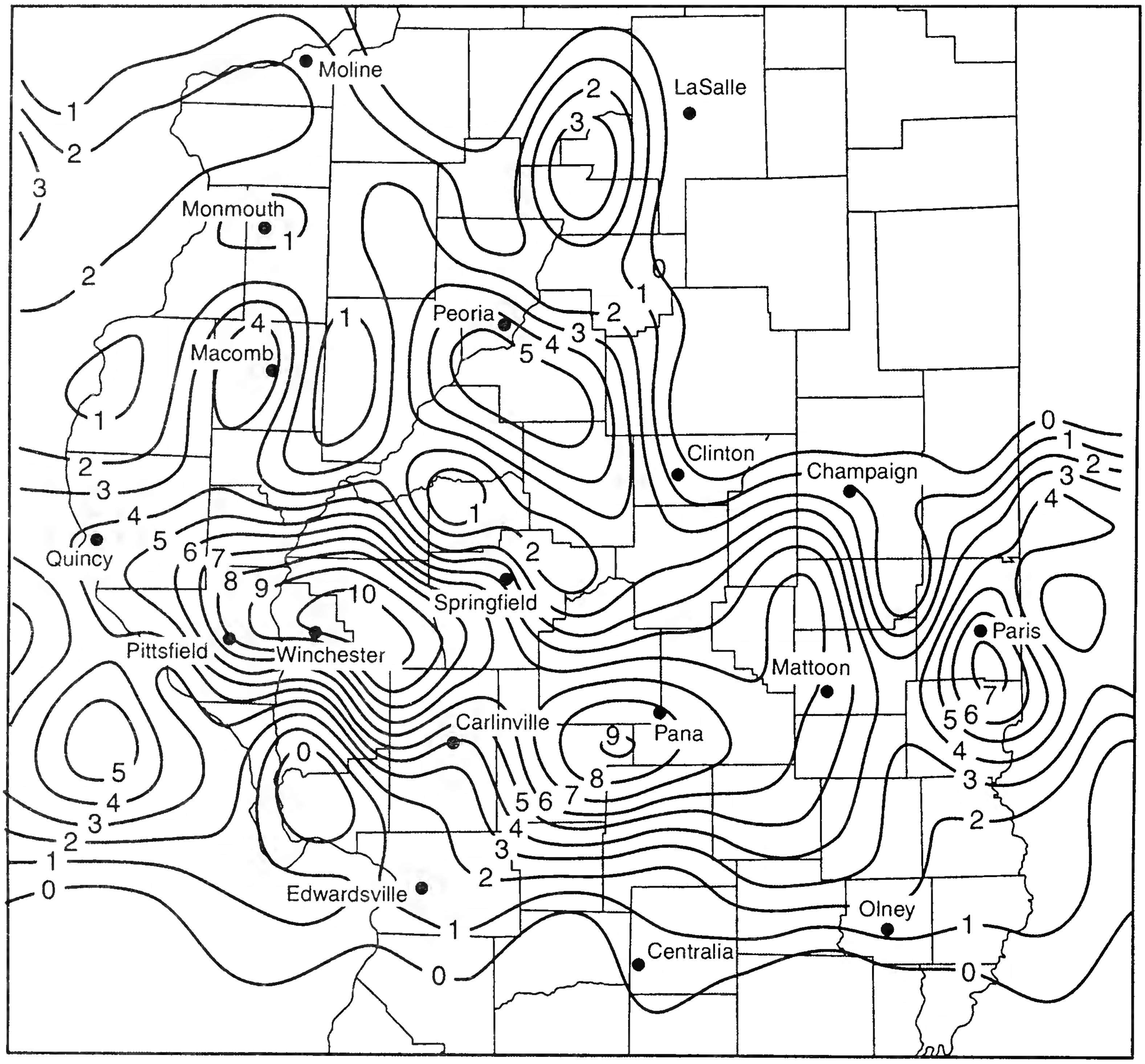


Figure 3. Pattern of snowfall (in inches) on March 21, 2006.



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# Prevalence of Lungworms in Illinois Coyotes

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## ABSTRACT

The increasing abundance and expanding geographic range of coyotes in the eastern U.S. raises questions regarding the importance of parasites as limiting factors and the role of coyotes as a potential reservoir for parasites transmissible to other wild or domestic carnivores. We surveyed the prevalence and intensity of lungworms in 341 coyotes collected throughout Illinois and compared body mass and winter fat levels of infected and uninfected animals. Four lungworm species were found, including *Capillaria aerophila*, *Oslerus osleri*, *Paragonimus kellicotti* and *Crenosoma vulpis*. *C. aerophila* was the most prevalent and widespread lungworm occurring in 15.2% of coyotes, but had the lowest mean intensity of the four species. Body masses were lower and kidney fat indices tended to be lower for lungworm-infected versus uninfected males, but mass and fat levels did not differ in females. We conclude that lungworms may impact the condition of individual coyotes, but the prevalence and intensity of these parasites are currently too low to affect the population dynamics of coyotes in Illinois.

Key words: *Canis latrans*, *Capillaria aerophila*, coyote, *Crenosoma vulpis*, lungworm, *Oslerus osleri*, *Paragonimus kellicotti*, parasites

## INTRODUCTION

Coyotes (*Canis latrans* Say) have increased in abundance in Illinois and throughout the eastern U.S. in recent decades (Hoffmeister, 1989; Lovell et al., 1998.). This species may serve as an important reservoir for a variety of parasites transmissible to domestic animals and humans, including several species of lungworms (Gier et al., 1978). Although mild lungworm infections in dogs are asymptomatic, provoking sporadic coughing, nasal discharge, and mild catarrhal inflammation, more severe infections can cause tissue damage, dypsnea, and predispose infected individuals to pneumonia. Parasites might be expected to have a greater impact on highly active wild canids by reducing respiratory function, movements, foraging efficiency, and survival, especially during periods of high host density, severe weather, or when individuals are in poor physical condition (Sacks and Blejwas, 2000).

Several studies have documented the prevalence of lungworms in local or regional coyote populations (e.g. Morrison and Gier, 1978; Custer and Pence, 1981; Carlson and Nielsen, 1985), but few have surveyed large samples of coyotes and none have investigated the potential sublethal effects of lungworm infections on the physical condition and growth of coyotes. Consequently, the effects of these parasites on the health and ecology of coyotes are unclear. The objectives of this study were to: (1) survey the prevalence and intensity of lungworms in coyotes throughout Illinois; (2) assess whether prevalence varied between sexes and age-classes; and (3) determine whether lungworm intensity correlated with physical condition, particularly body mass and winter fat levels.

## MATERIALS & METHODS

The survey was conducted using 341 fresh coyote carcasses collected from fur buyers and trappers throughout Illinois during December-March, 1996 and 1997. The county of harvest, sex, and skinned body weight (kg) were recorded for each animal. Coyotes were classified as juveniles or adults based on the width of the pulp cavity measured on radiographs of a lower canine tooth (Kuehn and Berg, 1981). Skinned body weight, kidney fat index (KFI), and percent marrow fat were used as indicators of nutritional condition (Riney, 1955; Neiland, 1970).

Parasites were collected from the respiratory tract by inserting a small tube into the pulmonary artery and flushing with tap water while massaging the lungs for a minimum of 3 minutes. Water and parasites were flushed from the trachea onto a 120 µm sieve, then back flushed into a 90 µm sieve, and the contents examined for parasites at 15x using a dissecting microscope. In addition, the trachea and bronchi were carefully examined and nodules containing parasites were excised. Parasites were preserved in 70% ethanol and 5% glycerol, then mounted in lactophenol and identified using a compound microscope.

The prevalence (proportion of coyotes infected), mean abundance (number of lungworms/coyote examined), and mean intensity (number of lungworms/infected coyote) of all lungworms and each separate species were calculated for both sexes and age-classes of coyotes (Bush et al., 1997). Chi-square tests were used to test for differences in prevalence between the sexes and age-classes. Differences in the intensity of infections between sexes and age-classes were tested using t-tests (Sokal and Rohlf, 1995). We divided our sample into infected and uninfected groups to test whether lungworms affect body mass and fat reserves. Sample sizes varied among tests because individual organs were not used if they were damaged. All statistical tests were conducted at $\alpha = 0.05$

## RESULTS & DISCUSSION

### Prevalence and distribution

We identified 4 species of lungworms in coyotes: *Capillaria aerophila* (Creplin, 1839; Travassos, 1915), *Oslerus osleri* (Cobbold, 1879), *Crenosoma vulpis* (Dujardin, 1845), and *Paragonimus kellicotti* (Ward, 1908). *C. aerophila* was the most prevalent lungworm, occurring in 15.2% of coyotes (Table 1). The species was common throughout the state and found in 19 counties (Fig. 1). Nodules containing *O. osleri* were found in 2.9% of our sample from 7 counties across the state. Eight coyotes (2.3%) in 7 counties were infected with *P. kellicotti*. The least common lungworm was *C. vulpis*, found in 2 (0.6%) individuals, both from Clay Co. in southeastern Illinois (Fig. 1).

The prevalence of lungworms did not differ between sexes ($X^2 = 1.26$; $P = 0.262$) or age-classes ($X^2 = 1.78$; $P = 0.182$). A total of 67 coyotes (19.6%) were infected with at least 1 lungworm species. Five of these infected individuals were parasitized by 2 species; 4 by *C. aerophila* and *O. osleri* and 1 by *C. aerophila* and *C. vulpis*. The mean abundance of all 4 species combined was relatively low at 0.43. Intensity ranged from 1 to 10 with a mean of 2.2 (SE = 0.3) worms. Lungworm intensities did not differ significantly between sexes ($P = 0.25$) or age-classes ($P = 0.74$). Most infected coyotes had low intensity infections; 75% carried $\leq 3$ worms and only 7.5% were infected with >5 worms. Mean intensity was highest for *P. kellicotti* (mean = 4.3; SE = 1.3) and lowest for *C. aerophila* (mean = 1.7; SE = 0.2). No regional trends were apparent in the intensity of any of the 3 parasites found statewide.

None of these lungworms have been recorded previously from coyotes in Illinois, but 3 of the 4 have been reported previously in other regions (Custer and Pence, 1981; Ramsden and Presidente, 1975). Our study is the first to find *Crenosoma vulpis* in this host. *Capillaria aerophila*, which was prevalent in coyotes throughout the state, is a fairly common nematode in canids and was reported from 6% of dogs, 31% of red foxes (*Vulpes vulpes*), and 11% of gray foxes (*Urocyon cinereoargenteus*) in previous Illinois studies (Levine and Ivens, 1965; Dyer, 1984a). The parasite is transmitted directly and might be expected to pass from infected adults to pups during grooming or regurgitation of food. However, we did not find it to be more prevalent in juveniles. *C. aerophila* can be pathogenic, particularly in foxes, but its effects on coyotes are unknown. The current prevalence and mean intensity of this lungworm in Illinois coyotes are probably too low to impact survival or recruitment, but coyotes may serve as a reservoir for transmission of this parasite to dogs and other wild carnivores.

*O. osleri* is a nematode with worldwide distribution in canids (Soulsby, 1982). Custer and Pence (1981) found the species in 52% of coyotes in Texas where it had little impact on the host's health. We found this species most commonly in small (5-6 mm), submucosal nodules that projected into the trachea. No lesions were apparent and obstruction of the airways was minimal. Severe infections of *O. osleri* cause dypsnea and emaciation in juvenile dogs, leading to high mortality in affected litters (Dorrington, 1968). Similar effects in coyotes would be difficult to detect because diseased pups are likely to die undetected in the den and sublethal cases may restrict their movements and likelihood of harvest. However, it is doubtful whether this parasite can cross-infect dogs and therefore coyotes do not appear to be an effective reservoir for *O. osleri* infection in dogs (Foreyt and Foreyt, 1981).

The lung fluke, *P. kellicotti*, normally parasitizes mink, but has been reported in coyotes and a wide range of other vertebrate hosts (Ramsden and Presidente, 1975; Dubey et al., 1978). It can be transmitted to domestic animals and is a potential zoonotic (DeFrain and Hooker, 2002). In Illinois, Dyer (1984b) found this trematode in 2.4% of red foxes and 1.2% of gray foxes. We found the species to be rare, but widely distributed in coyotes. Its impact on infected individuals appeared to be negligible. *C. vulpis* was found only in 2 males from 1 location. The species has not been reported in coyotes, but has been found in dogs, gray wolves (*Canis lupus*), and foxes in the eastern U.S. (Levine, 1968). Gregory (1998) found its prevalence to be higher (6.6%) in a sample of 15 red foxes from Illinois. The potential impact of *C. vulpis* on wild canids is poorly understood, but it has been studied in dogs where it can cause respiratory distress, bronchitis, pneumonia, and emphysema (Stockdale and Hulland, 1970).

### Body mass and fat levels

Body mass and marrow fat levels differed between males and females ($t = 7.5$, $P < 0.001$; $t = 2.3$, $P = 0.023$), but not between juveniles and adults of either sex, so we pooled the age-classes and tested each sex separately to investigate whether body mass and fat levels differed between lungworm-infected versus uninfected coyotes. Lungworm-infected male coyotes weighed less ($t = 2.25$; $P = 0.026$) and tended to have lower KFIs ($t = 1.43$; $P = 0.134$) than uninfected males, but marrow fat levels did not differ between these groups ($t = 0.33$; $P = 0.744$; Table 2). None of the condition indices differed between infected and uninfected females ($P = 0.651$-$0.893$).

Given the relatively low intensities of lungworm infections in most of the coyotes that we examined, we were surprised to find lower winter body mass in infected males. This trend may reflect the sublethal effects of lungworms on respiratory efficiency and physical condition of infected individuals, but causal relationships should not be inferred from our data. We conclude that lungworms may affect the physical condition of some infected coyotes, but the current prevalence and intensity of these parasites appear to be too low to impact the population dynamics of coyotes in Illinois.

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Table 1. Age-specific prevalence of 4 species of lungworms in Illinois coyotes collected during 1996-97.

| Species | Juveniles | | Adults | | Total |
|---|---|---|---|---|---|
| | Males (N=105) | Females (N=84) | Males (N=88) | Females (N=64) | |
| *C. aerophila* | 22 (21.0%) | 11 (13.1%) | 11 (12.5%) | 8 (12.5%) | 52 (15.2%) |
| *O. osleri* | 4 ( 3.8%) | 2 ( 2.4%) | 2 ( 2.3%) | 2 ( 3.2%) | 10 ( 2.9%) |
| *P. kellicotti* | 4 ( 3.8%) | 1 ( 1.2%) | 2 ( 2.3%) | 1 ( 1.6%) | 8 ( 2.3%) |
| *C. vulpis* | 1 ( 0.9%) | 0 ( 0.0%) | 1 ( 1.1%) | 0 ( 0.0%) | 2 ( 0.6%) |

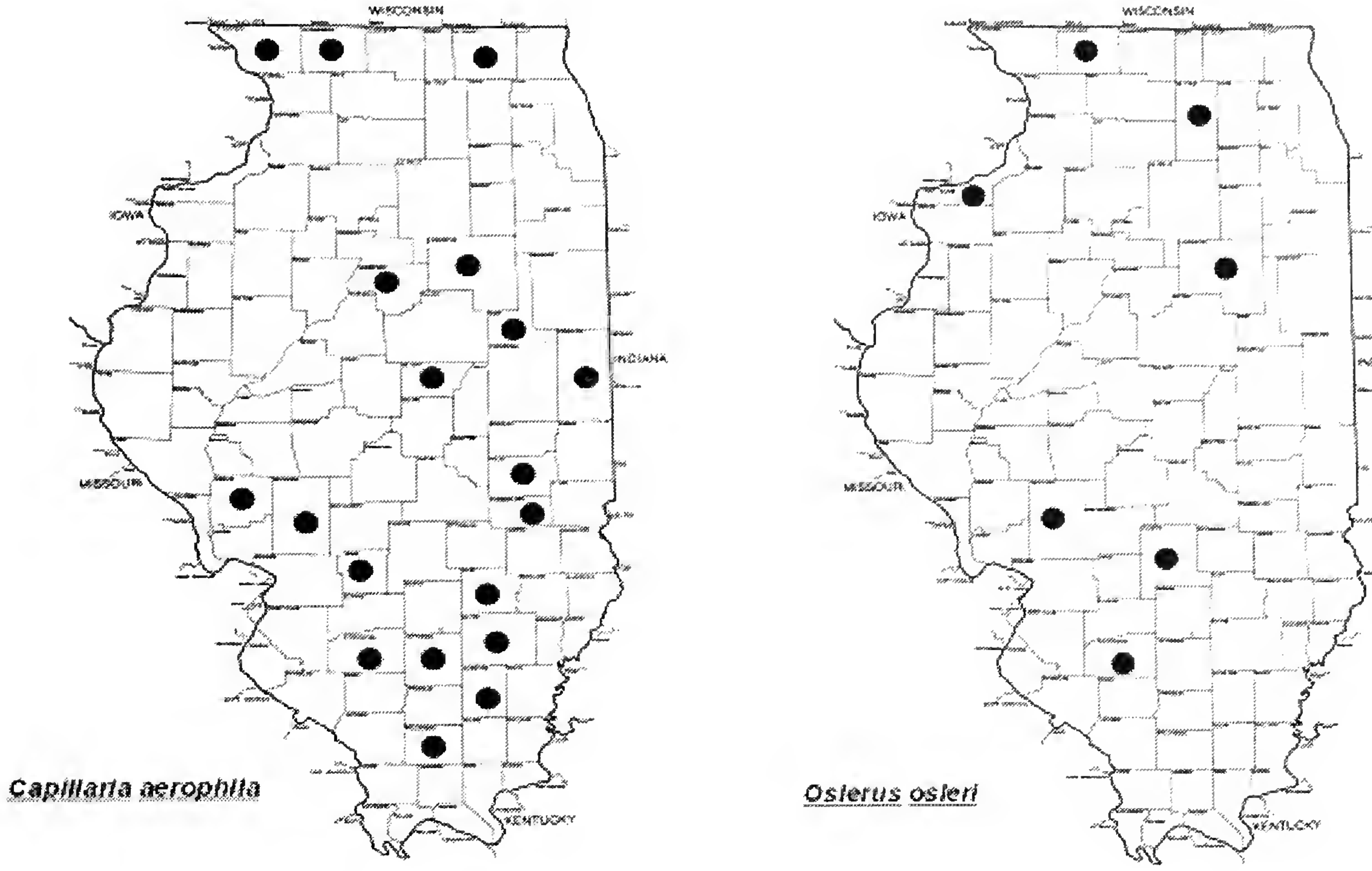
Table 2. Comparisons of body mass and fat indices for lungworm-infected versus uninfected coyotes in Illinois, 1996-97. Standard deviations are shown in parentheses.

| Subsample | N | Mean skinned body weight (kg) | Mean KFI[1] | Mean percent marrow fat |
|---|---|---|---|---|
| Uninfected males | 131 | 11.3[2] (2.0) | 47 (20) | 88.4 (4.9) |
| Infected males | 35 | 10.4 (2.0) | 42 (17) | 87.8 (4.0) |
| Uninfected females | 104 | 9.2 (2.1) | 50 (23) | 90.8 (3.7) |
| Infected females | 23 | 9.0 (2.0) | 52 (28) | 90.6 (4.5) |

[1] Kidney fat index = (weight of kidney fat / weight of kidneys) x 100.

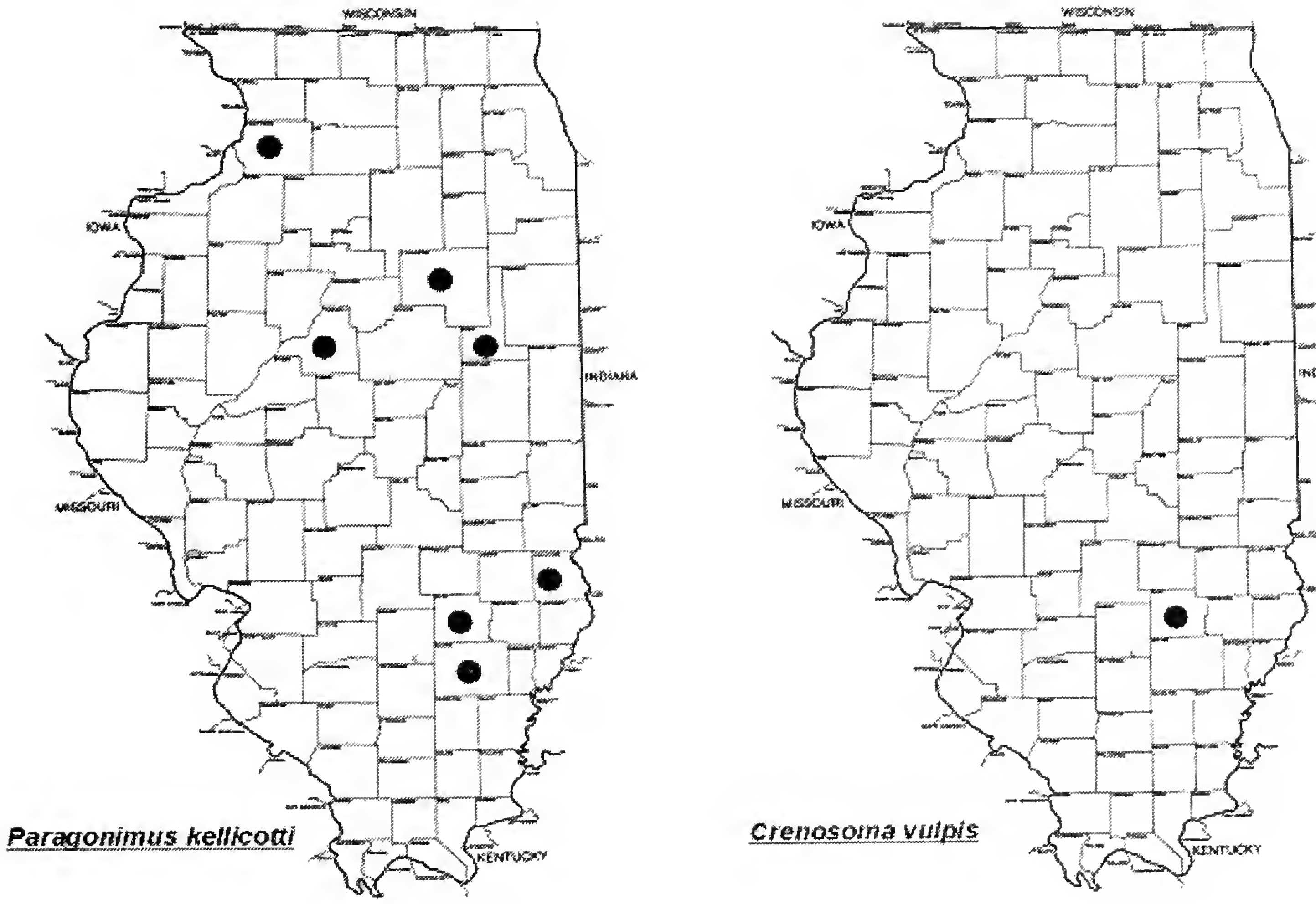
[2] Mean body weights of males differs significantly at $\alpha = 0.05$.

Figure 1. Distribution maps for 4 lungworm species found in coyotes collected from Illinois during 1996-97.



*Capillaria aerophila*

*Oslerus osleri*



*Paragonimus kellicotti*

*Crenosoma vulpis*

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# Social Relationships of White-Tailed Deer In Illinois

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## ABSTRACT

Social relationships of 633 marked white-tailed deer (*Odocoileus virginianus*) were studied on 3 areas in central and northern Illinois, 1980-1993, where landscapes are dominated by agriculture. Deer showed some unique social behaviors including formation of large mixed sex groups following crop harvest that remained intact until spring, much higher spring dispersal of female fawns and yearlings, and higher associations of yearlings with maternally related deer in summer and early fall compared with deer observed in southern Illinois. Other intraspecfic associations and behaviors were similar to those described for deer in the more wooded parts of Illinois. Dispersals of both sexes into areas devoid of deer in the spring remains an important aspect of hunting success in central and northern Illinois each fall.

## INTRODUCTION

Social relationships enable white-tailed deer to maximize their individual fitness through intraspecific competition as they mature (Hirth 1977). Such behavior is directed at others to alter behaviors such as spacing, access to various resources and, with kin, to promote cohesiveness among group members (Brant 1992). Male and female deer have different life history strategies with a male's reproductive success measured by the number of females he can breed while a female's success depends on the number of young she can recruit into the population (Clutton-Brock et al. 1982). Deer behaviors and social relationships have evolved to promote these objectives within the limitations imposed by their environment.

Hawkins and Klimstra (1970) have identified the basic social groupings of deer in southern Illinois with the primary association that of mother and fawn(s). As fawns mature, males generally leave their natal range after family breakup and avoid their female relatives during the breeding season, while females that do not disperse continue to associate, at least occasionally, with their female relatives (Hawkins and Klimstra 1970, Hirth 1977).

However, where deer must cope with landscapes providing limited permanent cover in winter-early spring and where deer densities are high, social relationships may differ from areas where forests are abundant (Hirth 1977). Hirth (1977) observed more aggregations of mixed sex groups of white-tailed deer throughout the year in south Texas compared with deer observed in a more wooded area in Michigan. In much of Illinois and throughout the Midwestern Agricultural Region, where woody cover is often sparse, the annual cycle of growth and destruction of the "corn forest" creates and then destroys thousands of hectares of food producing cover (Gladfelter 1984). In central and northern Illinois this represents several million acres (Iverson et al. 1989). Deer must adjust socially to this expansion and contraction of habitat where for 8–9 months they are crowded together within the existing forest cover. Do social interactions among sex and age groups change because of the adjustments deer must make seasonally to varying amounts of cover? Do social interaction frequencies differ seasonally by gender and age? Finally, does the fragmented landscape of central and northern Illinois affect emigration rates of both sexes? We examine social relationships observed among deer living in the intensively farmed landscapes of central and northern Illinois and compare these relationships with those described in a previous study of deer life history in southern Illinois (Hawkins and Klimstra 1970).

## STUDY AREAS

Between 1980 and 1993, 633 deer were marked November-April using rocket-powered or drop nets (Hawkins et al. 1968) on study areas in east-central (Piatt county, 1980-85), west-central (Brown and Adam counties, 1990-93), and northern (DeKalb county, 1990-93) Illinois. Each area contained a mix of public and private lands and included a wooded public park, providing deer with abundant diurnal cover, protection from severe winter weather, and a refuge from firearm hunters. These protected core areas were surrounded by privately owned farms dominated by row crops and were hunted by archers or firearm hunters from October to early January (archers) and November–early December (firearm hunters) under "any sex" regulations.

The 2,953-ha east-central site consisted of 64% row crops and 36% forest located in within Piatt County, only 2.4% forested in 1985 (Iverson et al. 1989). The 5,942-ha west-central study area was 52% forest, 39% row crops, 5% pasture, and 3% tame hay fields or restored prairie. The surrounding counties were about 20% forested in 1985. The 1,648-ha northern site was 59% row crops, 14% second-growth hardwood forest, 7% tallgrass prairie, 6% mixed species pine plantations, and 5% savanna. Nine percent consisted of a small suburban area, a golf course, and a 128-ha lake. Dekalb County was only 1.6% forested at the time of our study.

Corn and soybeans were planted in about a 50:50 ratio on each area. Following harvest, most fields were disced or chisel plowed further reducing winter-spring food resources and cover.

Hunters concentrated on harvesting antlered males, resulting in high survival of females and increasing numbers of deer on each study area (Nixon et al. 2001). Deer density averaged 10–12/km$^2$ on the northern area, 12–25/km$^2$ on the west-central area, and 4–6/km$^2$ on the east-central area during our studies (Nixon et al. 1995).

## METHODS

Captured deer were aged as fawn (< 1 year), yearling (12–24 months), or adult (≥ 25 months) using tooth replacement and wear (Severinghaus 1949). Live deer can be aged up through 2 years based on tooth replacement and wear of their premolars. Females were marked with plastic collars bearing reflective numbers or cattle-type plastic ear tags and males with metal ear tags, colored plastic ear streamers, or numbered cattle-type plastic ear tags. A subset of each sex (51 males, 137 females) were marked with radio collars, with selection of radio marked deer based on the number of radios active at the time and the availability of new radios for deer on each study area. The marking of family groups were often a priority on each area.

Social relationships of marked deer were determined from observations made daily on the Piatt and Brown-Adams study areas and weekly on the DeKalb study area. We include here only observations where we obtained a complete count of deer present during each encounter. Deer were considered unrelated if there was aggression between marked individuals or if deer ignored one another. Maternally related deer were those that were marked and traveled together, did not manifest aggression, and were often seen grooming each other.

All births were assumed to occur June 1. The year was divided into intervals differing in the life history stresses that would affect social contacts. These intervals were June–September (parturition and caring for young fawns for females and antler growth and weight gain for males), October–November (breeding), and December–May (winter-spring foraging, advancing pregnancy and recovery from breeding activities). In Illinois, fawn females often breed at 6–8 months old (Nixon et al. 1995), and a pregnancy for these fawn females was determined from blood progesterone levels (Wood et al. 1986) or from frequent observations of these females as yearlings during late summer into fall. Virtually all yearling and adult females breed each year in Illinois (Pederson 1982, Nixon et al. 1991). Yearling males may engage in breeding activities (Marchinton and Hirth 1984, Sorin 2004) but are often excluded by more dominant older males (Miller et al. 1987).

The frequency of observations among maternally related and unrelated deer was compared seasonally using Chi-square likelihood ratios (Sokal and Rohlf 1995). When multiple comparisons of observations among the sexes and various ages were made, two-tailed tests were adjusted using the Bonferroni correction, resulting in significance levels of 0.012 or 0.017, the level used dependant on the number of comparisons made for the same sex and age class (Holm 1979).

## RESULTS

Crop harvests coincided with the breeding season. Family groups remained relatively discrete at this time as males continually searched for females in estrous. These family groups interacted socially when feeding on crop fields but usually bedded apart. Females approaching or experiencing estrous were usually alone or with a mature male, often with 1 or more attendant yearling males present but unable to mate. Once she was bred, any living fawns quickly rejoined her. Postbreeding, with crops removed and crop fields barren of cover, family groups and antlered males began forming large mixed sex aggregations (up to 80 deer) usually led by a mature doe that fed and bedded together from late December to late February or early March.

In the spring, after breakup of these large groups, pregnant females reduced their home range to a parturition site and drove away their fawns of the previous year. This family breakup resulted in a spring-early summer dispersal of these yearlings of both sexes. Marked male dispersals averaged 57%, 78%, and 68% and marked female dispersals averaged 49%, 22%, and 45% from the east-central, west-central, and northern study areas, respectively. While the bulk of emigration occurred in the late spring, there was an additional dispersal in fall among males only (75% in spring, 25% in the fall). Following parturition, females fed and bedded alone or with their fawns throughout the summer into early fall.

### Social interactions

Fawn males were somewhat less likely to be seen with their mother than were fawn females during June–November, but they were equally likely to be with their mother December–May (Tables 1 and 2). Male fawns were also more likely to be seen alone during fall than were female fawns. When not alone, male fawns were more likely to be with male siblings October–May than with female siblings (Table 1). Fawn females were seen with their mother about half of all observations throughout the year. Fawn females also associated with siblings of both sexes at about the same level throughout the year (Table 2).

Yearling males spent about the same amount of time with their mother throughout the year (Table 1) but were more likely to be seen alone during the fall than were female yearlings ($X^2$ = 25.3, df = 1,386, P < 0.0001). Yearling males were much more likely to be with a brother in summer than with either mother or sister (53% of summer observations with a brother, 28% with a sister, and only 12% with their mother, $X^2$ = 53.6, df = 2,803, P < 0.0001). They avoided their sister during the breeding season ($X^2$ = 7.5, df = 1,383, P < 0.007), when they were usually seen alone. During post-breeding, they spent most of their time in company with other yearling or adult males (Table 1).

We found that barren and pregnant female yearlings were about equally likely to associate with their mother during June-September (P > 0.05), but barren females were more likely to be seen with mother from October through May ($X^2$ = 43.4, df = 1,877, P < 0.0001) (Table 2). Parous yearling females were more likely to be seen alone during June-September than were barren females, who were more likely to associate with brothers ($X^2$ = 8.1, df = 1,342, P < 0.004) or sisters ($X^2$ = 12.7, df = 1,342, P < 0.0004) during this interval.

Adult males ignored their mother and other relatives throughout the year, associated with unrelated adult females only during the breeding season and were most often seen alone or with other unrelated males (Table 1). During late spring and summer, these adult males left their winter range and ventured into crop fields devoid of woody cover and separated from females. For 6 adults on the east-central area, these movements averaged 1.2 km; 3 adults on the northern area averaged 0.65 km away from their winter-spring range. They were usually alone or with 1 or more males on these summer ranges (Table 1).

During June–September, 2-year-old females were usually alone and less likely to associate with their mother than were parous yearlings ($X^2 = 6.9$, df = 1,514, $P < 0.009$). During December–May, 2-year-old females were also less likely to associate with a sister ($X^2 = 10.7$, df = 1,1175, $P < 0.001$) than were parous yearlings.

Females > 3 years old were less likely to associate with their mother throughout the year (all seasons, $P < 0.002$) compared with 2-year-old females, but were as likely to be alone during the parturition season (32% for 2-year-old and 31% for 3-year-old females). These older females were also less likely to be alone during the breeding season compared to 2-year-old does ($X^2 = 7.07$, df = 1,735, $P < 0.007$). Fawns of older females seem to be more active, with less time spent hiding compared with fawns of 2-year-old does, perhaps because these more dominant females could better defend these active fawns from other deer.

## DISCUSSION

The basic social interactions observed by us were similar to those reported by Hawkins and Klimstra (1970) as occurring among deer in southern Illinois (primary association of mother and fawns, family breakup in late spring, male groups forming post breeding, regrouping of maternally related females in the fall and winter). However, the restrictions imposed on deer by the fragmented landscapes of central and northern Illinois have created conditions for some behaviors unique to the agriculturally dominated Midwest. These include: (A) formation of large intact feeding and bedding groups of mixed sex following crop harvest. This behavior has been observed in South Dakota (Sparrowe and Springer 1970),. Iowa (Zagata and Haugen 1973), and Missouri (Zwank et al. 1979). Hawkins and Klimstra (1970) observed smaller feeding groups of 25–30 deer that separated frequently from day-to-day. The feeding association of mixed sex groups in Illinois was similar to associations observed in south Texas, an area of large openings in the landscape (Hirth 1977); (B) Higher associations of yearling males with their female relatives following family breakup (Table 1). In southern Illinois, yearlings of both sexes had little contact with their dam in summer after family breakup in late spring (Hawkins and Klimstra 1970). The fragmented nature of woody cover and high densities of deer likely resulted in the higher interaction of yearlings with female relatives; (C) Much higher dispersal of females from our study areas compared to southern Illinois where female dispersal averaged only 13% (Hawkins and Klimstra 1970). Aycrigg and Porter (1997) noted a more complex social system occurs where female survival is high and habitat is extensive. Where female survival is lowered and habitat fragmented, female philopatry would be lessened, the situation in much of Illinois (Nixon et al. 2001). Nixon et al. (2007) believed a combination of high female densities and reduced habitats suitable for parturition contributed to this high rate of dispersal among females; (D) Habitat fragmentation and crop harvest facilitates breeding as deer come together within the remaining cover after crop harvest. Fawn production was high on our study areas (Nixon and Etter 1995) and fawn recruitment to one year old was also quite high (Fawn breeders – 0.62-0.78 fawns per doe; yearling breeders – 1.05-1.45 fawns per doe; adult breeders – 1.39-1.79 fawns per doe) (Nixon et al. 1995).

Male fawns are considered to be more independent of family at an earlier age than are female fawns (Schwede et al. 1993). Male fawns are also reported to dominate female siblings beginning at about 6 months old, which may affect their association (Townsend and Bailey 1981) and our male fawns associated more with male siblings during fall and winter (Table 1). Guinness et al. (1979) found that female red deer calves (*Cervus elaphus*) were more frequently seen with their mother than were male calves.

Other studies have indicated that fawns are not often seen with their mother before September (Hawkins and Klimstra (1970). Our data tallies closely with that of southern Illinois wherein 30-40% of the females observed in summer were alone. We did, however, occasionally observe fawns with their mother even in June (Tables 1 and 2). The reduced habitat available on our study areas may have made observations of these young fawns somewhat more likely. The social position of the mother may also affect fawn hiding behavior. Female No. 110, a dominant doe and leader of up to 40 deer in winter, made no effort to isolate herself from other deer pre-or postpartum.. One of her fawns was seen < 48 hours postpartum with 110 amid a group of deer and was later captured and tagged while with 6–8 other females. This suggests that very dominant females may not have to isolate themselves from other females postpartum because they can retrieve any fawn that wanders into the home range of other females before imprinting on their mother, a problem faced by less dominant females (Ozoga et al. 1982).

During summer, yearling males were often associated with their siblings, were alone, or with unrelated yearling males. They also associated more often with their mother (14%) than yearling males observed in southern Illinois (3%, Hawkins and Klimstra 1970). During the breeding season, yearling males were usually alone or with other yearling males

During the prebreeding season, adult males were seen alone or with other adult and yearling males, often well out in crop fields and away from females and fawns. These male associations often persisted all summer and are thought to reduce male aggression in the fall because of dominance hierarchies formed during the spring and summer (Brown 1974). In the fall they were also usually alone and constantly moving throughout their home range except when with adult females. This pattern of behavior is common with Cervidae where the prevailing breeding system is the “tending bond” type where a dominate male attempts to isolate a female during estrous (Clutton-Brock et al. 1982, Kucera 1978, Marchinton and Hirth 1984).

Barren yearling females associated with their mother and other female relatives more often than parous yearlings throughout the year. Maternal success determines the social status of young females (Miller and Ozoga 1997) and our barren females apparently reverted to fawn status in the social hierarchy. They attempted to associate with their mother as soon as she would permit it after her parturition. We observed that these yearlings usually dominated their younger half siblings of both sexes as they traveled together. Guinness et al. (1979) found that barren red deer hinds also were more likely to associate with female relatives than were parous hinds.

Older females (> 3 years) were seen less often with their mother than were 2-year-old females throughout the year. Schwede et al. (1993) also observed that older females avoided their mother during the summer. Clutton-Brock et al. (1982 ) observed that red deer female association with their mother declined with age. They also reported that daughters of dominant mothers spend more time associating with their mothers than daughters with subordinate mothers.

The greater tendency for solitary behavior of male fawns compared to female siblings did not increase male fawn mortality on our study areas (Nixon and Etter 1995). The large numbers of fawns and yearlings dispersing from our areas did impact hunting success over a considerable area. For example, we tracked dispersers over a 40,000 km$^2$ area surrounding the east-central study area (Nixon et al. 1991), frequently onto areas devoid of deer by late spring (Nixon and Hansen 1992). If, as seems likely, such dispersals occur throughout central and northern Illinois, hunters often depend on dispersal behavior to restock many heavily hunted areas each fall (Hansen et al. 1997). The success of such restocking would depend on the distance from a source population and hunting pressures existing from year-to-year. The fall dispersal of yearling males also contributes to harvests as hunters seek antlered males, and these yearlings traverse areas where the dangers are unknown.

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Table 1. Frequency (% of total observations per period) of observations of marked male deer with relatives and strangers during three seasonal periods on three study areas in central and northern Illinois, 1980–1993. Birth date is assumed to be June 1 of the birth year.

| Period | No. marked deer seen per month | Total Observations | Mother | Siblings | | Half Sibling | | Other Relatives | Alone | Strangers | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | M | F | M | F | | | YM | AM | YF | AF |
| Fawn | | | | | | | | | | | | | |
| Jun–Sept | 3-8 | 52 | 35 | 19 | 40 | 0 | 0 | 0 | 6 | | | | |
| Oct–Nov | 8-10 | 21 | 29 | 33 | 14 | 0 | 0 | 0 | 24 | | | | |
| Dec–May | 17-78 | 1,191 | 43 | 24 | 19 | <1 | 7 | 4 | 3 | | | | |
| Yearling | | | | | | | | | | | | | |
| Jun–Sept | 30-37 | 316 | 14 | 10 | 13 | <1 | 5 | 0 | 17 | 20 | 6 | 8 | 6 |
| Oct–Nov | 21-22 | 69 | 11 | 0 | 3 | 0 | 6 | <1 | 48 | 13 | 9 | 3 | 6 |
| Dec–May | 17-25 | 240 | 14 | 4 | <1 | <1 | 5 | 0 | 25 | 26 | 19 | 2 | 5 |
| Adult | | | | | | | | | | | | | |
| Jun–Sept | 10-15 | 80 | 0 | 0 | 0 | 0 | 0 | 0 | 40 | 31 | 24 | 0 | 5 |
| Oct–Nov | 16-23 | 65 | 0 | 0 | 0 | 0 | 0 | 0 | 54 | 5 | 11 | 0 | 31 |
| Dec–May | 13-19 | 220 | <1 | <1 | 0 | 0 | <1 | 0 | 22 | 31 | 42 | 0 | 2 |

Table 2. Frequencies (% of total observations per period) of social contacts by marked female deer (with breeding status) with relatives (other includes aunt, cousin, nephew, niece, grandmother) during three seasonal periods on three study areas in central and northern Illinois, 1980–1993. Birth date is assumed to be June 1 of the birth year.

| | No. marked deer seen per month | Total Observations | Mother | Fawns | | | Sibling | | Half Sibling | | Other Relatives | Alone |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Period | | | | M | F | Unk | M | F | M | F | | |
| Fawn (not breeding) | | | | | | | | | | | | |
| Jun–Sept | 1-5 | 27 | 56 | | | | 22 | 19 | 0 | 3 | 0 | 0 |
| Oct–Nov | 8-10 | 54 | 48 | | | | 15 | 28 | 0 | 7 | 0 | 2 |
| Dec–May | 43-84 | 1,211 | 45 | | | | 21 | 20 | <1 | 3 | 8 | 2 |
| Yearling (barren) | | | | | | | | | | | | |
| Jun–Sept | 17-24 | 154 | 23 | | | | 19 | 14 | <1 | 9 | 14 | 21 |
| Oct–Nov | 14-22 | 109 | 38 | | | | 2 | 6 | 8 | 20 | 14 | 12 |
| Dec–May | 11-23 | 382 | 39 | | | | <1 | 5 | 14 | 25 | 12 | 4 |
| Yearling (parous) | | | | | | | | | | | | |
| Jun–Sept | 20-15 | 168 | 14 | 4 | 1 | 22 | 7 | 3 | 0 | 3 | 2 | 41 |
| Oct–Nov | 19-21 | 96 | 18 | 10 | 12 | 27 | 0 | 11 | 0 | 11 | 2 | 8 |
| Dec–May | 17-26 | 497 | 19 | 8 | 13 | 25 | <1 | 14 | 1 | 8 | 11 | 1 |
| 2 year-old (parous) | | | | | | | | | | | | |
| Jun–Sept | 31-45 | 348 | 7 | 9 | 10 | 29 | 0 | 2 | 1 | 5 | 5 | 32 |
| Oct–Nov | 32-37 | 208 | 5 | 19 | 19 | 33 | 0 | 4 | 1 | 5 | 5 | 9 |
| Dec–May | 27-45 | 680 | 18 | 11 | 16 | 25 | 0 | 8 | 1 | 10 | 9 | 3 |
| ≥3 year-old (parous) | | | | | | | | | | | | |
| Jun–Sept | 61-89 | 1,016 | 2 | 15 | 21 | 26 | 0 | 2 | 0 | <1 | 4 | 31 |
| Oct–Nov | 65-75 | 529 | <1 | 23 | 28 | 33 | 0 | 2 | 0 | 1 | 7 | 4 |
| Dec–May | 59-90 | 2,097 | 2 | 22 | 33 | 17 | 0 | 6 | <1 | 1 | 10 | 4 |

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# Updates to the Distributional Checklist and Status of Illinois Freshwater Mussels (Mollusca: Unionidae)

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## ABSTRACT

Literature reviews and voucher specimens housed in museum collections were examined to update the distributional checklist and status of Illinois freshwater mussels (Mollusca: Unionidae). Data collected includes information for 51 species, including new drainage records for 37 species and status updates for 40 species. Also reported are corrections of seven errors from the last checklist of the freshwater mussels of Illinois.

## INTRODUCTION

A decade has passed since Cummings and Mayer (1997) published a checklist of the freshwater mussels (Mollusca: Unionidae) of Illinois that summarizes the distribution and status of unionids within the state. This article is an updated contribution to that paper, and is a continuation for the preparation of a new Freshwater Mussels of Illinois. Additional collecting and compilation of museum records are still needed to complete that task.

## METHODS

The format of this paper follows Cummings and Mayer (1997). The state was divided into 25 subunits that correspond to the major rivers and drainages within and bordering Illinois (Table 1, Figure 1). Information was updated on the distribution and status of freshwater mussels in each basin with data being taken from literature reviews and voucher specimens housed in museum collections. Any records of live individuals collected after 1969 were considered to indicate that a given species was extant within a given drainage. The species are arranged alphabetically by genus and species within subfamilies. The new distributional data are presented by species and includes 1) state and federal status, if applicable; 2) remarks on historic and current distributions within the state; and 3) comments on new drainage or status records. Numbers following species names indicate updated drainage records, where numbers in **bold** designate that at least one individual of that species was collected alive in the corresponding drainage since 1970 (Table 1, Figure 1). New records for "Galena, Apple, and Plum River Drainages" (#1 in Table 1) are not current due to two ongoing studies in the Wisconsin Driftless

Division in northwestern Illinois: 1) freshwater mussels of the Menominee, Little Menominee, Sinsinawa, and Galena river drainages in Jo Daviess County by J.S. Tiemann (Illinois Natural History Survey), and 2) freshwater mussels of the Apple River drainage in Jo Daviess and Carroll counties by B.E. Sietman (Minnesota Department of Natural Resources) and E.A. Anderson (Illinois Department of Natural Resources). Specimens with catalogue numbers reported herein are housed in the Illinois Natural History Survey Mollusk Collection (INHS) in Champaign or the University of Michigan Museum of Zoology (UMMZ) in Ann Arbor; specimens without catalogue numbers were observed but not vouchered and are cited as "INHS Mollusk Collection."

## RESULTS

### Family Unionidae

Subfamily Ambleminae

*Amblema plicata* (Say, 1817), threeridge. Updated drainage records: **3**, **10**, **16**. The threeridge is generally distributed throughout Illinois (Cummings and Mayer 1997). A live *A. plicata* specimen was discovered in South Branch Larry Creek (Middle Mississippi River tributaries), 5 mi W Ferris at the junction of Co. Rd 1100E and Co. Rd 1900N, Hancock County on 2 August 2000 (INHS 25376). One live *A. plicata* individual was collected in LaMoine River, 3 mi ENE Carthage, Hancock County on 2 October 1991 (Baumgardner 1995). Over a hundred live *A. plicata* individuals were collected in the Cache River, 1.5 mi NW Forman, Johnson County on 4-6 August 1997 (INHS Mollusk Collection). The threeridge has been found alive in 22 drainages in Illinois since 1970 and was historically present in all 25 drainages in the state.

*Elliptio dilatata* (Rafinesque, 1820), spike (state-threatened). Updated drainage records: **2**, **11**, 17, **23**. The spike was historically distributed throughout Illinois, and was thought to be alive only in the Fox, Kankakee, Vermilion of the Illinois, Sangamon, Kaskaskia, and Little Wabash river drainages in the state (Cummings and Mayer 1997). A live *E. dilatata* specimen was discovered in the Rock River, 2 mi SE Rockton at the Hononegah Forest Preserve, Winnebago County on 25 August 2005 (INHS Mollusk Collection). Two live *E. dilatata* individuals were collected in the Mackinaw River, 3.5 mi NE Congerville at the Chinquapin Bluff Nature Preserve, Woodford County on 31 August 2001 (INHS 25833). A recent-dead *E. dilatata* specimen was found in Big Grand Pierre Creek (Ohio River tributaries), 1 mi NE Blackman Cemetery, Pope County on 15 June 2002 (INHS 27666). A live *E. dilatata* individual was found in the Mississippi River, Cordova, Rock Island County on 24 July 2001 (INHS Mollusk Collection). The spike has been collected alive in nine drainages in Illinois since 1970 and was historically present in 21 drainages in the state.

*Fusconaia ebena* (Lea, 1831), ebonyshell (state-threatened). Updated drainage records: **19**, **22**. The ebonyshell was historically distributed in the larger streams in Illinois, and was thought to be alive only in the Ohio, Mississippi, and Wabash rivers in the state (Cummings and Mayer 1997). A live *F. ebena* individual was collected in the Little Wabash River, 4 mi S Golden Gate at the Saxe Bridge, Wayne County on 22 August 2002 (INHS 27514). A live *F. ebena* specimen was found in the Illinois River, 2 mi SW Meredosia, Morgan County on 14 August 2002 (INHS 27946). The ebonyshell has been collected alive in five drainages in Illinois since 1970 and was historically present in 11 drainages in the state.

*Fusconaia flava* (Rafinesque, 1820), Wabash pigtoe. Updated drainage records: **10**, 17. The Wabash pigtoe is generally distributed throughout Illinois (Cummings and Mayer 1997). A live *F. flava* individual was discovered in the East Fork LaMoine River, 3 mi W Macomb at the Co. Rd 900N Bridge, McDonough County on 16 July 1997 (INHS 21612). A recent-dead *F. flava* specimen was found in Big Grand Pierre Creek (Ohio River tributaries), 1.5 mi SSE Herod near the Blackman Road Bridge, Pope County on 31 August 2000 (INHS 25207). The Wabash pigtoe has been collected alive in 16 drainages in Illinois since 1970 and was historically present in 23 drainages in the state.

*Megalonaias nervosa* (Rafinesque, 1820), washboard. Updated drainage records: 2, 10, **16**. The washboard is sporadically distributed in the larger streams in Illinois (Cummings and Mayer 1997). A relict *M. nervosa* valve was encountered in the Rock River, Milan, Rock Island County on 16-17 May 1988 (INHS 23324). A relict *M. nervosa* specimen was found in the East Fork LaMoine River drainage, 3 mi WSW Bushnell at the Co. Rd 1700N Bridge, McDonough County on 31 July 1990 (Baumgardner 1995). A live *M. nervosa* individual was found in the Cache River, 1 mi NE Belknap, Johnson County on 26 September 1997 (INHS 21671). The washboard has been collected alive in 11 drainages in Illinois since 1970 and was historically present in 16 drainages in the state.

*Plethobasus cooperianus* (Lea, 1834), orangefoot pimpleback (state-endangered, federally-endangered). Updated drainage record: 25. The orangefoot pimpleback is extant in what was thought to be its only know historical drainage, the Ohio River, in Illinois (Cummings and Mayer 1997). A relict *P. cooperianus* specimen was collected in the Wabash River, White County in 1885 (no specific locality or date data were given; INHS 22581). This individual, initially catalogued as *Quadrula pustulosa*, was recently transferred to the INHS Mollusk Collection from the A.A. Hinkley Collection at the University of Illinois Museum of Natural History, Champaign. The orangefoot pimpleback has been collected alive in one drainage in Illinois since 1970 and was historically present in two drainages in the state.

*Pleurobema clava* (Lamarck, 1819), clubshell (state-endangered, federally-endangered). Updated drainage records: 20, **22**, 24. The clubshell was historically distributed throughout the Wabash River drainage in Illinois, and was thought to be extirpated from the state (Cummings and Mayer 1997). A relict *P. clava* valve was collected in the Embarras River, 1.5 mi SW Timothy, Cumberland County on 30 October 1998 (INHS 22609). A live *P. clava* was discovered in the North Fork Vermilion River of the Wabash River drainage (Szafoni et al. 2000). A relict *P. clava* valve was located in the Ohio River, Metropolis at Fort Massac State Park, Massac County on 24 September 1999 (INHS 24135). The clubshell has been collected alive in one drainage in Illinois since 1970 and was historically present in four drainages in the state.

*Pleurobema cordatum* (Rafinesque, 1820), Ohio pigtoe (state-endangered). Updated drainage record: 19. The Ohio pigtoe was historically widely distributed in the Wabash and Ohio rivers in Illinois, but is now alive only in the Ohio River in the state (Cummings and Mayer 1997). A relict *P. cordatum* specimen was collected in the Little Wabash

River, Carmi at the Ill. Rte 1 Bridge, White County on 13 August 1997 (INHS 20766). The Ohio pigtoe has been collected alive in one drainage in Illinois since 1970 and was historically present in three drainages in the state.

*Pleurobema rubrum* (Rafinesque, 1820), pyramid pigtoe (state-extirpated). Updated drainage record: 2, 12. The pyramid pigtoe was historically known to inhabit the Ohio River drainage and the Illinois River in Illinois, and is likely extirpated from the state (Cummings and Mayer 1997). A relict *P. rubrum* valve was found in the Rock River, 2 mi SW Byron, Ogle County on 27 August 1996 (INHS 18829). A relict *P. rubrum* valve was found in Salt Creek (Sangamon River drainage), Lincoln at the I-55 Business bridge, Logan County on 22 June 2006 (INHS 31227). The pyramid pigtoe has not been collected alive since pre-1970 in Illinois and was historically present in six drainages in the state.

*Pleurobema sintoxia* (Rafinesque, 1820), round pigtoe. Updated drainage records: **22**, **23**. The round pigtoe is occasionally found in northern Illinois (Cummings and Mayer 1997), and is expanding its range in the Illinois River drainage (Sietman et al. 2001). One live *P. sintoxia* individual was collected in the Illinois River, 4 mi SSW Minooka downstream of Big Dresden Island, Grundy County on 4 May 1999 (INHS 23881). Two live *P. sintoxia* specimens were discovered in the Mississippi River, Pool 15 near Campbell Island, Rock Island County on 24 July 1998 (INHS 22894). The round pigtoe has been collected alive in 12 drainages in Illinois since 1970 and was historically present in 17 drainages in the state.

*Quadrula nodulata*, (Rafinesque, 1820), wartyback. Updated drainage records: 10, 13, 17, **18**. The wartyback is generally found in the larger streams in Illinois, but also can be sporadically found in the downstream reaches of the larger tributaries to those rivers (Cummings and Mayer 1997). A relict *Q. nodulata* specimen was found in the East Fork LaMoine River drainage, 3 mi WSW Bushnell at the Co. Rd 1700N Bridge, McDonough County on 31 July 1990 (Baumgardner 1995). Two relict valves were found in Clear Creek of the Indian Creek drainage (Lower Illinois River tributaries), 4 mi SSE Beardstown at the Burlington Northern Railroad Bridge, Cass County on 22 May 1996 (INHS 19438). A relict *Q. nodulata* valve was discovered in Big Creek (Ohio River tributaries), 1.5 mi SW Elizabethtown at the Ill. Rte 146 Bridge, Hardin County on 28 June 2001 (INHS 25697). Seven live *Q. nodulata* individuals were collected in the Saline River, 9 mi W Shawneetown at the Ill. Rte 1 Bridge, Gallatin County on 21 June 2005 (INHS 30545). The wartyback has been collected alive in ten drainages in Illinois since 1970 and was historically present in 15 drainages in the state.

*Quadrula pustulosa* (Lea, 1831), pimpleback. Updated drainage records: **10**, 17, **18**. The pimpleback is generally distributed throughout Illinois (Cummings and Mayer 1997), and is expanding its range in the Illinois River drainage (Sietman et al. 2001). Four live *Q. pustulosa* specimens were discovered in the East Fork LaMoine River, 3 mi W Macomb at the Co. Rd 900N Bridge, McDonough County on 16 July 1997 (INHS 21616). A recent-dead *Q. pustulosa* specimen was found in Bay Creek (Ohio River tributaries), 1.5 mi W Homberg at the Homberg Bridge, Pope County on 7 July 2000 (INHS 28691). One live *Q. pustulosa* individual was collected in the Saline River, 9 mi W Shawneetown at the Ill. Rte 1 Bridge, Gallatin County on 21 June 2005 (INHS 30545). The pimpleback has been collected alive in 18 drainages in Illinois since 1970 and was historically present in 21 drainages in the state.

*Quadrula quadrula* (Rafinesque, 1820), mapleleaf. Updated drainage records: **10**, **16**. The mapleleaf is generally distributed throughout Illinois (Cummings and Mayer 1997). Four live *Q. quadrula* individuals were collected in the East Fork LaMoine River, 3 mi W Macomb at the Co. Rd 900N Bridge, McDonough County on 16 July 1997 (INHS 21616). Eight live *Q. quadrula* individuals were found in the Cache River, 1 mi NE Belknap, Johnson County on 26 September 1997 (INHS 21673). The mapleleaf has been collected alive in 23 drainages in Illinois since 1970 and was historically present in 24 drainages in the state.

*Tritogonia verrucosa* (Rafinesque, 1820), pistolgrip. Updated drainage record: **10**. The pistolgrip is sporadically distributed throughout Illinois (Cummings and Mayer 1997), and is expanding its range in the Illinois River drainage (Sietman et al. 2001). A live *T. verrucosa* specimen was collected in Camp Creek (LaMoine River drainage), 5 mi S Fandon at the Co. Rd 800E Bridge, McDonough County on 18 September 2002 (INHS 27806). The pistolgrip has been collected alive in 16 drainages in Illinois since 1970 and was historically present in 21 drainages in the state.

*Uniomerus tetralasmus* (Say, 1831), pondhorn. Updated drainage records: **3**, 4, **14**, **20**. The pondhorn is typically found in small streams in Illinois (Cummings and Mayer 1997). A live *U. tetralasmus* specimen was found in Bay Creek (Middle Mississippi River tributaries), 1.5 mi E Pittsfield at the Ill. Rte 106 Bridge, Pike County on 7 July 1998 (INHS 21931). A relict *U. tetralasmus* valve was located in Spring Brook of the DuPage River basin (Des Plaines River drainage) in the Blackwell County Forest Preserve in Warrenville, DuPage County on 1 October 2004 (INHS 30361). Four live *U. tetralasmus* individuals were found in Jonathon Creek (Kaskaskia River drainage), 3 mi E Sullivan at the Ill. Rte 121 Bridge, Moultrie County on 2 August 2002 (INHS 27205). Live *U. tetralasmus* were found in 2004 throughout Brouilletts Creek, a Wabash River tributary (Tiemann 2005). The pondhorn has been collected alive in 14 drainages in Illinois since 1970 and was historically present in 20 drainages in the state.

Subfamily Anodontinae

*Alasmidonta viridis* (Rafinesque, 1820), slippershell mussel (state-threatened). Updated drainage records: **2**, **4**, 6, **20**. The slippershell mussel is sporadically distributed in northern Illinois (Cummings and Mayer 1997). Two live *A. viridis* specimens were found in Piscasaw Creek (Rock River drainage), 3 mi SW Chemung at the Streit Road Bridge, McHenry County on 19 August 1996 (INHS Mollusk Collection). One live *A. viridis* specimen was collected in Hickory Creek (Des Plaines River drainage), near New Lenox, in Will County in the 1970-80s (INHS 9599). A relict *A. viridis* valve was discovered in Big Bureau Creek (Middle Illinois River tributaries), 2.5 mi WNW Bureau, Bureau County on 30 September 2004 (INHS 29910). One live *A. viridis* individual was found in the Embarras River, 2 mi SE Hugo near the Co. Rd 1900E Bridge, Douglas County on 6 September 2001 (INHS Mollusk Collection). The slippershell mussel has been collected alive in eight drainages in Illinois since 1970 and was historically present in 16 drainages in the state.

*Anodonta suborbiculata* Say, 1831, flat floater. Updated drainage record: 10. The flat floater is occasionally encountered in lentic waters including floodplain ponds and quiet backwaters of large streams in Illinois (Cummings and Mayer 1997), and is expanding its range in the Illinois River drainage (Sietman et al. 2001). A recent-dead *A. suborbiculata* specimen was found in a wetland in the LaMoine River drainage, 1.5 mi SW Briggs Landing, Brown County on 5 August 2005 (INHS 30569). The flat floater has been collected alive in nine drainages in Illinois since 1970 and was historically present in 17 drainages in the state.

*Anodontoides ferussacianus* (Lea, 1834), cylindrical papershell. Updated drainage records: **6**, 10, **14**. The cylindrical papershell is commonly distributed in small streams in northeastern Illinois (Cummings and Mayer 1997). A live *A. ferussacianus* individual was collected in Big Bureau Creek (Middle Illinois River tributaries), 2.5 mi SW Compton at the Carnahan Road Bridge, Lee County on 1 May 2002 (INHS 28548). A relict *A. ferussacianus* valve was discovered in the LaMoine River, 4.5 mi SW Bushnell at the Co. Rd 1650N Bridge, McDonough County on 1 August 2005 (INHS Mollusk Collection). A live *A. ferussacianus* specimen was collected in East Fork Shoal Creek (Kaskaskia River drainage), 2 mi SE Coffeen at the Ill. Rte 185 Bridge, Montgomery County on 5 September 2002 (INHS 27436). The cylindrical has been collected alive in 14 drainages in Illinois since 1970 and was historically present in 19 drainages in the state.

*Arcidens confragosus* (Say, 1829), rock pocketbook. Updated drainage record: **16**. The rock pocketbook is generally distributed in the larger streams in southern Illinois (Cummings and Mayer 1997). Fifteen live *A. confragosus* individuals were collected alive in the Cache River, 1.5 mi NW Forman, Johnson County on 4-6 August 1997 (INHS Mollusk Collection). The rock pocketbook has been collected alive in nine drainages in Illinois since 1970 and was historically present in 13 drainages in the state.

*Lasmigona complanata* (Barnes, 1823), white heelsplitter. Updated drainage records: **6**, 17. The white heelsplitter is one of the most widespread and common unionids in Illinois (Cummings and Mayer 1997). One live *L. complanata* specimen was found in Big Bureau Creek (Middle Illinois River tributaries), 1.25 mi NW Dover at the confluence Master's Fork, Bureau County on 30 September 2004 (INHS 29916). A relict *L. complanata* specimen was discovered in Bay Creek (Ohio River tributaries), Grantsburg at the Ill. Rte 146 Bridge, Johnson County on 3 July 2002 (INHS 27481). The white heelsplitter has been collected alive in 23 drainages in Illinois since 1970 and was historically present in 24 drainages in the state.

*Lasmigona compressa* (Lea, 1829), creek heelsplitter. Updated drainage records: **13**, **20**. The creek heelsplitter is occasionally found in small streams in northern Illinois (Cummings and Mayer 1997). One live *L. compressa* specimen was discovered in Holiday Lake (Lower Illinois River tributaries drainage) near Holiday Shores, Madison County on 28 June 2004 (INHS 28775). Live *L. compressa* were found in 2004 throughout Brouilletts Creek, a Wabash River tributary (Tiemann 2005). The creek heelsplitter has been collected alive in 11 drainages in Illinois since 1970 and was historically present in 17 drainages in the state.

*Lasmigona costata* (Rafinesque, 1820), flutedshell. Updated drainage record: **22**. The flutedshell is sporadically distributed in northern Illinois and is presently found in about half of its historical drainages in the state (Cummings and Mayer 1997); however, it is expanding its range in the Illinois River drainage (Sietman et al. 2001). One live *L. costata* specimen was found in the Illinois River, 4 mi SSW Minooka downstream of Big Dresden Island, Grundy County on 4 May 1999 (INHS 23876). The flutedshell has been collected alive in ten drainages in Illinois since 1970 and was historically present in 17 drainages in the state.

*Pyganodon grandis* (Say, 1829), giant floater. Updated drainage record: **6**. The giant floater is the most widespread and common unionid in Illinois (Cummings and Mayer 1997). A live *P. grandis* specimen was found in Big Bureau Creek (Middle Illinois River tributaries), 3 mi SW LaMoille, Bureau County on 1 October 2004 (INHS Mollusk Collection). The giant floater has been collected alive in all 25 drainages in Illinois since 1970 .

*Strophitus undulatus* (Say, 1817), creeper. Updated drainage records: **4**, **6**, **10**. The creeper is generally distributed throughout Illinois (Cummings and Mayer 1997), and is expanding its range in the Illinois River drainage (Sietman et al. 2001). One live *S. undulatus* individual was found in the DuPage River (Des Plaines River drainage), Plainfield at the Ill. Rte 59 Bridge, Will County on 7 August 1990 (INHS Mollusk Collection). A live *S. undulatus* specimen was found in Big Bureau Creek (Middle Illinois River tributaries), 3 mi SW LaMoille, Bureau County on 1 October 2004 (INHS 29923). Two live *S. undulatus* individuals were collected in the LaMoine River, 4.5 mi SW Bushnell at the Co. Rd 1650N Bridge, McDonough County on 1 August 2005 (INHS 30621). The creeper has been collected alive in 19 drainages in Illinois since 1970 and was historically present in 22 drainages in the state.

*Utterbackia imbecillis* (Say, 1829), paper pondshell. Updated drainage records: **4**, **11**, **13**, **21**. The paper pondshell is generally distributed throughout Illinois (Cummings and Mayer 1997). One live *U. imbecillis* individual was found in Powder Horn Lake (Calumet River drainage), 0.5 mi N Calumet City, Cook County on 24 August 2002 (INHS 27089). One live *U. imbecillis* individual was collected in Panther Creek (Mackinaw River drainage), 1.5 mi S Secor at the Co. Rd 800N Bridge, Woodford County on 30 August 2005 (INHS Mollusk Collection). Five live *U. imbecillis* specimens were discovered in Holiday Lake (Lower Illinois River tributaries drainage) near Holiday Shores, Madison County on 28 June 2004 (INHS 28778). Two live *U. imbecillis* individuals were found in the Little Vermilion River of the Wabash River drainage, 1 mi S Georgetown at the Ill. Rte 1 Bridge, Vermilion County on 4 September 1997 (INHS 20018). The paper pondshell has been collected alive in 21 drainages in Illinois since 1970 and was historically present in 23 drainages in the state.

### Subfamily Lampsilinae

*Cyprogenia stegaria* (Rafinesque, 1820), fanshell (state-endangered, federally-endangered). Updated drainage record: 21. The fanshell was historically known to inhabit the Ohio River and the Wabash River drainage in Illinois, but is now alive only in the Wabash River in the state (Cummings and Mayer 1997). A relict *C. stegaria* valve was discovered in the Vermilion River of the Wabash River drainage, 4.25 mi E Westville, Vermilion County on 6 October 1997 (INHS 21625). The fanshell has been collected alive in one drainage in Illinois since 1970 and was historically present in five drainages in the state.

*Ellipsaria lineolata* (Rafinesque, 1820), butterfly (state-threatened). Updated drainage records: **2**, 20. The butterfly was historically distributed in the larger streams in Illinois, and was thought to be alive only in the Illinois, Mississippi, and Ohio rivers in the state (Cummings and Mayer 1997). Three live *E. lineolata* specimens were found in the Rock River, Milan near the Milan Dam, Rock Island County on 25 August 2003 (INHS Mollusk Collection). Three relict *E. lineolata* valves were discovered in the Embarras River, 1 mi E Lawrenceville at the Business Rte 50 Bridge, Lawrence County on 13 September 2001 (INHS 26099). The butterfly has been collected alive in four drainages in Illinois since 1970 and was historically present in nine drainages in the state.

*Epioblasma triquetra* (Rafinesque, 1820), snuffbox (state-endangered). Updated drainage record: 5. The snuffbox was historically distributed in the larger streams in Illinois, but is now alive only in the Embarras River in the state (Cummings and Mayer 1997). Schanzle et al. (2004) reported collecting a relict *E. triquetra* valve in Nippersink Creek (Fox River drainage) near Spring Grove at the Richardson Road Bridge, McHenry County on 12 June 1997 (INHS 20037). The snuffbox has been collected alive in one drainage in Illinois since 1970 and was historically present in 14 drainages in the state.

*Lampsilis abrupta* (Say, 1831), pink mucket (state-endangered, federally-endangered). Updated drainage records: 25. The pink mucket is likely extirpated from Illinois since it has not been collected alive in the state in over 40 y; it was thought to be known from only the Ohio River in the state (Cummings and Mayer 1997). Relict *L. abrupta* valves were discovered in the Wabash River, Rochester, Wabash County on 14 September 1998 (INHS 24365). The pink mucket has not been collected alive in Illinois since pre-1970 and was historically present in two drainages in the state.

*Lampsilis cardium* Rafinesque, 1820, plain pocketbook. Updated drainage records: **10**, **24**. The plain pocketbook is generally distributed throughout Illinois (Cummings and Mayer 1997), and is expanding its range in the Illinois River drainage (Sietman et al. 2001). Three live *L. cardium* individuals were collected in the East Fork LaMoine River, 3 mi W Macomb at the Co. Rd 900N Bridge, McDonough County on 16 July 1997 (INHS 21613). One live *L. cardium* specimen was collected in the Ohio River, 4 mi SE Olmsted, Pulaski County on 15 August 2002 (INHS Mollusk Collection). The plain pocketbook has been collected alive in 20 drainages in Illinois since 1970 and was historically present in 22 drainages in the state.

*Lampsilis siliquoidea* (Barnes, 1823), fatmucket. Updated drainage records: **6**, **10**, 18, **23**. The fatmucket is commonly found throughout Illinois (Cummings and Mayer 1997), and is expanding its range in the Illinois River drainage (Sietman et al. 2001). Ten live *L. siliquoidea* specimens were found in Big Bureau Creek (Middle Illinois River tributaries), 1.25 mi NW Dover at the confluence Master's Fork, Bureau County on 30 September 2004 (INHS 29915). One live *L. siliquoidea* individual was collected in the East Fork LaMoine River, 3 mi W Macomb at the Co. Rd 900N Bridge, McDonough County on 16 July 1997 (INHS 21614). A relict *L. siliquoidea* valve was discovered in the North Fork

Saline River, 1.5 mi E Broughton at the Co. Rd 200N Bridge, Hamilton County on 3 July 2003 (INHS 28821). One live *L. siliquoidea* specimen was discovered in the Mississippi River, 1.5 mi N Cordova, Rock Island County on 17 September 1999 (INHS Mollusk Collection). The fatmucket has been collected alive in 18 drainages in Illinois since 1970 and was historically present in 24 drainages in the state.

*Lampsilis teres*, (Rafinesque, 1820), yellow sandshell. Updated drainage records: **3**, **16**, 17. The yellow sandshell is occasionally found throughout Illinois (Cummings and Mayer 1997). A live *L. teres* specimen was found in Bay Creek (Middle Mississippi River tributaries), 1.5 mi E Pittsfield at the Ill. Rte 106 Bridge, Pike County on 7 July 1998 (INHS 21930). One live *L. teres* individual was discovered in the Cache River, 1.5 mi NW Forman, Johnson County on 4-6 August 1997 (INHS Mollusk Collection). A recent-dead *L. teres* valve was found in Lusk Creek (Ohio River tributaries), Golconda at the Ill. Rte 146 Bridge, Pope County on 28 August 1999 (INHS 23482). The yellow sandshell has been collected alive in 14 drainages in Illinois since 1970 and was historically present in 22 drainages in the state.

*Leptodea fragilis* (Rafinesque, 1820), fragile papershell. Updated drainage records: **6**, **16**, **17**. The fragile papershell is generally distributed throughout Illinois and might be expanding its range in the state (Cummings and Mayer 1997). One live *L. fragilis* specimen was collected in Kickapoo Creek (Middle Illinois River tributaries), 1 mi SE Oakhill at the Ill. Rte 8 Bridge, Peoria County on 15 August 1999 (INHS 23645). One live *L. fragilis* individual was discovered in the Cache River, 1.5 mi NW Forman, Johnson County on 4-6 August 1997 (INHS Mollusk Collection). One live *L. fragilis* specimen was found in Big Grand Pierre Creek (Ohio River tributaries), 7 mi SE Vaughn Cemetery at the Ill. Rte 146 Bridge, Pope County on 10 July 2001 (INHS 25654). The fragile papershell has been found alive in 21 drainages in Illinois since 1970 and was historically present in all 25 drainages in the state.

*Ligumia recta* (Lamarck, 1819), black sandshell (state-threatened). Updated drainage records: 3, **5**, **14**, **21**. The black sandshell was historically distributed in large streams throughout Illinois, and was thought to be alive only in the Galena/Apple, Rock, and Kankakee river drainages as well as the Mississippi and Ohio rivers in the state (Cummings & Mayer 1997). Two relict *L. recta* specimens were discovered in Edwards Creek (Middle Mississippi River tributaries) near Aledo in Mercer County, but no date was given (UMMZ 98299). Schanzle et al. (2004) reported collecting two live *L. recta* specimens in the Fox River, West Dundee, Kane County on 7 September 2000 (INHS 25184). One live *L. recta* specimen was discovered in West Okaw River (Kaskaskia River drainage), 4 mi SW Lovington, Moultrie County on 26 September 2003 (INHS Mollusk Collection). Four live *L. recta* individuals were collected in the Vermilion River of the Wabash River drainage, Danville, Vermilion County on 7 September 2005 (INHS Mollusk Collection). The black sandshell has been collected alive in eight drainages in Illinois since 1970 and was historically present in 16 drainages in the state.

*Ligumia subrostrata* (Say, 1831), pondmussel. Updated drainage records: **10**, **13**, **14**, **17**. The pondmussel is occasionally found in small streams in southern Illinois (Cummings and Mayer 1997). Seven live *L. subrostrata* specimens were found in Drowning Fork of the East Fork LaMoine River drainage, 4 mi SW Bushnell at the Co. Rd 1700N Bridge, McDonough County on 1 August 2005 (INHS 30616). Six live *L. subrostrata* specimens were discovered in Holiday Lake (Lower Illinois River tributaries drainage) near Holiday Shores, Madison County on 28 June 2004 (INHS 28776). Five live *L. subrostrata* individuals were collected in East Fork Shoal Creek (Kaskaskia River drainage), 2 mi SE Coffeen at the Ill. Rte 185 Bridge, Montgomery County on 5 September 2002 (INHS 27438). One live *L. subrostrata* individual was discovered in Hayes Creek (Ohio River tributaries), 3 mi SW Eddyville at the Ill. Rte 145 Bridge, Pope County on 13 August 1998 (INHS 22711). The pondmussel has been collected alive in eight drainages in Illinois since 1970 and was historically present in 16 drainages in the state.

*Obliquaria reflexa* Rafinesque, 1820, threehorn wartyback. Updated drainage records: 17, **18**. The threehorn wartyback is generally distributed in larger streams in Illinois (Cummings and Mayer 1997). A recent-dead *O. reflexa* specimen was discovered in Lusk Creek (Ohio River tributaries), Golconda at the Ill. Rte 146 Bridge, Pope County on 28 August 1999 (INHS 23484). A live *O. reflexa* was found in the Saline River, 9 mi W Shawneetown at the Ill. Rte 1 Bridge, Gallatin County on 21 June 2005 (INHS 30543). The threehorn wartyback has been found alive in ten drainages in Illinois since 1970 and was historically present in 15 drainages in the state.

*Obovaria olivaria* (Rafinesque, 1820), hickorynut. Updated drainage record: **21**. The hickorynut is generally found in the larger streams of Illinois (Cummings and Mayer 1997). Three live *O. olivaria* individuals were discovered in the Vermilion River of the Wabash River drainage, 4.25 mi E Westville at old railroad trestles, Vermilion County on 6 October 1997 (INHS 21635). The hickorynut has been found alive in six drainages in Illinois since 1970 and was historically present in 11 drainages in the state.

*Obovaria subrotunda* (Rafinesque, 1820), round hickorynut (state-extirpated). Updated drainage record: 19. The round hickorynut was historically known to inhabit the Ohio and Wabash river drainages in Illinois, but is now alive only in the Vermilion of the Wabash River drainage in the state (Cummings and Mayer 1997). A relict *O. subrotunda* valve was found in Horse Creek (Little Wabash River drainage), 2.5 mi NNW Keenes at the Co. Rd 200E Bridge, Wayne County on 8 August 2003 (INHS 28840). The round hickorynut has been collected alive in one drainage in Illinois since 1970 and was historically present in five drainages in the state.

*Potamilus alatus* (Say, 1817), pink heelsplitter. Updated drainage records: **5**, **8**, **9**, **10**, 13, **16**, **18**, **21**. The pink heelsplitter is commonly distributed in streams in central and southern Illinois (Cummings and Mayer), and is expanding its range in the Illinois River drainage (Sietman et al. 2001). A live *P. alatus* specimen was discovered in Aux Sable Creek, 2.25 mi W Minooka at the Minooka Road Bridge, Grundy County on 13 July 2005 (INHS Mollusk Collection). A live *P. alatus* specimen was collected in the Mazon River, 1 mi SE Morris, Grundy County on 25 August 2000 (INHS Mollusk Collection). A live *P. alatus* was found in the Spoon River, 4 mi S Seville at an abandoned bridge, Fulton County on 3 August 2004 (INHS 28874). A live *P. alatus* individual was found in Town Creek (LaMoine River drainage), 2 mi SE Good Hope at the Co. Rd 1400E Bridge, McDonough County on 17 May 1990 (Baumgardner 1995). A recent-dead *P. alatus* specimen was discovered in Mauvaise Terre Creek (Lower Illinois River tributaries), 5.5 mi WNW Jacksonville, Morgan County on 23 August 1996 (INHS 19434). A live *P.*

*alatus* individual was found in the Cache River, 1 mi NE Belknap, Johnson County on 26 September 1997 (INHS 21672). A live *P. alatus* was found in the Saline River, 9 mi W Shawneetown at the Ill. Rte 1 Bridge, Gallatin County on 21 June 2005 (INHS 30544). A live *P. alatus* specimen was discovered in the Vermilion River of the Wabash River drainage, 2 mi SE Danville at old railroad trestles, Vermilion County on 21 July 2000 (INHS 24755). The pink heelsplitter has been found alive in 18 drainages in Illinois since 1970 and was historically present in 22 drainages in the state.

*Potamilus capax*, (Green, 1832), fat pocketbook (state-endangered, federally-endangered). Updated drainage record: **19**. The fat pocketbook was historically known from the Mississippi, Wabash and Ohio rivers and their larger tributaries in Illinois, and was thought to be alive only in the Wabash and Ohio rivers in the state (Cummings and Mayer 1997). A live *P. capax* specimen was discovered in the Little Wabash River, Carmi at the Ill. Rte 1 Bridge, White County on 8 September 1998 (INHS 22242). The fat pocketbook has been collected alive in three drainages in Illinois since 1970 and was historically present in six drainages in the state.

*Potamilus ohiensis* (Rafinesque, 1820), pink papershell. Updated drainage records: **6**, 16, 17, **21**. The pink papershell is widely distributed throughout Illinois and might be expanding its range in the state (Cummings and Mayer 1997). Two live *P. ohiensis* specimens were discovered in Big Bureau Creek (Middle Illinois River tributaries), 1.75 mi ENE Tiskilwa, Bureau County on 1 October 2004 (INHS 29913). A recent-dead *P. ohiensis* specimen was found in Bear Creek Ditch (Cache River drainage), 2 mi ESE New Columbia at the New Columbia Road Bridge, Massac County on 1 July 2002 (INHS 27674). A recent-dead *P. ohiensis* specimen was found in Big Creek (Ohio River tributaries), 1.5 mi SW Elizabethtown at the Ill. Rte 146 Bridge, Hardin County on 28 June 2001 (INHS 25695). A live *P. ohiensis* specimen was discovered in the Vermilion River of the Wabash River drainage, 4.25 mi E Westville at old railroad trestles, Vermilion County on 2 October 1997 (INHS 20740). The pink papershell has been collected alive in 21 drainages in Illinois since 1970 and was historically present in 24 drainages in the state.

*Potamilus purpuratus* (Lamarck, 1819), bleufer (species of special concern). Updated drainage record: **24**. The bleufer was historically known from only the Wabash and lower Mississippi rivers in Illinois; it is at the northeastern edge of its geographic range in the state (Cummings and Mayer 1997). Relict valves were located in the Ohio River, 3 mi NE Mound City, Pulaski County on 22 September 1999 (INHS 24128), and a live *P. purpuratus* individual was found here on 27 July 2005 (INHS 31099). This specimen is the first recorded live individual of *P. purpuratus* for the state. The bleufer has been collected alive in one drainage in Illinois since 1970 and was historically present in three drainages in the state.

*Toxolasma lividus* (Rafinesque, 1831), purple lilliput (state-endangered). Updated drainage record: **17**. The purple lilliput was historically found in the Wabash River and its tributaries in Illinois, and was thought to be alive only in two Wabash River tributaries in the state: the Vermilion and Little Wabash rivers (Cummings and Mayer 1997). Two live *T. lividus* specimens were discovered in Big Grand Pierre Creek (Ohio River tributaries), 1.75 mi SE Herod near the Blackman Road Bridge, Pope County on 14 May 1997 (INHS

19620). The purple lilliput has been collected alive in three drainages in Illinois since 1970 and was historically present in five drainages in the state.

*Toxolasma parvus* (Barnes, 1823), lilliput. Updated drainage records: **3**, **9**. The lilliput is commonly distributed throughout Illinois (Cummings and Mayer 1997). One live *T. parvus* specimen was found in Burton Creek (Middle Mississippi River tributaries), 2 mi NW Payson at the Ill. Rte 96 Bridge, Adams County on 21 October 1997 (INHS 20078). One live *T. parvus* was discovered in Haw Creek (Spoon River drainage), 3.5 mi W Maquon at the Co. Rd 550N Bridge, Knox County on 15 August 1999 (INHS 25776). The lilliput has been collected alive in 21 drainages in Illinois since 1970 and was historically present in 24 drainages in the state.

*Toxolasma texasiensis* (Lea, 1857), Texas lilliput. Updated drainage record: **19**. The Texas lilliput is restricted to southern Illinois. Two live *T. texasiensis* were collected in the Little Wabash River, Carmi at the Ill. Rte 1 Bridge, White County on 3-4 August 1999 (INHS 23430). The Texas lilliput has been found alive in five drainages in Illinois since 1970 and was historically present in six drainages in the state.

*Truncilla donaciformis* (Lea, 1828), fawnsfoot. Updated drainage records: 3, 7, **14**, 15. The fawnsfoot is commonly found in the larger streams in Illinois (Cummings and Mayer 1997). A relict *T. donaciformis* valve was discovered in Edwards Creek (Middle Mississippi River tributaries) in Mercer County (Bryant Walker Collection; UMMZ 70893). This specimen recently was acquired from the University of Illinois Museum of Natural History. A relict *T. donaciformis* valve was collected in the Kankakee River near Kankakee, Kankakee County (no date was given; UMMZ 154008). Six live *T. donaciformis* specimens were found in Shoal Creek (Kaskaskia River drainage), 2 mi SE Pocahontas at the Doll's Orchard Avenue Bridge, Bond County on 6 September 2002 (INHS 27469). A relict *T. donaciformis* valve was discovered in the Big Muddy River, 0.7 mi N Grassy Knob, Jackson County on 25 August 2001 (INHS 26388). The fawnsfoot has been discovered alive in 14 drainages in Illinois since 1970 and was historically present in 20 drainages in the state.

*Truncilla truncata* Rafinesque, 1820, deertoe. Updated drainage records: **5**, 7, **8**, **17**. The deertoe is generally distributed in large streams in Illinois (Cummings and Mayer 1997), and is expanding its range in the Illinois River drainage (Sietman et al. 2001). A live *T. truncata* specimen was collected in Aux Sable Creek, 5 mi ENE Morris, Grundy County on 26 July 2005 (INHS 30683). A recent-dead *T. truncata* valve was found in the Kankakee River, Langham Island at Altorf, Kankakee County on 5 Aug 2004 (INHS 29180). One live *T. truncata* specimen was collected in the Vermilion River of the Illinois River drainage, 3 mi ENE Leonore at the Co. Rd 57 bridge, LaSalle County on 27 July 2004 (INHS 30120), and three live were collected in the Mazon River, 1 mi SE Morris, Grundy County on 25 August 2000 (INHS 25341). A live *T. truncata* specimen was discovered in Bay Creek (Ohio River tributaries), 2.5 mi SE Brownfield at the Co. Rd 700E Bridge, Pope County on 30 August 1998 (INHS 23112). The deertoe has been found alive in 16 drainages in Illinois since 1970 and was historically present in 20 drainages in the state.

*Venustaconcha ellipsiformis* (Conrad, 1836), ellipse. Updated drainage record: 25. The ellipse is restricted to northern Illinois (Cummings and Mayer 1997). Two relict V. *ellipsiformis* specimens were recorded for the Wabash River, Mount Carmel, Wabash County (A.A. Hinkley Collection, pre-1921; INHS 30207). This specimen recently was acquired from the University of Illinois Museum of Natural History. The ellipse has been found alive in seven drainages in Illinois since 1970 and was historically present in 13 drainages in the state.

*Villosa fabalis* (Lea, 1831), rayed bean (state-extirpated). Updated drainage record: **21**. The rayed bean was historically distributed in the Wabash River and its tributaries in Illinois, and was thought to be extirpated from the state (Cummings and Mayer 1997). Live *V. fabalis* specimens were collected in the Middle Fork Vermilion River, 0.75 mi WSW Armstrong at the Ill. Rte 49 Bridge, Vermilion County on 9 July 1991 (INHS 12158). The rayed bean has been found alive in one drainage in Illinois since 1970 and was historically present in four drainages in the state.

*Villosa iris* (Lea, 1829), rainbow (state-endangered). Updated drainage record: 2. The rainbow was historically distributed in northern and eastern Illinois, but is now alive only in the Vermilion River basin of the Wabash River drainage in the state (Cummings and Mayer 1997). Relict *V. iris* valves were discovered in the Kishwaukee River (Rock River drainage), 2 mi WNW Marengo, McHenry County on 17 September 1996 (INHS 19486). The rainbow has been found alive in one drainage in Illinois since 1970 and was historically present in nine drainages in the state.

*Villosa lienosa* (Conrad, 1834), little spectaclecase (state-threatened). Updated drainage records: 16, 17, 18. The little spectaclecase was historically found throughout the Wabash River drainage in addition to the upper Sangamon River in Illinois, but is now only alive in two drainages in the state: 1) the Embarras River and Wabash River tributaries (e.g., Brouilletts Creek), and 2) the Vermilion River (Cummings and Mayer 1997; Tiemann 2005). A relict *V. lienosa* valve was found in Lake Creek (Cache River drainage), 2 mi E Miller City just downstream of Horseshoe Lake spillway, Alexander County on 12 October 2005 (INHS 31115). A recent-dead *V. lienosa* specimen was found in Big Grand Pierre Creek (Ohio River tributaries), 1.5 mi SE Herod near the Blackman Road Bridge, Pope County on 31 August 2000 (INHS 25205). A relict *V. lienosa* valve was found in the North Fork Saline River, 5.5 mi W Norris City at the Co. Rd 500N Bridge, Hamilton County on 3 November 2005 (INHS 31082). The little spectaclecase has been found alive in two drainages in Illinois since 1970 and was historically present in nine drainages in the state.

## DISCUSSION

An examination of museum records and literature reviews of freshwater mussels from Illinois uncovered information for 51 species, including new drainage records for 37 species and status updates for 40 species, since Cummings and Mayer (1997). These data suggest that reduction of unionids in Illinois might not be as high as originally reported in Cummings and Mayer (1997). Although there are still considerable differences between current and historical species richness in many drainages, additional collecting would likely reveal more taxa due to the fact that many of these areas have not been adequately sampled. Disturbances to freshwater mussel faunas are similar to those affecting other riverine faunas, and continued work on managing stream habitats is vital to protecting the remaining diversity of those faunas.

Morphological and genetic work still needs to be done to determine range and status of a few species in Illinois, including winged mapleleaf *Quadrula fragosa* (Conrad, 1835), gulf mapleleaf *Quadrula nobilis* (Conrad, 1854), *Lampsilis ovata* (Say, 1817), and Louisiana fatmucket *Lampsilis hydiana* (Lea, 1838). Updated records for these four species were not included in this paper.

We also would like to correct seven records reported in Cummings and Mayer (1997). Evidence could not be found for *Cyclonaias tuberculata* (Rafinesque, 1820), purple wartyback, in the Little Wabash River; *A. ferussacianus* in the Wabash River in Illinois, although there are records for it in Indiana (INHS 6235); *P. alatus* in the Big Muddy River; and *V. iris* in the Mississippi River mainstem. Also, although *F. ebena* was known to occur in the Rock River, evidence of recent live individuals as reported in Cummings and Mayer (1997) could not be found. Records of *M. nervosa* occurring in both Middle Mississippi River tributaries and Ohio River tributaries (or "Massac, Bay, Lusk, Big Grand Pierre, and Big Creek Drainages") were re-identified as *A. plicata*. The live and historical numbers listed both in the species accounts (in results section) and in Table 1 have the above errors taken into consideration; *C. tuberculata*, which is not listed in the species account section, has been discovered alive in three drainages in Illinois since 1970 and was historically present in 11 drainages in the state.

## ACKNOWLEDGMENTS

The Illinois Department of Transportation provided partial funding for this study. Many collectors, notably R.W. Schanzle (Illinois Department of Natural Resources), J.E. Schwegman (Illinois Department of Natural Resources, Retired), and R.E Szafoni (Illinois Department of Natural Resources), deposited their specimens in the INHS Mollusk Collection. R.V. Anderson (Western Illinois University) shared J.A. Baumgardner's thesis, G. Levin (Illinois Natural History Survey), D. Thomas (Illinois Natural History Survey), and B. Tiemann offered constructive criticism on the manuscript.

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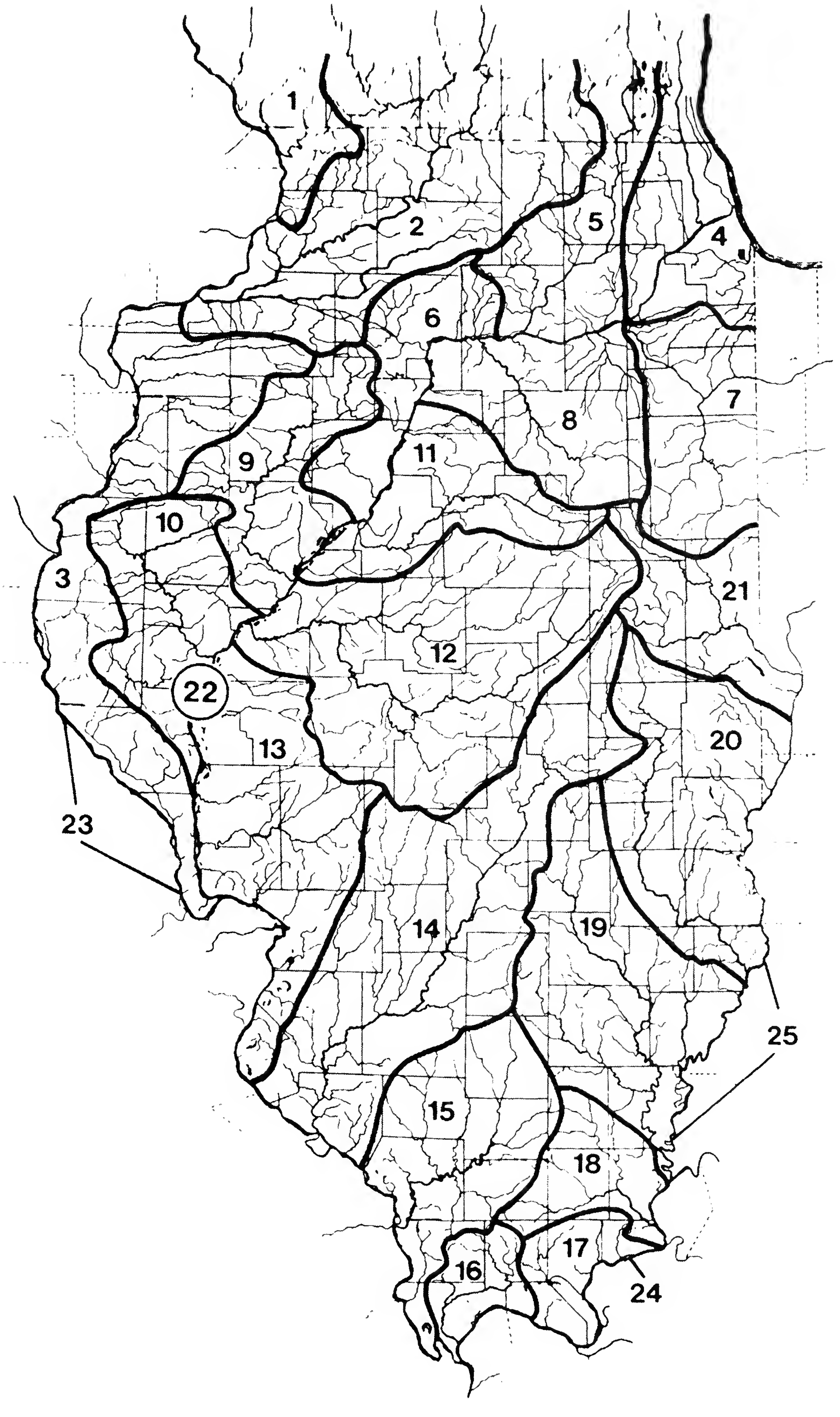
Table 1. Extant and historic freshwater mussel species counts known from Illinois by drainage. 'No.' is the drainage number in Figure 1. Species count data were taken from literature reviews and voucher specimens housed in museum collections. Asterisks (*) indicate projects that currently are ongoing within the drainage and species counts are not current. [1]Data from Aux Sable Creek were not included with data from the Fox River in Cummings and Mayer (1997). [2]Middle Illinois River tributaries are referred to as "Little Vermilion River, Big Bureau, and Kickapoo Creek Drainages" in Cummings and Mayer (1997). [3]Lower Illinois River tributaries are referred to as "Lower Illinois River tributaries and American Bottoms" in Cummings and Mayer (1997). [4]Ohio River tributaries are referred to as "Massac, Bay, Lusk, Big Grand Pierre, and Big Creek Drainages" in Cummings and Mayer (1997).

| No. | Drainage | Extant Species Count | Historic Species Count |
|---|---|---|---|
| 1. | Galena River, Apple River, and Plum River* | 11 | 19 |
| 2. | Rock River | 32 | 47 |
| 3. | Middle Mississippi River tributaries | 11 | 27 |
| 4. | Des Plaines River and Lake Michigan tributaries | 11 | 38 |
| 5. | Fox River and Aux Sable Creek[1] | 26 | 34 |
| 6. | Middle Illinois River tributaries[2] | 7 | 16 |
| 7. | Kankakee River-Iroquois River | 27 | 40 |
| 8. | Vermilion River and Mazon River | 25 | 31 |
| 9. | Spoon River | 20 | 41 |
| 10. | LaMoine River | 15 | 23 |
| 11. | Mackinaw River and Quiver Creek | 26 | 35 |
| 12. | Sangamon River | 34 | 48 |
| 13. | Lower Illinois River tributaries[3] | 12 | 19 |
| 14. | Kaskaskia River | 31 | 43 |
| 15. | Big Muddy River | 17 | 24 |
| 16. | Cache River | 16 | 20 |
| 17. | Ohio River tributaries[4] | 15 | 26 |
| 18. | Saline River | 18 | 24 |
| 19. | Little Wabash River and Bonpas Creek | 35 | 47 |
| 20. | Embarras River and Wabash River tributaries | 35 | 47 |
| 21. | Vermilion River and Little Vermilion River | 37 | 45 |
| 22. | Illinois River | 29 | 49 |
| 23. | Mississippi River | 35 | 50 |
| 24. | Ohio River | 35 | 57 |
| 25. | Wabash River | 29 | 74 |

Figure 1. The 25 major river drainages in Illinois (figure taken from Cummings and Mayer 1997). See Table 1 for drainage key.



## BOOK REVIEW 2007 - #1

Crum, Howard. Mosses of the Great Lakes Forest. Fourth Edition. 2004. viii + 592 pages; introduction; dichotomous keys; illustrations; taxonomic descriptions; black and white photographs; glossary; index to Latin names. University of Michigan Herbarium, Ann Arbor, Michigan. Hard Cover. ISBN: 0-9620733-6-3. Price: US $40.00. Available from University of Michigan Herbarium, Publications, 3600 Varsity Drive, Ann Arbor, MI 48108-2287.

The highly respected bryologist, Howard Crum, died in April 2002 before he could complete the fourth edition of his important and useful set of manuals entitled Mosses of the Great Lakes Forest (1973, 1976, and 1983). But fortunately and thankfully, William ~~C~~. Buck and Christiane Anderson took on the task of editing and seeing Crum's beautiful fourth edition to completion.

R/

Although the title, Mosses of the Great Lakes Forest, indicates a regional moss flora, the manual has a much broader application and can serve as an effective introductory taxonomic manual for the identification of mosses in the northeastern United States. In this respect, it is a handy companion to the more comprehensive two volume taxonomic publication entitled Mosses of Eastern North America (Crum and Anderson, 1981).

A significant feature following the introduction of Mosses of the Great Lakes Forest is the dichotomous key to genera treated in the manual; a feature not found in Mosses of Eastern North America. Descriptive materials (including illustrations) follow, with 545 pages for moss species of two divisions; Sphagnophyta (Peat Mosses) and Bryophyta with two classes Andreaeopsida (Granite Mosses) and Bryopsida (True Mosses).

Following a description and noteworthy comments about the Sphagnophyta, and hence the only family Sphagnaceae, is a key to species of the single genus *Sphagnum* (pp. 26-70). Subsequent to the key, the species are described and illustrated under one of six sections of the genus covered in this manual. The author's more comprehensive treatment of *Sphagnum* includes a dichotomous key to ten sections of the genus (Crum, 1984).

Next, the class Andreaeopsida (pp. 71-73) and the family Andreaeaceae are discussed followed by descriptive comments and illustrations of two species.

Subsequently, the Bryopsida are described followed by the treatments of the species arranged according to their assigned families (pp. 74–568). Typically in this section of the book, the families are described followed by a dichotomous key to genera. Then in turn, the genera are described and accompanied by dichotomous keys to species.

Treatments of the species in both divisions include taxonomic descriptions, illustrations (for nearly all species), habitat notations, comments on global distributions, and county distributions in Michigan. In addition, the treatments of the species often end with interesting comments about some of their salient features that often include noteworthy distinctions from closely related species. Here too, one may find anecdotal comments about the species from the author's personal observations, from other bryologists, or from other sources; any of which provide enjoyable reading.

With respect to mosses of Illinois, this manual is very useful because it treats 80% of the 368 species of mosses (Sphagnophyta and Bryphyta) reported by McKnight (1987) [Note: The count of 368 species of mosses does not include numerous varieties in McKnight's checklist]. Of the 295 species reported in both publications, only 14 species have synonyms. (Table 1).

Of the remaining 73 species in the checklist of Illinois mosses, but not covered in the author's moss flora 61 species are treated in Crum and Anderson's Mosses of Eastern North America; five additional species are mentioned in various discussions (*Brachythecium collinum, Dicranoweisia cirrata, Fabronia wrightii, Grimmia ovalis,* and *G. trichophylla*); and seven species are not reported (*Barbula vinealis, Bryohaplocladium microphyllum, B. virginianum, Fabronia gymnostoma, Grimmia calyptrata, Hypnum subimponens,* and *Tortula subulata*).

A useful and needed glossary follows the descriptive materials (pp. 569-580). Although the book does not have a list of references, relevant literature citations are provided within its text. However, if one has a copy of an earlier edition of the manual, keep it handy because a useful bibliography follows its glossary.

We highly recommend this book to anyone interested in learning about mosses. For botanists, plant ecologists, environmentalists, and others needing to learn how to identify mosses for detailed vegetational studies in Illinois, Mosses of the Great Lakes Forest and Mosses of Eastern North America are essential.

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Table 1. List of synonyms – the primary list of Latin names for mosses are from McKnight's checklist (1981), whereas the generic names and/or specific epithets shown in parentheses are from Crum's manual (2004).

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*Amblystegium* (= *Hygroamblystegium*) *fluviatile*

*Amblystegium* = (*Leptodictyum*) *humile*

*Brachythecium oxycladon* (= *B. laetum*)

*Brotherella* (= *Pylaisiadelpha*) *tenuirostris*

*Bryum creberrimum* (= *B. lisae* var. *cuspidatum*)

*Cratoneuron commutatum* (= *Palustriella falcate*)

*Didymodon* (= *Barbula*) *fallax*

*Drepanocladus uncinatus* (= *Sanionia uncinata*)

*Fissidens cristatus* (= *F. dubius*)

*Grimmia affinis* (= *G. longirostris*)

*Mnium longirostrum* (= *M. rostratum*)

*Pylaisiella* (= *Pylaisia*) *intricata*

*Pylaisiella* (= *Pylaisia*) *polyantha*

*Pylaisiella* (= *Pylaisia*) *selwynii*

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**Transactions of the Illinois State Academy of Science** **Volume 100 (2007)**

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# Errata

The authorship of the paper by Mina A and Laurence Leff, on A Case Study in Reuse: An XML-Editing Component and Contract Editor, which appeared in Issue #1 of *Transactions* volume 100 (2007) inadvertently has Mina A listed as the second author, rather than as the principle author. Corrected pages are reprinted following this notice. The reprinted pages include the original paper numbering for easy insertion into previously printed volumes.

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# A Case Study in Reuse: An XML-Editing Component and Contract Editor

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## I. INTRODUCTION AND OVERVIEW

Many decades ago, Bill Joy developed the first full-screen editor for UNIX, **vi**. Users could edit files on ASCII terminals by moving the cursor up, down, backwards and forwards with the **h**, **j**, **k**, **l** keys (the home keys) and press other sequences to delete lines, words, sentences and insert text. On a slow connection on an ASCII terminal, a few lines might be displayed; if one enjoyed a relatively high speed connection, one would be able to edit using a full screen. Note that this was before "WIMP" interfaces, such as the Xerox Star, Macintosh, and Windows, were widely available.

This worked using the "escape codes" on the terminal. When a computer program sent a sequence of characters to the terminal, it might move the cursor, clear the screen, delete a line or ring the bell. Unfortunately, this was different for each brand of terminal. So Bill Joy "abstracted" the problem. A file named **termcap** contained the sequences needed for each operation. The users would set an environment variable to indicate which terminal they were using. **vi** would read the **termcap** file and issue the correct sequence of escape codes to implement the user's editing request. (Gaughan, 2003) This was called optimal cursor movement, as the logic in vi will determine the sequence of escape codes with the fewest, or close to the fewest, number of characters needed to change the display.

Ken Arnold created a library called **curses** by "simply lifting nearly intact" the routines to implement "optimal cursor movement" from Bill Joy's editor. (Arnold), (Arnold and Amir). This was used for many full-screen programs, most notably, an "adventure game" called Rogue (Wichman, 1997). Wichman indicated that his group, which originally implemented Rogue, simply used it after "it made the rounds to other Universities." Some web sites, however, including (die.net) (Foldoc, 1993), indicate that **curses** was developed specifically to support games.

In this article, we report an analogous sequence, over two decades later. Mr. Go Eguchi developed a Graphical User Interface (GUI) to create rule-base for transforming XML files (Eguchi and Leff, 2002) (Tong, et. al., 2005). Those works define two expert systems that would examine XML files. It would match this information against the XML appearing in the left-hand side of the rule. These expert systems would then generate the XML designated by the right-hand side of the rule, transferring information from the input. The standard (Leff, 2002) also defined additions to the XML so that when the expert system is run, information that was in the input file being matched is transferred

into the output XML. The goal of the editor was to allow the rule-writer or user to create the XML defining the transformations to occur.

That editor's user interface had two panes, a menu bar and three sets of buttons. The user, or rule writer, develops the XML rule-base in the right-hand pane. The rule-writer loads samples of the XML to be transformed in the left-hand pane. They use the left-hand set of arrow buttons to move within that XML. Then, using the right-hand set of arrow buttons, the rule-writer moves within the rule-base to indicate which rule to create or modify. In the middle set of buttons, there is a "Move From Sample" button. The user presses this to set up the example. Then, the user has to modify the XML moved to the left hand set of the rules to add the special markup. The rule writer moves within the rule-base (again with the right set of buttons) and inserts the special markup to indicate how to recognize the inputs that are considered similar. Lastly, the user loads a sample of the XML to be produced when the input is recognized, and similarly, they move some of the XML to the "right hand side" of the rule. The reader of this paper does not have to be concerned with the above detail; only to realize that Mr. Eguchi implemented code to allow transformation of XML for the specific purpose of implementing the above-described system, and he embedded that within his system without planning for any reusability.

The first author extracted this into a Java Swing "component" for general use. Swing is a package, provided by Sun, which programmers use to develop GUIs using the Java programming language. The items on one of these implemented GUIs which includes other panels, edit boxes, buttons, sliders, and menus are all components (Walrath and Campione, 1998) derived from the class **Component** (Java, 2004). The programmer sets up a "containment hierarchy" in their GUI; for example, a main screen might contain several panels, some of which may have buttons or edit boxes.

The XML-Editing **Component** which is the subject of this report contains a panel in which XML is displayed with a set of four arrow buttons; the user uses these to navigate the XML. One element or "tag" is always highlighted in red. That is, when the user clicks the left arrow, the containing tag is highlighted; when the user clicks the right arrow, the highlight changes from the current tag to the immediate child on which the mouse is selected. The Up and Down arrows move the cursor from the current tag to the subsequent, or previous tag at the same level.

The programmer creates the XML editing component using its constructor and adds it to the frame or another panel using the **add** method of the frame. This is precisely how they would add an ordinary built-in edit box or button. Then they can use **setParser** to load an XML file, which is displayed. The programmer can retrieve a **parser** object. This allows the user to add or otherwise manipulate elements. It also supports the operation **getPointer** so the programmer can get the node that the user has highlighted. For example, assume the user selected an element that represents an "if," and selected a button to add a "then" part. The logic for a button would use the **getPointer** method to get a pointer to this element and then use the XML manipulation methods that are part of the packages that come with the Java programming language to add the new information.

The senior author developed an XML standard for legal contracts (Leff, 2000). It was proposed to the Legal XML standards organization. A legal contract can be viewed as a

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# Comparisons of Genetic Variation and Outcrossing Potential Between the Sensitive Species *Rudbeckia fulgida* var. *sullivantii* (Asteraceae) and Its Cultivar

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## ABSTRACT

*Rudbeckia fulgida* var. *sullivantii* (Sullivant's Coneflower, Asteraceae) is a target species for conservation and restoration at the Midewin National Tallgrass Prairie in Will County, Illinois because it is classified as a sensitive species by the USDA Forest Service. This species also has an extensively used cultivar named 'Goldsturm.' To aid in the restoration efforts of this species, the genetic diversity and cross pollination potential of *R. fulgida* var. *sullivantii* populations in Illinois were investigated. Random amplified polymorphic DNA results show high levels of genetic diversity in most of the populations surveyed. Little difference in genetic variation was observed between wild and cultivar populations. Cross pollination potential was confirmed as reciprocal crosses between wild and cultivar plants set seeds. Until additional research is conducted to understand better the reproductive and ecological consequences of cross pollination between wild and cultivar populations, these populations should be kept separate to prevent gene flow and maintain the genetic integrity of the wild populations.

Key words: cross pollination, cultivar, genetic diversity, Goldsturm, Midewin National Tallgrass Prairie, RAPD, *Rudbeckia fulgida* var. *sullivantii*

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## INTRODUCTION

A major problem for conservation managers in the preservation, (re)introduction, and management of sensitive, threatened, or endangered species is the lack of species-specific information. The successful implementation of an effective management plan for these species depends on understanding the basic biology of the species as well as the overall genetic diversity found in populations (Timmerman-Erskine and Boyd, 1999). Knowledge of this information helps managers decide how to alleviate stresses brought through demographic, environmental, and genetic stochasticity. Specifically, loss of genetic variation is thought to reduce the ability of populations to adapt to changing environments, and to increase their susceptibility to pest and disease pressures (Barrett and Kohn, 1991).

The genetic variation of a species can be impacted by its reproductive biology (Wong and Sun, 1999), population size (Goodell et al., 1997), and proximity of populations to one another that affects gene flow (Foré and Guttman, 1999; Morris, 1993). In small, isolated populations, genetic drift combined with the potential increase in inbreeding can reduce genetic variation (Ellstrand and Elam, 1993; Foré and Guttman, 1999). This reduction is especially of concern in outcrossing species, which can be more susceptible to inbreeding depression than species with a long history of inbreeding (Treuren et al., 1993). Historically inbreeding populations may show a decrease in deleterious recessive alleles as these alleles become homozygous and are purged by selection against them. Outbreeding populations, on the other hand, are expected to show a higher frequency of deleterious recessive alleles that are not purged during many generations of inbreeding because they can be hidden from selection in heterozygous individuals (Treuren et al., 1993). This increased susceptibility to inbreeding depression is why sufficient gene flow in outbreeding populations is especially important.

On the other hand, gene flow between populations also can lead to outbreeding depression; the reduction of fitness following intraspecific hybridization between individuals from spatially separated genetic sources (Barrett and Kohn, 1991). This outbreeding depression can occur when populations are locally adapted to environmental conditions and hybrids between the populations are less fit in either location. A decrease in fitness could eventually decrease population size and therefore reduce genetic variability. Both inbreeding and outbreeding depressions reduce genetic variation, and affect the flexibility with which a population can respond successfully to changing abiotic and biotic environmental conditions by limiting the expression of beneficial alleles (Ellstrand and Elam, 1993; Hueneke, 1991; Luijten et al., 2000). Therefore, it is important to determine the distribution and levels (i.e., within and among) of a species' genetic diversity in order to more effectively apply conservation and restoration programs (Holsinger and Gottlieb, 1991).

An additional factor influencing the effectiveness of conservation and restoration programs is the threat of gene flow between wild species and their cultivated forms. Several studies have shown gene flow between wild types and cultivars resulting in the long-term establishment of cultivar alleles in wild populations (Barbour et al., 2002; Burke et al., 2002; Ellis et al., 2006; Ellstrand et al., 1999; Whitton et al., 1997). These studies also highlight additional concerns regarding the effects of this gene flow such as the facilitation and evolution of weedy and invasive species (Burke et al., 2002), pollen swapping resulting in extensive introgression and even extinction by hybridization (Barbour et al., 2002; Wolf et al., 2001), and the reduction of a population's growth rate by adversely affecting its reproductive effectiveness, its competitive status, and its interactions with pathogens and herbivores (Levin et al., 1996). While many studies have focused on hybridization and gene flow within large-scale agriculture systems (Ellstrand, 1992; Ellstrand, 2003; Ellstrand et al., 1999; Linder et al., 1998; Lu and Snow, 2005; Raybould and Gray, 1993; Snow et al., 2005), the cultivation of one or more plants in a small scale backyard setting can also result in low levels of gene flow (Ellstrand et al., 1999).

At Midewin National Tallgrass Prairie (MNTP), a USDA Forest Service unit in Will County, IL, there are a number of sensitive, threatened, and endangered species. One of these species, *Rudbeckia fulgida* Ait. var. *sullivantii* (C.L. Boynt and Beadle) Cronq. (Sullivant's Coneflower, Asteraceae), a perennial prairie forb, is listed as sensitive by the USDA Forest Service (USDA Forest Service, 2001). The sensitive status indicates this species is susceptible or vulnerable to habitat alterations and/or management activities, resulting in viability concern for its long-term persistence (USDA Forest Service, 2001). As with many sensitive, threatened, and endangered species, no information is available about its population genetic diversity. In addition, this species has a very popular world-wide cultivar known as *R. fulgida* var. *sullivantii* 'Goldsturm.'

Because of limited information on the genetic diversity of this species and the popularity of its cultivar, the objectives of our study were to determine: 1) the genetic diversity of *R. fulgida* var. *sullivantii* populations found at MNTP and compare diversity levels with the cultivar 'Goldsturm' and, 2) whether cross pollination occurs between the wild type and cultivar forms. We believe that this information can aid in the proper development of a conservation management plan that addresses concerns of gene flow between wild type and the cultivar for this species.

## MATERIALS AND METHODS

### Species Description

*Rudbeckia fulgida* var. *sullivantii* - wild type. This species is found in nine states, mostly in the midwest to eastern United States (Urbatsch and Cox 2006; USDA, NRCS, 2004). Currently, only Illinois and Michigan consider the species rare, while states such as New York and Ohio consider it common (Molano-Flores, 2005). In Illinois, the species is documented in 12 of 102 counties. *Rudbeckia fulgida* var. *sullivantii* grows between 30-70 cm tall (USDA Forest Service, 1999). This species has alternate, lanceolate to ovate leaves with sharply dentate margins and primarily pinnate venation (Urbatsch and Cox 2006, USDA Forest Service, 1999). There are typically several terminal inflorescences on an individual, each with 2.5-4 cm orange-yellow rays (Gleason and Cronquist, 1991; USDA Forest Service, 1999). This species blooms from mid-July through late September and forms discrete colonies through asexual propagation via stolons (Gleason and Cronquist, 1991, Urbatsch and Cox 2006). Scott (2005) determined that *R. fulgida* var. *sullivantii* is mostly a self-incompatible species. The primary pollinators for *R. fulgida* var. *sullivantii* are considered generalists. The most common insect families visiting the inflorescences are: Apidae, Cantharidae, Halictidae, Hesperiidae, Nymphalidae, Pieridae, and Syrphidae (Scott, 2005). In Illinois, *R. fulgida* var. *sullivantii* is found in woodland edges, old pasture, mesic prairie, and along roadsides (Molano-Flores, 2005).

*Rudbeckia fulgida* var. *sullivantii* - 'Goldsturm' cultivar. This rhizomatous perennial cultivar can grow taller than the wild type (to heights of 75 cm). Like the wild type, leaves are dark green and range from lanceolate to ovate. 'Goldsturm's golden-yellow ray florets can be slightly longer than the wild type ranging between 2.5-5 cm long. 'Goldsturm' tends to form tight clumps whereas the growth habit of the wild type is more spaced between ramets. This cultivar blooms from mid-July to October, and can survive in a wide range of temperatures from Florida to Alberta, Canada in hardiness zones 3-9 (Green Beam, 2004; PPA, 2002). 'Goldsturm' is said to grow best in well-drained, consistently moist soils, but will tolerate clay to sandy soils and mild droughts (PPA, 2002). This cultivar originated in Germany in 1937, but was not used extensively in Europe until 1949 (PPA, 2002). Between the 1960's and the 1980's, 'Goldsturm' was brought to the United States (Green Beam, 2004). Here its increase in popularity was aided by Kurt Bluemel, a perennial grower and Wolfgang Oehme, a landscape architect (Green Beam, 2004). This cultivar was originally selected for uniform height and bloom time; however, stringent selection for these traits has not been retained due to ease of seed propagation (R. Diblick, Northwind Perennial Farm Nursery Grower, pers. comm. 2003). In 1999, 'Goldsturm' was selected as the perennial plant of the year (PPA, 2002). One reason for this honored designation was this cultivar's ability to grow well in diverse climates (PPA, 2002). Finally, this cultivar is propagated by seed, division, or stem cuttings.

### Study Sites

This study was conducted using eight populations in Will County northeastern Illinois from 2003-2004, primarily at MNTP (six populations), but also included one population at Grant Creek Prairie (GCP), and one population along Illinois Route 53 (Rt. 53). Habitat for these wild populations includes woodland edge, old pasture, mesic prairie, and roadside. At MNTP, the species is found from multiple dense populations to scattered individuals across the site.

### Population Sampling Genetic Diversity

Wild Type. In 2003, leaf sampling for genetic analysis took place at MNTP, GCP, and along Illinois Rt. 53. The number of individuals sampled from each population ranged from 19-30 depending on population size. Two to four leaves per individual were collected, with particular attention paid to collecting leaf tissue from individuals separated by at least 91 cm (3 feet) to minimize collecting from genetically identical individuals. Leaf tissue was placed in a dry coin envelope and kept in a dry place until the tissue could be ground for DNA extraction.

Cultivar. In 2003, two nurseries were visited and at each nursery between two to four leaves were collected from 24 individuals to represent genetic diversity found in the cultivar. The first nursery, Green Glen Nursery (GGN), is located in Joliet, IL near MNTP. The second nursery, Country Arbors Nursery (CAC), is located in Urbana, IL. The leaves were placed in dry coin envelopes and kept in a dry place until they could be ground for DNA extraction.

### Genetic Analysis

Random amplified polymorphic DNA (RAPD) procedures followed those of Koontz et al. (2001), with the exceptions listed below. DNA was extracted from approximately 20 mg of dried leaf tissue using the Wizard DNA extraction Kit (Promega, Madison, WI) following the manufacturer instructions. The ground leaf material was incubated in the nuclei lysis solution at 65° C for at least 45 minutes. DNAs were quantified with a SmartSpec 3000 spectrophotometer (Bio-Rad, Hercules, CA) and diluted to a standard 10 ng/μl with TE pH 8.0 buffer. The RAPD primers Operon (Qiagen; Valencia, CA) A1, A4, B3, B7, B8 and B12 were selected after screening a total of 36 primers. The primers selected showed the most robust, repeatable markers. To ensure repeatability, select samples were run multiple times. Loci that failed to repeat were dropped from the analysis. The RAPD reactions were separated on a 1.5% agarose (Amresco Type I, Solon, OH) gel using 0.5x TBE buffer. Gels were run until a bromophenol blue dye marker had migrated 8 cm. Fragments were sized with a 1 Kb DNA ladder (Promega). Gels were stained for 20 minutes using ethidium bromide, destained in distilled water for 30 minutes, and then visualized and photographed in UV light using the Kodak 1D analysis software (Kodak 1D Image Analysis Software, 2000). To help reduce scoring bias, this software was used to score and size the resulting RAPD loci. The band sensitivity was adjusted to -3 for the most conservative scoring.

Genetic diversity levels were determined using percent polymorphic loci. A locus was considered monomorphic if present in 95% or more of the individuals. To assess the similarity of wild and cultivar populations, Shannon's Information Index was calculated using POPGENE (Yeh and Boyle, 1997). DistAFLP (Mougel et al., 2002) was used to create a Jaccard similarity matrix from the raw RAPD data. The matrix then was used in ARLEQUIN (Schneider et al., 2000) to run two Analysis of Molecular Variance (AMOVA): one that separated the wild and cultivar populations, and one that combined all the populations together. A principal coordinates analysis (PCo) was used to analyze the raw binary presence absence data using the R-package (v. 4.0, Casgrain and Legendre, 2001). JMPin (v. 5.1, SAS Institute, 2003) was used to display graphically RAPD marker distributions by plotting the first four eigenvectors from the PCo.

### Cross Pollination Potential - Greenhouse Crosses

In June 2003, 30 wild plants were transplanted from population 4 at MNTP to the Illinois Natural History Survey (INHS) greenhouses in Champaign, IL. Transplanting took place early in the growing season before the development of stems to ensure individual plants would establish well in the greenhouse environment. Crosses were done in 2003 and 2004 at the INHS greenhouses between the transplanted wild individuals and cultivar individuals purchased from the Green Glen Nursery in Joliet, IL. It should be noted that the same wild individuals were used for the crosses in 2003 and 2004. However, in 2004 it became evident that the cultivar plants purchased from Green Glen Nursery in Joliet, IL were not going to bloom that year. Therefore, new cultivar plants that were expected to bloom were purchased from Country Arbors Nursery in Urbana, IL and used for the crosses. In both years, newly forming wild and cultivar inflorescences were bagged with bridal veil to reduce pollen contamination from stray pollinators in the greenhouse. Bridal veil bags have been extensively used to exclude the great majority of pollinators. Nonetheless small insects such as thrips, which have been shown to be effective pollinators may not have been excluded. This could account for the observed seeds that were found throughout the inflorescence where hand cross-pollination had not occurred in this study (see Results section). Reciprocal crosses between the wild type and cultivar were made as follows; florets used for crosses were marked with pink nail polish, and using fine tip forceps pollen was squeezed out from the anther tube of a donor plant and place on the receptive stigma of recipient plant. Twenty-six wild heads were bagged and pollinated with cultivar pollen. An average of 7 florets per head, were pollinated for a total of 165 wild type florets. Eighteen cultivar heads were bagged and pollinated with wild type pollen. On average, 6 florets per head were pollinated, for a total of 118 cultivar florets. A two-way ANOVA was used for the analysis followed by a post-hoc Fisher's LSD multiple comparison test (SigmaStat, 1997).

## RESULTS

### Genetic Diversity

RAPD results produced a total of 35 repeatable loci to score for each of the 10 populations. No loci were unique to individual populations; however, cultivar populations did not contain a locus that was observed in the wild populations (primer-fragment size: B7-1980; Table 1). In the eight wild and two cultivar populations tested, 25 loci were missing in individual populations (Table 1). Because of repeatability issues and the dominant nature of the RAPD data, population genetic inferences were restricted to percent polymorphic loci. The average percent polymorphic loci (*P*) for all 10 populations was 45%, ranging from 14.3% (population 6) to 68.6% (population 9; Table 2). Percent polymorphic loci for cultivar populations fell within the wild population range (CAC - 40.0% and GGN - 62.8%).

The Shannon's Information Index partitioned diversity between the wild and cultivar populations. Results from this test supported the percent polymorphic loci findings. The total population index was 0.61. Wild type populations had an index value of 0.59, while the cultivar populations had an index of 0.52.

When the wild and cultivar populations were combined, AMOVA results indicated significant structure both within and among populations, with most of the variation found within populations (64.24%; Table 3a). When the wild and cultivar populations were separated, significant structure existed at all hierarchy levels (among populations, among populations within groups, and within populations), again with most of the variation found within populations (63.06%; Table 3b).

The plot resulting from the PCo analysis of the RAPD data separates the wild populations Rt. 53 and population 5 from one another as well as the remaining wild and cultivar populations (Figure 1). All other populations (wild and cultivar) aggregate to form a relatively indistinguishable group of individuals (Figure 1).

### Cross Pollination Potential

In 2003, 23 seeds developed from 165 wild florets crossed with cultivar pollen (Figure 2). The 118 cultivar florets crossed with wild pollen formed 26 seeds (Figure 2). In 2004, 50 seeds developed from 205 wild florets crossed with cultivar pollen. Of 135 cultivar florets crossed with wild pollen, 2 seeds were formed (Figure 2). A two-way ANOVA showed no significant differences between year or treatment (F=1.705, df=1, P=0.195 and F=3.155, df=1, P=0.080, respectively), but did show a significant interaction term (F=14.359, df=1, P<0.001). It should be noted that in all cases seeds were found throughout the inflorescence where hand cross-pollination had not occurred.

## DISCUSSION

Conservation managers are continually challenged with the need to protect sensitive, threatened, and endangered species. In order to conserve these rare species effectively, adequate species-specific information is needed. In conservation, some of this information includes a thorough understanding of the species' genetic diversity (Holsinger and Gottlieb, 1991). The threat of gene flow between wild species and their associated cultivar also presents conservation managers with the need to understand the potential risk of hybridization (Ellstrand, 1992). This study on the sensitive species *Rudbeckia fulgida* var. *sullivantii* helps to provide information to conservation managers, enabling successful long-term management of this species. This information can also be applied to other species facing similar threats.

### Genetic Diversity

Genetic diversity levels in *R. fulgida* var. *sullivantii* expressed as percent polymorphic loci (*P*), showed a wide range in diversity levels encompassing both the wild and cultivar populations (from 14.3% in population 6 to 68.6% in population 9). Of all the populations sampled, population 6 was the smallest in size (less than 50 ramets) and had the lowest percent polymorphic loci (14.3%). This result is similar to other studies that found smaller populations have lower genetic diversity than larger ones (Fischer and Matthies, 1998; Luijten et al., 2000). The lower levels of genetic diversity in this population may be the result of few genetically diverse founding individuals or loss of genetic diversity as the result of individual loss due to mowing, grazing, or herbicide application at the site.

Few studies on other *Rudbeckia* species have been done to compare levels of genetic diversity with *R. fulgida* var. *sullivantii.* However, one study that used Restriction Fragment Length Polymorphisms (RFLPs) to look at isolated *Rudbeckia missouriensis* populations in Missouri glades, found very low levels of overall diversity (5%; King and Schaal, 1989). While higher diversity levels are expected when using RAPDs, the discrepancy between 5% and an average of about 50% in *R. fulgida* var. *sullivantii* is substantially different. A study done on a related genus using allozyme markers showed varying degrees of genetic variation depending on whether the species was endemic or more widespread (widespread *Echinacea angustifolia* – 40.1% *P* and the endemic *Echinacea tennesseensis* – 23.0% *P*; Baskauf et al., 1994). Within Asteraceae, levels of percent polymorphic loci (using allozyme data) average 45.3% (Hamrick and Godt, 1996). While direct comparisons of these different studies are not possible given that they examined different genera and species as well as different molecular markers, the totality of data can at least be used to approximate expected levels of diversity for *R. fulgida* var. *sullivantii* and 'Goldsturm.'

Diversity levels of cultivar populations are a function of both the biological characteristics of the species and the cultural breeding practices (Godt and Hamrick, 1991). Within cultivated plant populations, genetic variation is either deliberately reduced or enhanced (Godt and Hamrick, 1991). In the case of *R. fulgida* var. *sullivantii*, the plant was cultivated initially for uniform height and bloom time; however, owing to the popularity of the plant and ease of seed and vegetative propagation, the rigorous standards for specific trait selection are no longer followed (R. Diblick, Northwind Perennial Farm Nursery Grower, pers. comm., 2003). This lack of trait selection may have contributed to the similar diversity levels found in 'Goldsturm' when compared to the wild type (as seen here in percent polymorphic loci, Shannon's Information Index, and the Principal Coordinates Analysis). However, the unique wild locus (B7-1980) combined with loci that were common in wild populations, but only present in sporadic cultivars (B7-510 and B8-610), indicate the importance of maintaining the genetic integrity of the wild populations by reducing contact with the cultivar. Physical separation of the wild and cultivar is recommended since it could reduce possible gene flow which, as other studies have shown, can result in hybridization, loss of genetic diversity or even extinction of the wild type (Ellstrand et al., 1999; Ellstrand, 2003; Lu and Snow, 2005; Rhymer and Simberloff, 1996; Snow et al. 2005).

The analysis of molecular variance indicates most of the genetic differentiation is partitioned within as opposed to among both wild and cultivar populations of *R. fulgida* var. *sullivantii* (64.24%; Table 3b). This partitioning of variation is expected for a perennial, outcrossing species because of increased gene flow between individuals and populations (therefore populations are genetically more similar). It is also an important factor to keep in mind when considering management strategies that seek to monitor and maintain population-level genetic diversity (Hamrick et al., 1991).

The Principle Coordinates Analysis (PCo) showed all cultivar and wild populations (except populations 5 and Rt. 53) to have similar RAPD marker distributions (Figure 1). Of the 35 loci analyzed, no allele was observed for nine and six loci in populations 5 and Rt. 53, respectively. On average, the remaining populations sampled lacked the presence of an allele in only one of the 35 loci. For the Rt. 53 population, this difference could possibly be explained by its isolated location from other MNTP populations as well as by its small size (200 ramets or less). Both the degree of isolation and size of a population increase the risk of genetic drift, potentially decreasing genetic diversity in a population (Ellstrand and Elam, 1993). It is possible that a slight decrease in genetic diversity is already seen in Rt. 53 based on its lower percent polymorphic loci (34.3%) relative to other populations (Table 2). These results suggest within a small geographic range (5 miles) distinct genetic differences between populations can be found. Additional research should be done to see if differences exist between populations throughout Illinois as well as the entire range of *R. fulgida* var. *sullivantii.*

Unlike Rt. 53, population 5 is located within MNTP. A different feature of population 5 that could account for its separation in the PCo plot is the habitat where samples were collected. This dispersed population was small and located on either side of a railroad. One part of the population was adjacent to a forested area with taller vegetation surrounding individual plants, while the portion on the other side of the railroad was located in a more open old field. A majority of the other populations sampled were located in open prairie habitat. Another likely reason for the differences could be the reduced number of RAPD loci scored for this population (i.e., five loci were scored as missing).

## Cross Pollination Potential

Studies have shown gene flow provides an avenue for the transfer of genes from cultivated to natural populations (Burke et al., 2002; Linder et al., 1998; Whitton et al., 1997). Through gene flow, these introduced genes have shown increased invasiveness, weediness, and even extinction (Barbour et al., 2002; Burke et al., 2002). In both 2003 and

2004, reciprocal greenhouse crosses of *R. fulgida* var. *sullivantii* and 'Goldsturm' resulted in seeds set, suggesting that gene flow is possible between the wild and cultivar form. The risk of the transfer of genes can be considered high because bloom time for both the cultivar and wild populations is the same. In addition, the growing popularity of 'Goldsturm' in home gardens (evidenced by its perennial plant of the year award in 1999) increases the likelihood of gene flow between the wild and cultivar forms.

Although the two-way analysis of variance did not show significant differences between years, the significant interaction draws attention to the low seed set found in 2004 when crossing the cultivar inflorescences with wild pollen. One possible reason for the large variation between cultivar seed set in 2003 and 2004 could be that the cultivar plants for each year were purchased from two separate nurseries. Cultivar varieties may differ between nurseries due to different seed sources, age, and/or size of plants resulting in varying levels of seed set. Also, issues of pollen contamination in 2003 due to the bridal veil touching the inflorescences may have inflated seed set and contributed to differences found between years. Finally, because the reciprocal crosses were conducted in a greenhouse, additional research is needed to determine if cross-pollination is actually occurring between populations within MNTP and cultivars planted at adjacent sites (e.g., home gardens). If this is the case, then, the conservation and ecological consequences for the wild type should be further investigated.

### Conclusion

Overall, these results suggest that within MNTP unique genetic differences occur among the wild populations. While little genetic difference appears between *R. fulgida* var. *sullivantii* and 'Goldsturm' populations, loci differences combined with confirmed gene flow potential indicate the importance of keeping the wild and cultivar populations separate to preserve the wild populations' genetic integrity. Finally, this study adds to the increasing number of works (Van Gaal et al., 1998; Whelan et al., 2006) voicing concern about the potential of gene flow between cultivated forms of native plants in home gardens with their wild type relatives.

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Table 1. RAPD markers missing in individual wild and cultivar populations of *Rudbeckia fuligda* var. *sullivantii*. Asterisks indicate loci were present in two or fewer of the individuals sampled. CAC, Country Arbors Nursery; GGN, Green Glen Nursery; Rt. 53, Route 53; GCP, Grant Creek Prairie, and MNTP, Midewin National Tallgrass Prairie.

| Populations | RAPD loci absent |
|---|---|
| CAC (cultivar) | B7-1980 |
| GGN (cultivar) | B7-1980 |
| GCP | A4-100 |
| MNTP-9 | A4-100, A1-920* |
| MNTP-7 | A4-100 |
| MNTP-6 | A4-100 |
| MNTP-5 | A1-645*, A1-1800, A4-575*, A4-910*, B7-1500, B7-1980, B8-700*, B8-980*,<br>B8-1150, B8-1500 |
| MNTP-4 | None |
| MNTP-3 | None |
| Rt. 53 | A1-730, A1-1800, A4-445, A4-630,<br>A4-1450, B7-1500, B7-1710, B7-1980 |

Table 2. Percent polymorphic loci of eight *Rudbeckia fulgida* var. *sullivantii* populations and two cultivar "populations" based on RAPD markers. A population is considered monomorphic if the locus is present in 95% or more of the individuals. Asterisks indicate cultivar populations. Abbreviations: N, number of individuals sampled; *P*, percent polymorphic loci; CAC, Country Arbors Nursery; GGN, Green Glen Nursery; Rt. 53, Route 53; GCP, Grant Creek Prairie, and MNTP, Midewin National Tallgrass Prairie.

| Population | N | P |
|---|---|---|
| *CAC | 24 | 40.0 |
| *GGN | 24 | 62.8 |
| GCP | 30 | 37.1 |
| MNTP-9 | 30 | 68.6 |
| MNTP-7 | 24 | 57.1 |
| MNTP-6 | 19 | 14.3 |
| MNTP-5 | 30 | 65.5 |
| MNTP-4 | 30 | 40.0 |
| MNTP-3 | 30 | 51.4 |
| Rt.53 | 23 | 34.3 |

Table 3. Results of analysis of molecular variance (AMOVA) for all tested *Rudbeckia fulgida* var. *sullivantii* populations (cultivar and wild) under two alternative groupings (a) combining wild and cultivar populations together and (b) separating wild and cultivar populations.

| | Df | Sums of squares | Variance components | % of variance |
|---|---|---|---|---|
| **(a) All populations (wild type and cultivar) combined** | | | | |
| Among populations | 9 | 19.689 | 0.074 | 35.76* |
| Within populations | 266 | 35.683 | 0.134 | 64.24* |
| **(b) Wild type and cultivar populations separated** | | | | |
| Among populations | 1 | 2.407 | 0.005 | 2.70* |
| Among populations within groups | 8 | 17.283 | 0.072 | 34.24* |
| Within populations | 266 | 35.683 | 0.134 | 63.06* |

* $P < 0.001$; significance tests after 1023 permutations

Figure 1. Graphical representation of Principal Coordinate Analysis showing RAPD marker distributions of *Rudbeckia fulgida* var. *sullivantii* cultivar populations (●) in relation to wild populations (x). Two distinct wild populations are labeled; population 5 (■), and Rt. 53 (○).

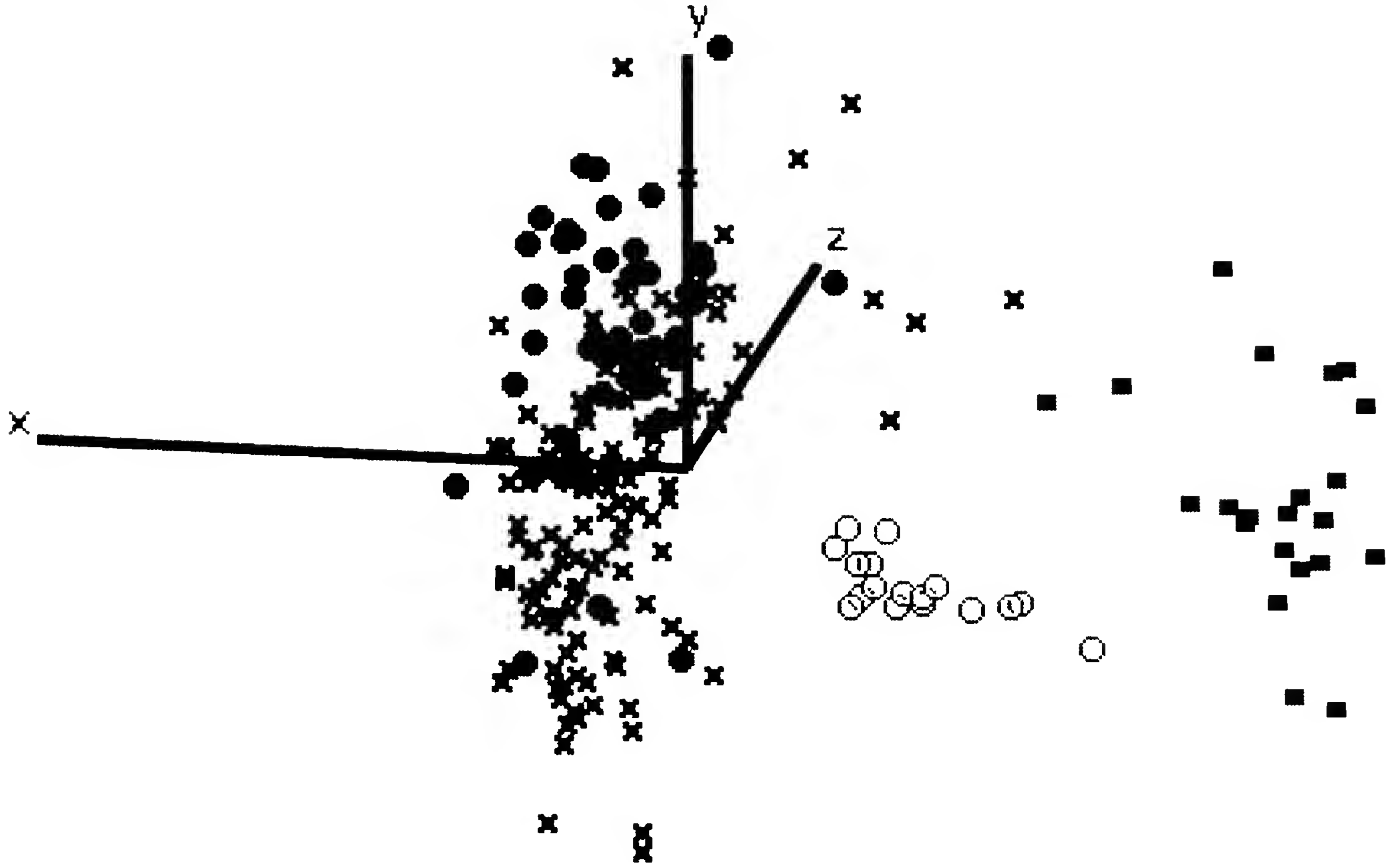
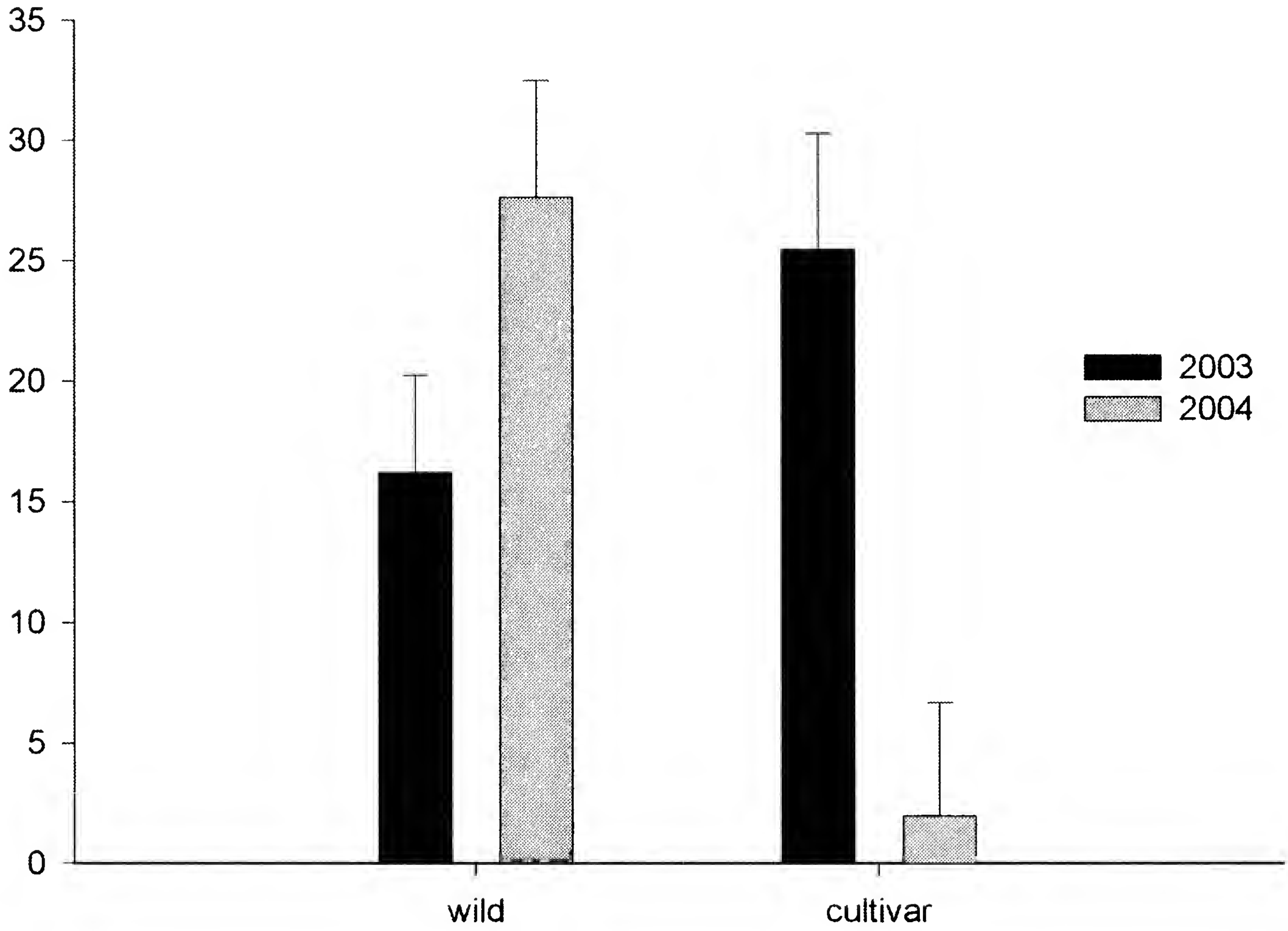


Figure 2. Percent seed set for 2003 and 2004 crosses between the wild type *Rudbeckia fulgida* var. *sullivantii* and cultivar 'Goldsturm.'



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# Study of the Levels of Insoluble Mercury in the Soil of the Lake Calumet and South Chicago Area

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## ABSTRACT

Over 100 randomly distributed soil samples were gathered in the Lake Calumet region on the south side of Chicago. The samples were gathered from the top few centimeters of soil. Locations were determined by GPS portable receivers and each site was described. The average mercury content in the samples was 122 parts per billion (ppb) with a large standard deviation of 180 ppb indicating at least a bimodal distribution of values. No significant evidence indicates appreciable deposition of this insoluble mercury pollution can be attributed to a nearby coal-fired power plant. The sites with large concentrations appear to be associated with past or continued use of mercury pesticides, industrial spills, or transportation related emissions.

## INTRODUCTION

For over the last decade since the Clean Air Act of 1990 (USEPA, 1990) there has been active research and policy formulation to reduce the emission of mercury from coal fired power plants (USEPA, 1997). In March 2005 a final rule on a mercury emissions cap and trade system (CAMR, 2005) was published. This rule sets nationwide caps for mercury emissions which will slowly decrease over the next 20 years and should allow power plants to trade emission credits as a mechanism for facilitating the process of emission reduction. In preparation for this final rule the United States Environmental Protection Agency has conducted and sponsored analyses and discussions (Sullivan, 2006) about issues pertaining to mercury emissions from coal fired power plants. One of the unresolved issues is whether there are "hot spots" of excess mercury deposition around the plants that would not be ameliorated under the new national standards and caps.

Most predictions of mercury deposition have been based on mathematical dispersion models based on emissions and simple models of deposition (Sullivan, 2006). These models have included atmospheric chemistry processes that affect the partitioning of Hg emissions into elemental ($Hg^0$) and reactive forms ($Hg^{2+}$ : soluble or insoluble) that may be deposited near sources (Sullivan, 2006). The possible depositions may be in the soil, the plant matter, and in water or aquatic animals. Recent evidence (Edgerton, 2004; Laudel, 2004) has suggested that reactive gaseous mercury in plumes emanating from coal fired power plants quickly reduces to elemental mercury. This effect would greatly reduce the deposition near coal fired power plants and bring into question whether there are significant “hot spots” near such plants.

A major study of localized mercury deposition by Brookhaven National Laboratory (Sullivan, 2004) surveyed all of the previous literature and conducted a follow up study of two rural power plants. One of these was the Kincaid power plant which is in a rural area just east of Springfield, Illinois and was being studied for a second time. The other studied plant was only identified as Plant A. Including the second Kincaid study there have been five studies of the Hg content of surficial soil samples around coal fired power plants. (Klein, 1973; Anderson, 1977; Crockett, 1979; Sullivan, 2006). The Klein study was conducted near Campbell, MI, around a 650 MW coal fired plant with a 122 m stack. There were 90 samples with a mean concentration of 10.2 ppb (parts per billion by weight, or, equivalently, micrograms of Hg per kilogram of soil) compared to an estimated background of 7.9 ppb. Anderson studied the Kincaid plant near Springfield in 1977. In this study there were 90 soil samples with a mean concentration of 22 ppb over an estimated background of 15.4 ppb. The Crockett study was conducted in the Four Corners area of the southwestern United States and measured 70 samples surrounding the 2150 MW Four Corners power plant. There was no measurement of the background concentration but they found an average concentration of 14.5 ppb in the area. A re-analysis of their concentrations as a function of the distance carried out by Sullivan found a logarithmic derivative of -0.11, though the standard deviations at each distance were up to two thirds of the average values at each distance and this estimate is not significant statistically.

Around Plant A (Sullivan, 2006), which burns locally mined lignite, soil and vegetation samples were collected at 54 selected sites in a region predicted by mathematical precipitation models. The average soil background for Plant A was 28.2 ppb. The soil Hg concentrations for this plant did not show any significant trend with distance and were not distributed as predicted by the deposition model.

The Kincaid plant (Sullivan, 2006) was sampled at 122 sites evenly spaced on a one mile square grid around the plant for radial distance of about 5 miles. The average soil concentration of Hg was found to be 32.4 ppb, with a standard deviation of 17.7 ppb. The range of values was 16.9 to 155.6 ppb. Eight additional sites were chosen along roads far from the plant to serve as background. It is interesting to note that these 8 samples from roadside sites 11 to 23 miles away were higher than sites nearer the plant, with an average value of 41.0 ppb. These samples were taken within 20 feet of the edge of the road in the right-of-way. The 2004 study of Kincaid (Sullivan, 2006) showed roughly the same range of soil samples as the 1977 study, with a number of higher values. Not all of the 1977 data was available so it was not possible to calculate whether the difference between the average values is significant.

All of these power plant site studies have been in rural areas. It is well known that in urban areas there will be a higher level of Hg concentration (Landis, 2002). This study of Hg in soil samples in an urban area was carried out to provide a contrast to the rural sites and to examine the question of “hot spots” in a heavily populated area.

## MATERIALS AND METHODS

The process of sampling began by generating 200 random sites within the Lake Calumet quadrangle map of the USGS, covering from (41°37'30''; 87°37'30'') in the lower left hand corner to (41°45'; 87°30') in the upper right hand corner. These 200 random sites were then divided into five groups and each of our researchers culled sites with inaccessible or dangerous locations in the midst of highways, lakes, industrial sites, or rail yards. Sites that were close to each other were merged and the final 100 sites were designated. Each of the five researcher groups were driven to the sites, determined the exact location using a GPS device, wrote a brief description of the site for further correlation, and collected a surface soil sample (1 to 5 cm in depth) (Sullivan, 2006). The soil samples were dredged from the shallow surface soil at each site and collected into a 50 ml centrifuge tube that was labeled by sample number. From each sample were weighed out two replicates of soil that had been separated from any organic material. The samples were then analyzed for mercury according to the protocols outlined as EPA Method 7473 (USEPA, 2000) using a Direct Mercury Analyzer (DMA-80, Milestone, Inc). Of all the 100 pairs of samples which were run for this study, only ten pairs were surprisingly disparate, and these samples were run a second time. Later in the fall one of us (J.F.) collected an additional 20 samples on the west side of the Calumet quadrangle.

## SAMPLE SITE GEOGRAPHY AND HISTORY

The Lake Calumet area in Illinois is the area including the southeast section of Chicago bounded on the east by the State of Indiana boundary and on the south by the suburbs of Dolton, Thornton and Calumet City. The area has quite a variety of ecosystems, ranging from densely populated single family residential areas, some multiple family housing, industrial sites (both active and inactive), navigable and re-constructed rivers, canals and basins and natural lakeside, grassland and forest. The soil region is mostly Wisconsian Outwash (NCRS, 2007). The Little Calumet River and the lakes connecting to the southern shore of Lake Michigan made this region a water transportation hub and industrial site almost from the earliest settlements in the region. The area has been an industrial and transportation center of the nation for almost 200 years. In particular, coke plants and steel plants have been very abundant in the northeast part of this area. In the Northeast corner of quadrant is the State Line coal-fired electricity generating plant (525 MW). Near the center of the region is an inactive coke plant that was used for many years to generate coke for use in nearby steel mills. Through the center of the region and across the northern third are two major highways: Interstate 90/94 and the Skyway I-90, connecting to the Indiana Tollway in the northeast. Interstate 57 begins near the center and proceeds to the southwest. Many railroads pass through this region with numerous sidings to active and inactive industrial sites. There are also several large high voltage lines that traverse the region. Two institutions of higher learning are in the area: Chicago State University and Olive Harvey College, one of the City Colleges of Chicago. A number of elementary schools and high schools are also in the area. The area also has a number of landfills and a number of chemical and chemical waste companies.

## RESULTS AND DISCUSSION

The average Hg concentrations for this study and the previously discussed studies are reported in Table 1. The average of this study was 122 ppb and the range of samples was 5.9 ppb to 1579.1 ppb.

Previous studies of mercury concentrations in soils by Sullivan (Sullivan, 2006) and Tack (Tack, 2005) have found that the distribution of concentration values follows a lognormal distribution. In order to compare our samples with these previous studies the cumulative distribution of mercury concentrations relative to the average of the distribution was plotted with a lognormal cumulative distribution with a geometric standard deviation of 0.4 and is shown in Figure 1. A cumulative distribution plots the log of the Hg concentration divided by the average concentration against the fraction of the observations with values below that concentration. Thus the value at the highest concentration is one and at the lowest concentration is zero and at the average concentration the value is 0.5.

A slight break in the distribution of concentrations in our sample is apparent in Figure 1 just above the 0.4 value of the sample fraction and just to the left of the zero value for the log of the concentration ratio. It can be seen that the actual distribution is above the lognormal distribution near 0.4 and slightly below at about 0.45, with only a few points in between. This represents a slight break in the distribution near 100 ppb and suggests that there might be a bimodal distribution with two different high and low averages. These Hg soil samples were also examined by a normal Q-Q probability plot of the logarithms of these values. This plot showed the same lognormal behavior as noted for Figure 1. The distribution is very close to lognormal except at the lowest four samples and the highest 25 samples.

To characterize the geographical distribution the Lake Calumet Quadrant was split into six regions, each containing approximately the same number of points. First, the region was split into eastern and western halves. Each of these two halves was then broken into a northern third, the central third and the southern third. Lake Calumet itself occupied most of the middle of the central regions. The concentration averages and their standard deviations by region are tabulated in Table 2.

The average of all six regions is 122 ppb with a standard deviation of 180 ppb. Many of the standard deviations are dominated by a few larger values. Having a large standard deviation suggests that there is at least a bimodal distribution. Indeed, the distribution seems to have many points of smaller concentrations and a collection of much higher concentration sites. The average of the lower 68 values is 49 ± 26 ppb and the average of the 40 values above 100 is: 219 ± 146 ppb.

The East Central Indiana border, which has the smallest average concentration, is the least populated region with the most open water: Eggers Woods Forest Preserve and the Wm. W. Powers Conservation Area of Wolf Lake. At the same time, this area is closest to and just southwest of the State Line coal burning power plant.

The southeast bottom grouping included several industrial sites on the east side of Lake Calumet as well as residential sites in the Hegwich neighborhood of Chicago and the northern neighborhoods of Dolton, Thornton, and Calumet City. In this grouping we have both the highest concentration site as well as some of the lowest concentration sites in residential areas.

The two northern regions of the survey included predominantly urban residential sites from the Dan Ryan expressway east toward Lake Michigan. In this region were found the remaining highest isolated residential sites. These high concentration sites had very neat monoculture yards of grass and highly manicured plants. Because of this observation it was suspected that previously or currently used fungicides or herbicides might be a very important contributor to these isolated high values. Mercury is currently now allowed in herbicides and if this is the source it must reflect use in the past. The Merck Index (Budovari, 1996) lists at least one mercury based herbicide, phenylmercuric acetate, which once was legal.

The distribution of concentrations around the region can further be studied in a number of ways. A GIS plot of the distribution of the mercury concentration throughout the region is shown in Figure 2. As can be seen in Figure 2, the spatial distribution is a mix of large and small quantities in close proximity. The average concentrations for varying intervals are represented by filled circles of increasing radius in the following order: (10, 25, 50, 75, 100, 250 ,500, 750, 1000) ppb. The coal fired power plant is located in the upper right hand corner of the figure on the small rectangular land mass that juts out into Lake Michigan at the Illinois and Indiana border. The power plant's location is indicated by a capital "X".

It is difficult to discern a pattern in the distribution of concentrations from Figure 2. There is a hint of a band of larger values in a semi-circle around the power plant with a radius of about 4 kilometers, but interspersed among these larger values are several smaller values. It is also worth noting that many of the large concentration values were near to roads through industrial areas along the eastern shore of Lake Calumet. There is no clear trend of mercury concentrations decreasing with distance from the power plant for distances less than approximately 6 Km.

The two largest concentrations were in mixed residential areas. The largest sample was from an unimproved lot used to sell used cars and could be the result of dumping. The second largest sample was in a northern section, a residential area with exceptionally well manicured lawns. It would appear that the most likely cause of many of the large mercury values could be residual pesticides, herbicides, or fungicides whose use was banned 15 years ago (ATSDR, 1999). The very largest concentration of the summer was found in a rose bed that had been under cultivation for several decades. This rose bed was not in the Calumet quadrant.

The mercury concentrations were plotted versus the radial distance from the power plant in Figure 3. In this plot, the fact that sites quite near each other in distance from the plant can have significantly different values is manifest in the mix of high and low values at close to the same distance from the power plant.

Several analyses were conducted using Log-Log plots to estimate the exponent of a functional form for the concentration $C(r) = Ar^{\beta}$ where r is the distance from the power plant, A is a constant, and $\beta$ is the exponent of the distribution. Presumably, if the power plant were the major source of Mercury in the region, this functional form should fit the data with a negative exponent at large distances from the plant. All fits using this form had very small correlation coefficients, primarily because of the intermingling of high and low concentrations as functions of the distance r. If we include all of the points, the best fit value of the exponent is positive. If we consider only points with concentrations below 100 ppb, the exponent was slightly negative (-0.03). However, the Correlation coefficients $R^2$ for all of the fits that were tried were very low ($R^2<0.1$) and none of the fits would be considered statistically significant. None of these analyses supports the assumption that the power plant is a significant source of the insoluble mercury concentrations that we measured.

The soil concentrations found in this urban/industrial area were much higher than those found by Sullivan et al. (2006) around two different rural power plants. Their average concentrations were around 30 ppb, while our overall average was four times larger. It must be concluded that the area we studied is significantly more polluted relative to mercury concentrations than rural areas. The EPA website (www.epa.gov) suggests that urban sites which have been occupied for many years would have average concentrations of about 100 ppb. The same website indicates that our levels are significantly below the superfund criterion of 20,000 ppb.

Another possible Hg source is suggested by the geographical distribution of this study as well as by the study of the Kincaid power plant near Springfield, IL, (Sullivan, 2006), in which samples taken within 10-20 feet of the edge of roads had higher mercury concentrations than sites close to the power plant and far from the road right-of-way. Similarly, a number of the larger concentrations in this study, but not all, were taken close to high density roads. It is possible that higher mercury concentrations on road right-of-ways reflect past use of mercury based herbicides to control visibility by suppressing growth of large plants. On the other hand, some evidence (Hoyer, 2002), suggests that some mercury pollution may be associated automobile traffic.

## SUMMARY

One hundred surface soil samples were collected in the Lake Calumet area. One has to conclude that in an urban area such as this, any "hot spots" associated with the power plant as measured by the insoluble Hg soil concentration are difficult to find. Soluble compounds would have been washed away by rains and elemental Hg is expected to be widely dispersed so these soil samples may observe only the smallest effects. There is little evidence in the Hg soil distribution that the power plant can be regarded as a major source of that distribution. Other accumulations over history would appear to be much more important. It would be interesting to determine the role of mercury fungicides, and possibly herbicides, used previously in both urban and rural areas. It would also be interesting to pursue the possibility of road traffic as a source of Hg near to roadways.

## ACKNOWLEDGMENTS

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Figure 1. The cumulative distribution of the mercury soil samples plotted relative to the average and compared to a lognormal distribution with a geometric standard deviation of 0.4. The closeness of the lognormal distribution of the actual data is consistent with other measurements of similar Hg concentrations.

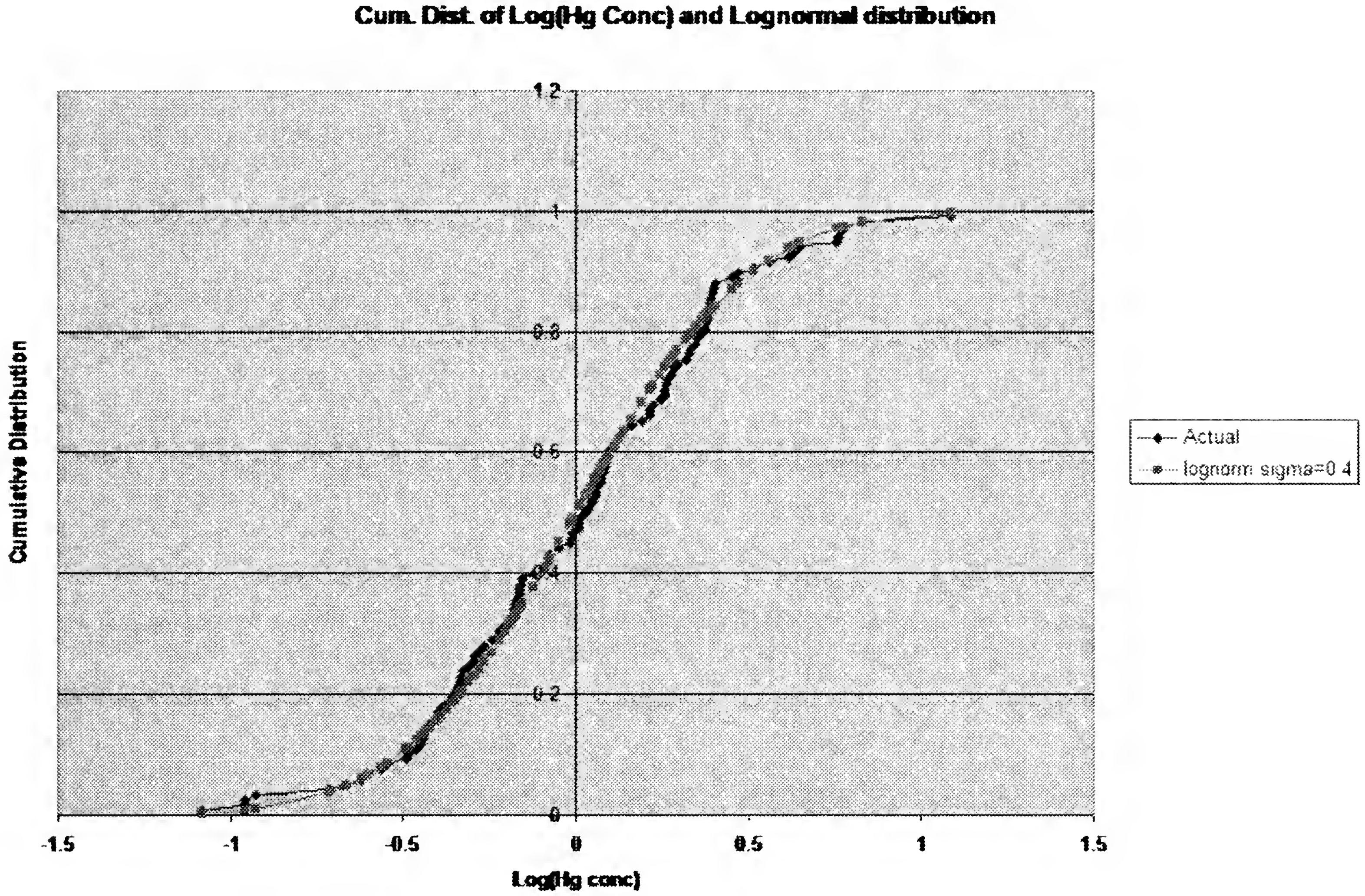


Figure 2. The concentration of mercury in the soil from this study is plotted as an overlay to a map of the Lake Calumet Region showing the incorporation limits, the waterways, and the major Interstate Highways. The average concentrations for varying intervals are represented by filled circles of increasing radius in the following order: (10, 25, 50, 75, 100, 250, 500, 750, 1000) ppb. The power plant, which could have been the source of this distribution is on a rectangular piece of land at the Lake Michigan shore where the Illinois and Indiana boundary intersects the lake. The power plant's location is indicated by a capital "X".

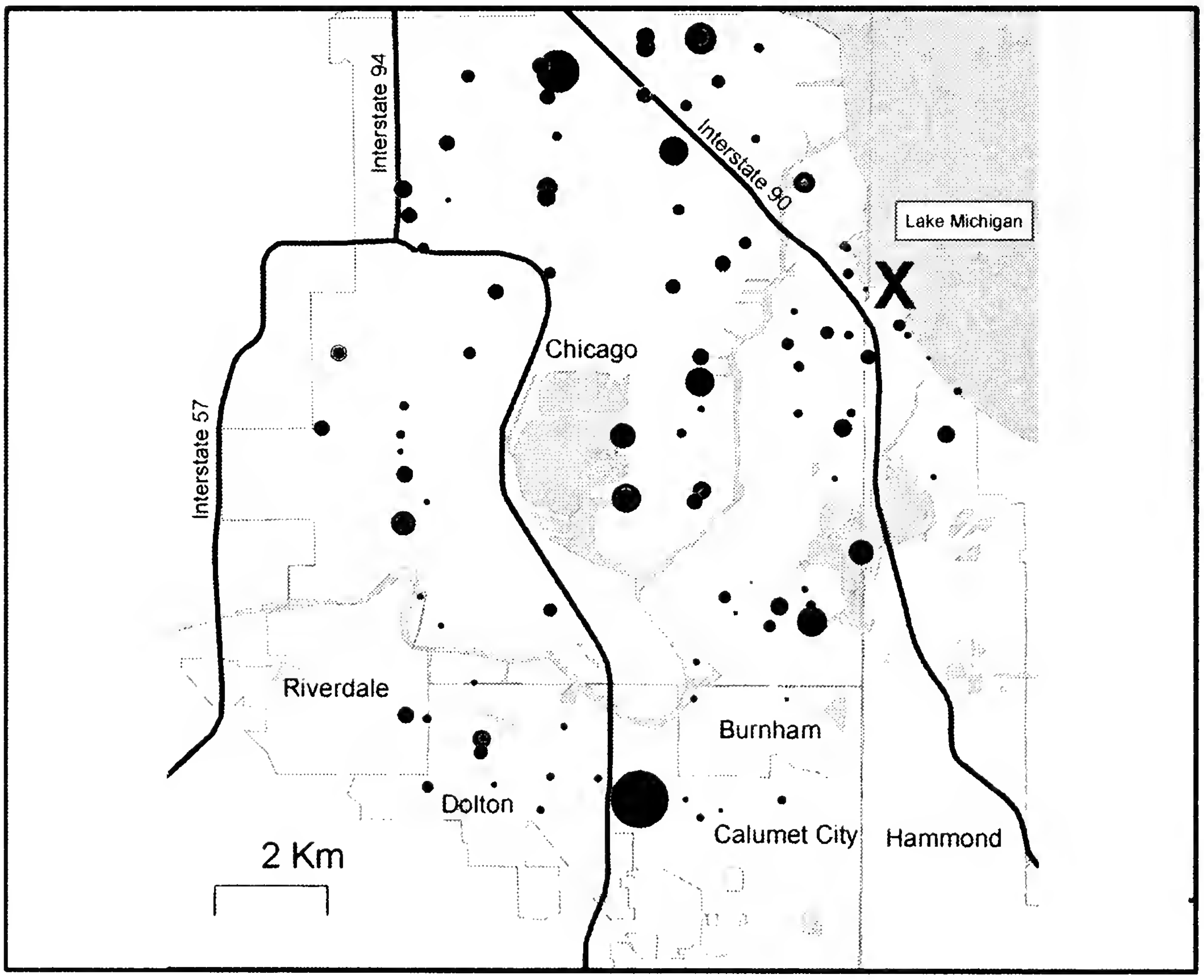
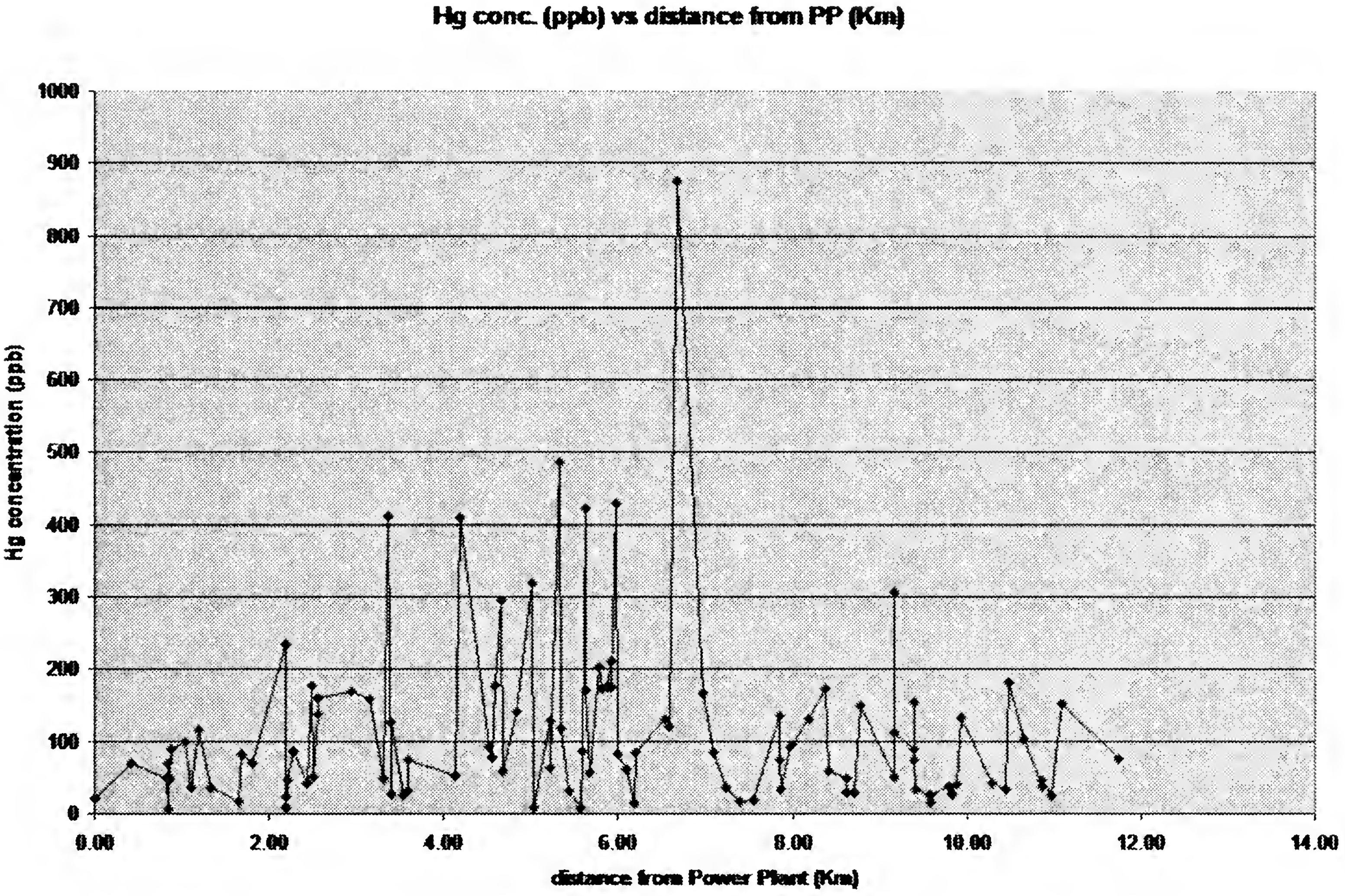


Figure 3. The mercury concentration values are plotted versus the distance from the power plant in kilometers. Note the mix of sites at similar distances with highly different concentration values.



You need a Table 1 description, similar to what you have for the Figures. Perhaps:

Table 1. Average Hg concentrations for this study and other discussed studies.

| Study | Average Hg Concentration (ppb) |
|---|---|
| Klein & Russel (1973) | 10.3 |
| Anderson & Smith (1977) | 22 |
| Crockett & Kinneson (1979) | 14.5 |
| Sullivan et al. (2006), Plant A | 28 |
| Sullivan et al. (2006), Kincaid | 32.4 |
| Lake Calumet (this study), (2007) | 122 |

You need a Table 2 description, similar to what you have for the Figures. Perhaps:

Table 2. Average Hg concentrations of the six regions of the Lake Calumet Quadrant.

| Region, No. of samples ( ) | Average Mercury Content (ppb) ± S.D. of samples in region |
|---|---|
| Northwest top - CSU (14) | 160 ± 170 |
| Northeast top - near Lake Michigan (25) | 130 ± 120 |
| West Central (13) | 100 ± 90 |
| East Central Indiana border (23) | 73 ± 47 |
| Southwest bottom (12) | 130 ± 330 |
| Southeast bottom (12) | 140 ± 140 |

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# Characterization of Wetlands in the Conservation Reserve Enhancement Program in Illinois

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## ABSTRACT

Farm Bill programs have been valuable tools for the restoration of wetland habitat on private lands in recent decades. Over 14,000 ha have been enrolled in the Conservation Reserve Enhancement Program's (CREP) wetland practices in Illinois alone. However, the amounts and types of wetland habitat resulting from these restorations efforts are not well documented. We surveyed a random sample of 33 CREP wetlands throughout central Illinois in 2004 and 2005 to determine the floristic, physical, hydrological, and spatial characteristics of sites representative of CREP in the Illinois River Basin. Twenty-eight of thirty-three (85%) sites achieved some degree of functional hydrology, but the area of wetland established on most of those (61%) was small (< 1 ha). Twenty-four percent of the total area enrolled in our sample qualified as wetland habitat. Among all functional sites, seasonal water regimes were the most prevalent. Many of our wetland study sites were overly dominated by upland cover. The wetland cover that was present was dominated by emergent habitat (91%), followed by forested (9%), and scrub-shrub (<1%) habitat. The mean floristic quality was relatively low among sites and varied little, with a mean C value across all sites of 4.06 ± 0.54 (mean ± SD). Neither hydrology nor wetland isolation had significant effects on floristic quality among sampled sites. We believe more time is needed for these wetlands to mature before spatial and hydrologic conditions begin to strongly affect floristic quality. However, we maintain that hydrologic management is vital for sustaining the hydroperiods necessary for establishment of wetland plant communities in restored CREP wetlands.

## INTRODUCTION

Wetlands provide valuable environmental and ecological services. However, less than 10% of the presettlement wetland acreage in Illinois that once supported these services now remains (Suloway and Hubbell 1994). Conservation programs administered by the United States Department of Agriculture over the last three decades have provided a major tool for the restoration of former wetland habitat on private lands (Natl. Res. Counc. 1992). By coupling conservation initiatives with landowner incentives, CREP has been able to achieve large-scale restoration of natural areas on private lands to stabilize soil, improve water quality, and support wildlife (Allen 2005). Some 14,000 ha have been enrolled in wetland conservation practices throughout the Illinois River Basin since the program's inception in 1998 (State of Illinois 2004). While the objectives of CREP include improvements in both environmental conditions and wildlife habitat, most of the assessment of CREP, in Illinois and nationwide has been limited to soil, nutrient, and water quality variables (Lamont 2005; Wanhong et al. 2005; Demissie et al. 2001).

With tracts scattered throughout the Illinois River Basin, it is difficult for the administrating agencies to effectively describe and monitor all of the habitat being produced through these restorations. The characteristics of the habitat enrolled are only recorded according to arbitrary conservation practices (CP) rather than actual habitat restored (Allen 2005). Wetland habitat can develop as a product of any CP, including the planting of grass cover (CP 1 and 2) and hardwoods (CP 3), and the establishment of filter strips and buffers (CP 13, 21, 22, 30), but explicit wetland practices (CP 9, 23, and 31) are the typical avenues for intentional restoration of wetland habitat. CP 9 and 31 are lesser-used practices associated with shallow water areas for wildlife and bottomland hardwoods respectively. CP 23 is the most common of the three encompassing the general practices of wetland restoration, including emergent marshes and wet meadows (Allen 2005). Even though there are many different CPs to facilitate various restoration goals, the type of physical and floristic conditions produced within a single CP, such as CP 23, can vary greatly.

Wetlands that are successfully restored through programs such as CREP are largely defined by the dominant vegetative community that colonizes the site following hydrologic restoration (LaGrange and Dinsmore 1989, Sewell and Higgins 1991, Galatowitsch and van der Valk 1996, Brown 1999, Reaves and Croteau-Hartman 1994). The response of vegetation to hydrologic restoration varies according to basin size and morphology, local drainage patterns, and landscape context (Rossiter and Crawford 1986; Galatowitsch and van der Valk 1993, 1996, 1996*b*; Bedford 1999). Assessment of the vegetative community restored in CREP wetlands is an essential first step in the evaluation of the program's overall contribution to potential wildlife habitat.

Brown and Phillips (2004) conducted the first and only floristic survey of 100 representative CREP tracts in central Illinois in 2003. The floristic quality of these wetlands was found to be moderate to low compared to regional standards (Brown and Phillips 2004). Indices of habitat quality were positively correlated with area, but were not related to the other independent variables of age and connectivity (Brown and Phillips 2004). We revisited Brown and Phillips (2004) study sites to further characterize each unique wetland according to spatial, floral, and physical characteristics of macro- and microhabitats.

## METHODS

### Study Area

A random number generator was used in 2003 by Brown and Phillips (2004) to select 100 CREP wetland and riparian contracts from 1,213 contracts included in the Illinois Department of Natural Resources' Conservation Practices Tracking System in 2003. Each contract represented an individual enrollment in CREP, and described the legal and financial agreement between the USDA and the landowner. These contracts also described the conservation practice being applied to the particular tract, which had physical geographic boundaries, but may not have coincided with natural boundaries. The sampled database included contracts from Sangamon, Christian, Schuyler, Fulton, and Knox Counties. In 2004 we revisited the sample of 100 wetland and riparian contracts from the Brown and Phillips (2004) study to determine the number of discrete CP 23 wetlands within their 100 contracts. We identified 33 wetland restoration sites that constituted independent and entire CP 23 wetlands. This sample is small relative to the total number of sites across the watershed, but we believe it is representative of all the sites in the region. The 33 wetlands were palustrine habitats ranging in age from 3-6 years, with a history of either row crop production or pasturing prior to restoration. Sites were dispersed throughout the watersheds of the Illinois, LaMoine, Spoon, and Sangamon Rivers (Figure 1), and fell within the Western Forest-Prairie, Illinois River Bottomlands, and Grand Prairie natural divisions.

### Floristic Data Collection

The flora of all 33 CREP wetlands were surveyed in the summer of 2003 using standard transect sampling techniques (Brown and Phillips 2004). Weighted indices such as the Floristic Quality Index (FQI) and its component the Mean Coefficient of Conservatism (mean C; Taft et al. 1997; Swink and Wilhelm 1979, 1994) have been found to be reliable indicators of wetland plant community integrity (Lopez and Fennessy 2002). A coefficient of conservatism is an integer ranging from 0 to 10 assigned a priori to each taxon in a regional flora that estimates the fidelity of a species to natural areas (Taft et al. 1997; Swink and Wilhelm 1979, 1994). Species with very low tolerances to disturbance and high fidelity to habitat integrity are assigned a coefficient near 10, while non-native and ruderal species that tolerate almost any disturbance and can be found in almost any type of habitat are assigned 0 or low values (Taft et al. 1997). To compare floristic quality across sites, we used the plant species list from each site to determine a mean C value for each wetland. Mean C is less strongly correlated with sampling date or area than FQI and provides a more robust indicator of relative site conservation value (Rooney and Rogers 2002; Lopez and Fennessy 2002; Matthews 2005). Each wetland also was surveyed in 2004 and 2005 to visually estimate areal coverage of herbaceous vegetation.

### Habitat Data Collection

We visited each of the 33 sites weekly during the growing seasons of 2004 and 2005 to monitor fluctuations in hydrology and determine duration of inundation as an indicator of wetland status and hydrology modifier class (NRCS 1997; Cowardin et al. 1979). Semi-permanent wetlands were identified as those having surface water throughout the growing season in most years. Seasonal wetlands were those having surface water for extended periods in the growing season but not at the end of the growing season, and temporary wetlands were those with surface water for only brief periods during the growing season (Cowardin et al. 1979). We also recorded the degree of hydrologic manipulation present in each wetland. A wetland was given a hydrologic manipulation score of 1 if no initial or ongoing physical manipulations of the hydrology were detected, 2 if it was hydrologically engineered at the time of construction by some form of an excavated basin, a dozier valve, stoplog, berm, or levee, or 3 if ongoing management of water depth was detected. We tested the hypothesis that floristic quality of wetland vegetation at a site was related to hydrology by regressing mean C against our hydrologic manipulation scores.

Using National Agriculture Imagery Program color-infrared digital orthoimagery (USDA 2004), we delineated wetland boundaries based on hydrologic indicators and the relative presence of hydrophytic vegetation (Reed 1988). We classified these areas as emergent, scrub-shrub, or forested habitat as defined by Cowardin et al. (1979). Emergent wetlands were characterized by erect, rooted, herbaceous hydrophytes, excluding mosses and lichens. Scrub-shrub wetlands included areas dominated by woody vegetation less than 6 m tall. Forested wetlands were characterized by woody vegetation ≥ 6 m tall (Cowardin et al. 1979).

Due to their previous use for intensive agriculture, our study areas were largely void of wetland flora prior to hydrologic restoration. Colonization by hydrophytes is dependent not only on germination of the dormant seed bank but also on wind, water, and animal-borne seed dispersal (Galatowitsch and van der Valk 1993). We tested the hypothesis that floristic quality at a site was influenced by the isolation of a site from potential seed sources by regressing mean C against the area of aquatic habitat within a 3-km buffer around the perimeter of each wetland (Fairbairn and Dinsmore 2001). We used National Wetlands Inventory data in ArcGIS 9.0 (United States Fish and Wildlife Service 1996; ESRI 2004) to quantify the areas of aquatic habitat within the buffers, and square-root transformed areal data to achieve a normal distribution.

## RESULTS

CREP tracts ranged in size from 1.9 to 149.0 ha, with a median of 19.7 ha. Twenty-eight of the 33 tracts (85%) had functional hydrological regimes ranging from temporary to semi-permanent (Cowardin et al. 1979; Table 1). The remaining 5 sites did not support enough water to meet wetland hydrologic criteria. The area of actual wetland ranged from 0.01 to 122.80 ha with a median of 0.9 ha (Table 1). Twenty-four percent of the total area across all sites qualified as wetland habitat. Twenty-five of the 28 functional wetlands (89%) were < 5 ha in size, and 17 (68%) of those 25 were < 1 ha in size.

Temporary wetlands accounted for 21.5% of total wetland area. Seasonal wetlands were the most prevalent, covering 57% of wetland area. Semi-permanent wetlands accounted for the remaining area (21.5%; Table 1). Only 2 of the 28 functional wetlands were actively managed for water depth throughout the year by opening and closing water structures to fill and drain the wetland according to season and river stage (Table 1). Thirteen of the 28 were hydrologically engineered at the time of construction, for a total of 15 out of 28 functional wetlands that were modified in one form or another, which is higher than the estimated percentage of modified wetlands statewide (27%; Suloway and Hubbell 1994). The remaining 13 sites lacked any hydrologic engineering or construction (Table 1).

CREP regulations call for a maximum ratio of 6:1 upland to wetland area for CP 23 wetland practices, yet 24 of the 33 (72%) sampled sites exceeded this maximum. Several other sites included little or no buffer within the contract boundaries, which resulted in 76% of the total area across all of the sampled sites being classified as upland buffer (Table 2). The remaining area was dominated by emergent vegetation association (22%), followed by forested (2.2%), and scrub-shrub (<0.1%; Table 2). Of the total functional wetland area, emergent vegetation associations constituted 90.6%, forested, 9.2%, and scrub-shrub, 0.2%. This distribution of wetland habitat differs from statewide coverage, which is comprised of 62% forested cover, 16 % emergent, and 4% scrub-shrub (Suloway and Hubbell 1994). The areal coverage of hydrophytic vegetation within functional wetlands ranged 0% to 100%, with a mean of 46 ± 34% (mean ± SD; Table 1).

Total species richness of CP 23 wetlands ranged from 11 to 41 with a mean of 26 ± 7 species (mean ± SD). Mean C values ranged from 3.45 to 4.79 with a mean of 4.06 ± 0.54 and FQI values ranged from 11.76 to 30.92 with a mean of 20.80 ± 4.50 (Table 1). The relationship between mean C values of hydrophytic vegetation and the level of hydrologic manipulation among all sites was not significant ($R^2 = 0.002$, $P=0.80$). The amount of aquatic habitat within a 3 km buffer around the wetland ranged from 27 to 1719 ha with a mean of 328 ± 438 ha (Table 1). Although there was a trend toward greater values of mean C with increasing area of wetland surrounding a site, the amount of variation explained by the relationship was small ($R^2=0.08$, $P=0.18$).

## DISCUSSION

Producing functional wetlands through the restoration of disturbed agricultural areas is a challenging task (Perrow and Davy 2002). Most of the CP23 projects we surveyed contained at least some functional wetland habitat, but the areal extent of these wetlands was small. A few sites supported extensive wetland complexes, but 54% of wetlands were <1 ha in size. Although these small wetlands can play an important role in reducing isolation among patches of wetland habitat (Gibbs 1993; Semlitsch and Bodie 1998), they typically support lower abundance and species richness of wildlife (Fairbairn and Dinsmore 2001). Overall, only 24% of the total area across our sample of 33 sites qualified as wetland habitat. Thus, although 14,000 ha have been enrolled in CREP CP 23 contracts in Illinois, the actual area of wetland restored may be closer to 3,360 ha if our study sites are representative.

The ratio of upland to wetland area in most CREP sites within our sample was well above the program's maximum ratio of 6:1 upland to wetland habitat. Wetland buffers and native grass cover are worthy and necessary restoration components that provide important filtering functions and valuable habitat for many fauna. However, many of the CP23 tracts we surveyed already had upland cover adjacent to them and were sufficiently buffered without relegating a majority of the CP23 tract to additional buffer. Furthermore, many other areas within the eligible enrollment region historically supported prairie habitat and as such possess conditions better-suited for restoring quality upland habitat. The low proportion of wetland coverage on CREP tracts reflects in part the difficulty of wetland restoration in a highly variable hydrologic setting (Galatowitsch and van der Valk 1996), but we believe improvements could be made by focusing more on the intended goal of wetland habitat and implementing the necessary measures to support a more extensive and sustainable hydrology.

An active effort to engineer a sustainable hydrology should be included in most restoration projects. Wetlands can and do naturally form solely from the cessation of crop production in drained floodplains, but many of these wetlands lack the hydrologic persistence necessary to support a viable wetland community. While temporary, ephemeral habitat is essential for many wildlife species (Swanson et al. 1974), it inevitably occurs in the periphery of seasonal and semi-permanent sites that also support water into the growing season. The use of excavation and water retention structures in small restoration projects provides greater potential for sustaining longer hydroperiods which can support the growth of emergent and aquatic wetland plants as well as a plethora of wildlife that require wetland habitat (Ehrenberger 2003). All of the hydrologically engineered sites that we sampled supported functional water regimes, while all of the sites that lacked a functional hydrology were passive restorations without any intentional hydrologic engineering. The level of hydrologic manipulation in our sample did not have a statistically significant effect on mean C values. Similarly, we did not detect a relationship between isolation and mean C. Most of CREP wetland plant assemblages were dominated by common generalist species leading to low variation in mean C among sites. This suggests that either a longer time will be needed for plants with high conservation values to successfully colonize suitable sites, or that high quality species will require active management. We believe that the inundation supported through hydrologic engineering may have an increasing effect on the recruitment of wetland plants as these CREP wetlands mature past their first few years of existence.

The targeting of specific habitat within CREP is limited by the first-come-first-served enrollment system, but even within this context, we believe that the areal extent of wetland habitat restored could be improved by placing wetlands on sites better suited for hydrologic restoration and by actively engineering these sites with simple hydrologic structures. While funds for extensive management are limited, managers and landowners could do more to utilize the resources allocated for initial restoration costs, such as implementation cost-shares and practice incentive payments. As the demand for enrollment among landowners grows, so should the standards for effective implementation of the CREP's restoration goals.

As we work to protect and restore more functional wetland habitat, there is a need to maximize and sustain the benefits of enrollments by better tracking the progression of restoration. CREP wetlands will invariably change with time through degradation from exotic species, sedimentation, and nutrient loading and/or enhancement brought by colonization of native species and development of hydric soils. Continued monitoring of the physical and floral characteristics of this habitat is necessary to understand, protect, and maximize the ecological investment these easements represent.

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Figure 1. CP23 CREP wetland study sites, Illinois River Basin, Illinois, USA. Black areas not representative of the size of the tracts, but enlarged for visibility.

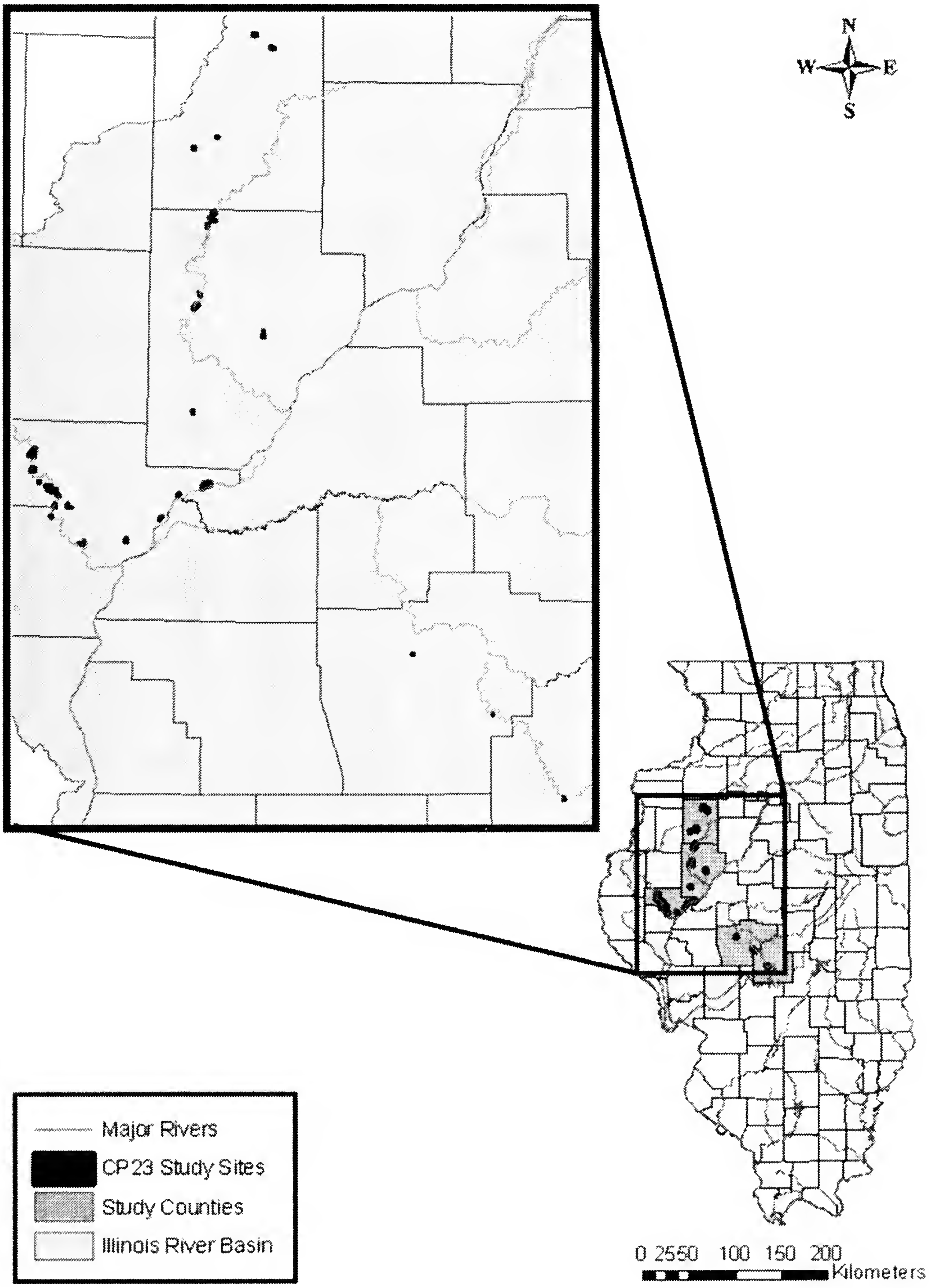

Table 1. Habitat characteristics of central Illinois CP23 CREP wetland study sites, 2005. HYDRO=the water regime modifier. Semi-permanent wetlands have surface water throughout the growing season in most years, seasonal wetlands have surface water for extended periods in growing season but not at the end of the growing season, and temporary wetlands have surface water for only brief periods during the growing season (Cowardin et al. 1979). ENG=the level of hydrologic engineering. ISOL=wetland isolation, estimated by the amount of aquatic habitat (ha) within a 3 km buffer around the perimeter of each wetland (Fairbairn and Dinsmore 2001). TRACT=the area (ha) of the enrolled contract tract. WETLAND=the area (ha) of the delineated wetland. HABITAT=the wetland class (Cowardin et al. 1979). C=the mean C value (Swink and Wilhelm 1994; Taft et al. 1997). VEG= percent areal coverage of wetland vegetation.

| SITE | COUNTY | WTRSHD | HYDRO | ENG | ISOL | TRACT | WETLAND | HABITAT | C | VEG |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Schuyler | Illinois | Semi-perm | 3 | 1502 | 149 | 122.80 | emergent | 4.3 | 10 |
| 2 | Schuyler | Illinois | Seasonal | 2 | 1356 | 11 | 11.10 | forested | 3.7 | 90 |
| 3 | Schuyler | Illinois | Seasonal | 1 | 1720 | 22 | 1.86 | forested | 3.9 | 100 |
| 4 | Schuyler | LaMoine | Temp | 1 | 172 | 47 | 0.13 | forested | 3.9 | 100 |
| 5 | Schuyler | LaMoine | Temp | 1 | 137 | 8 | 0.21 | scrub-shrub | 4.0 | 100 |
| 6 | Schuyler | LaMoine | Seasonal | 1 | 165 | 20 | 0.50 | emergent | 3.9 | 10 |
| 7 | Schuyler | LaMoine | Seasonal | 2 | 168 | 44 | 12.27 | emergent | 3.9 | 40 |
| 8 | Schuyler | LaMoine | Semi-perm | 2 | 132 | 17 | 16.44 | emergent | 4.3 | 40 |
| 9 | Schuyler | LaMoine | Seasonal | 1 | 196 | 21 | 8.19 | forested | 3.5 | 80 |
| 10 | Schuyler | LaMoine | Semi-perm | 2 | 218 | 17 | 4.97 | emergent | 4.3 | 50 |
| 11 | Schuyler | LaMoine | Temp | 1 | 324 | 82 | 15.79 | emergent | 3.9 | 30 |
| 12 | Schuyler | LaMoine | Seasonal | 1 | 419 | 6 | 0.21 | emergent | 4.5 | 90 |
| 13 | Schuyler | LaMoine | Temp | 1 | 461 | 40 | 0.09 | emergent | 4.2 | 100 |
| 14 | Schuyler | LaMoine | Semi-perm | 3 | 240 | 106 | 26.57 | emergent | 3.9 | 50 |
| 15 | Schuyler | LaMoine | Semi-perm | 2 | 243 | 36 | 12.36 | emergent | 4.2 | 20 |
| 16 | Fulton | Spoon | Seasonal | 2 | 78 | 6 | 0.24 | scrub-shrub | 4.1 | 20 |
| 17 | Fulton | Spoon | Seasonal | 2 | 158 | 29 | 0.94 | emergent | 4.1 | 20 |
| 18 | Fulton | Spoon | Temp | 1 | 118 | 35 | 0.01 | emergent | 4.1 | 0 |
| 19 | Fulton | Spoon | Temp | 1 | 128 | 8 | 0.01 | emergent | 4.2 | 0 |
| 20 | Fulton | Spoon | Seasonal | 1 | 206 | 58 | 0.66 | emergent | 4.1 | 10 |
| 21 | Fulton | Spoon | Seasonal | 1 | 152 | 30 | 0.01 | emergent | 4.2 | 0 |
| 22 | Knox | Spoon | Seasonal | 2 | 95 | 14 | 0.57 | emergent | 3.7 | 40 |
| 23 | Knox | Spoon | Seasonal | 2 | 34 | 10 | 0.89 | emergent | 4.3 | 30 |
| 24 | Knox | Spoon | Seasonal | 2 | 27 | 32 | 3.23 | emergent | 3.6 | 50 |
| 25 | Knox | Spoon | Semi-perm | 2 | 62 | 24 | 0.71 | emergent | 3.8 | 40 |
| 26 | Sangamon | Sangamon | Seasonal | 2 | 101 | 2 | 0.84 | emergent | 4.5 | 30 |
| 27 | Sangamon | Sangamon | Seasonal | 2 | 251 | 8 | 0.96 | emergent | 3.9 | 40 |
| 28 | Christian | Sangamon | Seasonal | 1 | 312 | 6 | 0.04 | emergent | 4.8 | 90 |

Table 2: Distribution of dominant vegetation associations among 33 CP23 CREP wetland sites in the Illinois River watershed (Cowardin et al. 1979).

| Dominant vegetation association | pooled area (ha) | % area |
|---|---|---|
| upland | 718.6 | 75.6 |
| emergent | 209.6 | 22.1 |
| scrub-shrub | 0.5 | <0.1 |
| forested | 21.3 | 2.2 |
| total | 950 | 100 |

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# Survey of *Baylisascaris procyonis* and Canine Distemper Virus in Southern Illinois Raccoons

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## ABSTRACT

Although diseases and parasites carried by raccoons (*Procyon lotor*) can have considerable impacts on wildlife populations, little is known about disease prevalence in southern Illinois raccoons. We surveyed raccoon latrine sites for raccoon roundworm (*Baylisascaris procyonis*) and quantified seroprevalence of canine distemper virus (CDV) in raccoons on the Union County Conservation Area (UCCA) during 2004-05. Most latrine sites (97%) were found on either downed logs or at tree bases; 16% of fecal samples at latrine sites exhibited *B. procyonis* eggs. The seroprevalence rate of CDV was 23%, with a slightly higher rate in females than males. Our survey indicates relatively low incidences of *B. procyonis* and CDV on the UCCA, even though raccoon density on the study area is one of the highest reported in the wildlife literature. We conclude it is unlikely that *B. procyonis* or CDV are appreciably affecting raccoons or mammalian species of concern on the UCCA.

Key words: *Baylisascaris procyonis*, canine distemper virus, disease, latrine, parasite, *Procyon lotor*, raccoon, southern Illinois

## INTRODUCTION

Raccoons (*Procyon lotor*) are important as parasite hosts and reservoirs of diseases that are potentially transmissible to other animals (Bigler et al. 1975, Kazacos 1982). Raccoon populations have increased nearly 20-fold during the last 70 years (Zeveloff 2002), heightening concern about potential impacts of raccoon-carried diseases on humans and wildlife. Two of the most important infectious agents associated with raccoons include raccoon roundworm (*Baylisascaris procyonis*; Kazacos 1982, Kazacos 2001, LoGiudice 2003) and canine distemper virus (CDV; Roscoe 1993, Mitchell et al. 1999).

*B. procyonis* is a well known cause of visceral, ocular, and neural larva migrans in humans and other animals (Sorvillo et al. 2002, Roussere et al. 2003). Fatal or severe central nervous system disease from *B. procyonis* has been reported in >90 species of birds and mammals; 13 known cases of neural larva migrans were reported in humans, primarily in young children (Kazacos 2001, Roussere et al. 2003:1516). Furthermore, *B. procyonis* may have contributed to the historical declines of eastern woodrats (*Neotoma* *floridana*) in southern Illinois (Birch et al. 1994) and Allegheny woodrats (*N. magister*) in New York and New Jersey (LoGiudice 2003).

Raccoon latrine sites can serve as long term sources of *B. procyonis* infection for susceptible animals, especially small vertebrates that forage for undigested seeds in raccoon feces (Roussere et al. 2003). Small vertebrates make use of the high seed content of raccoon feces, especially in times of food scarcity (Page et al. 2001a). Because raccoon latrines are most often found at the base of trees, in tree forks, on large logs, stumps, rocks, tree limbs, or other horizontally oriented structures in forested areas, some small vertebrates are more susceptible to infection than others (Page et al. 2001a, b).

Canine distemper virus is a contagious, incurable, often fatal, multisystemic viral disease that affects the respiratory, gastrointestinal, and central nervous systems (Carmichael 2005). Canine distemper virus can be an important cause of mortality in raccoon populations (Mech et al. 1968, Johnson 1970, Davidson and Nettles 1997, Gehrt 2003) and domestic dogs (Alexander and Appel 1994, Daszak et al. 2000). Infected raccoons can shed CDV via excretions and secretions; the primary mode of transmission is airborne viral particles that animals inhale. Other carnivore species affected by CDV include gray foxes (*Urocyon cinereoargenteus*; Nicholson and Hill 1984) and coyotes (*Canis latrans*; Bekoff and Gese 2003).

The wildlife literature is lacking information about *B. procyonis* and CDV in southern Illinois raccoons. The last study of *B. procyonis* in the region was >10 years ago (Birch et al. 1994). Given recent reintroductions of eastern woodrats in southern Illinois (G. Feldhamer, Southern Illinois University Carbondale, personal communication), an estimate of the prevalence of *B. procyonis* may help understand the likelihood of successful woodrat recovery. Although recent studies of CDV seroprevalence in raccoons have been conducted in west-central Illinois (Mitchell et al. 1999), no current information is available on CDV in southern Illinois raccoons. Our objectives were to (1) determine selected environmental attributes of raccoon latrine sites, (2) survey prevalence of *B. procyonnis* at latrine sites, and (3) determine seroprevalence of CDV in raccoons.

## MATERIALS AND METHODS

### Study Area

Our study was conducted on the Union County Conservation Area (UCCA), a 2,510 ha wildlife refuge located in southwest Illinois. Raccoons are protected from harvest on UCCA and existed at a population density of 1 raccoon/0.6 ha (Wilson 2005). Acquired by the Illinois Department of Conservation in 1947, UCCA is managed primarily as overwintering habitat for waterfowl. Forested and cultivated bottomlands are interspersed throughout UCCA and account for the 2,165 ha of dry land on the refuge. The temperate, mid-continental climate of southern Illinois is typified by cold winters, wet springs, and hot, humid summers. Annual precipitation for Union County is about 45 cm distributed evenly throughout the year (Illinois State Water Survey 2003).

### Latrine Site Characteristics

We sampled 3 bottomland hardwood forest patches for raccoon latrine sites on UCCA during January-April 2004. We walked transects, spaced 20 m apart, and looked for fresh raccoon latrine sites until each forest patch had been surveyed. A latrine site was defined as an area with ≥2 fresh (i.e., relatively intact and not yet disintegrated) raccoon scats. Each latrine site substrate was recorded as (1) on top of a downed log, (2) inside a downed log, (3) on a stump, (4) at the base of a tree (within 1 m), or (5) on the ground. If the latrine site was at the base of a standing tree, dbh (diameter at breast height) of the tree was recorded. If the latrine site was on a downed log, log diameter at the latrine site was measured, and an estimate of log length was recorded to the nearest 5 m. We then used correlations ($\alpha = 0.05$ throughout) to assess relationships between: (1) number of latrine sites per downed log and log length, (2) number of latrine sites per downed log and diameter of downed logs, and (3) number of latrine sites per standing tree base and tree dbh.

### Prevalence of *B. procyonis*

During February-March 2005, we sampled raccoon latrine sites for *B. procyonis* on the UCCA. We used Jacobson et al. (1982) as a guide to scat sample collection and used fecal flotation to assess prevalence of *B. procyonis* eggs in raccoon feces. We collected fecal matter (≥3 g) estimated to be <1 week old and included a small amount of soil with each sample. Fecal samples were then stored in 10% formalin. Samples were analyzed by using the Fecalyzer® flotation method and floated in Fecasol® solution (EVSCO Pharmaceuticals, Newington, New Hampshire, USA) with a specific gravity of 1.200. We then assessed specimens for *B. procyonis* eggs using a microscope.

### Seroprevalence of Canine Distemper Virus

We captured raccoons as part of a larger study of raccoon ecology on UCCA (Wilson 2005, Wilson and Nielsen 2007). Raccoons were live-trapped during 4 periods: 6 October-4 December 2003, 8 March-16 April 2004, 26 September-10 December 2004, and 2 March-10 April 2005. Each trapping period, 40 wire cage traps (30x30x70 cm) were set along linear transects adjacent to water or field edges, and spaced at 100 m intervals. Trap density averaged 1 trap/0.6 ha of forested land. Traps were baited with commercial cat food and checked each morning from 0700-1100 hr. Live trapped raccoons were anesthetized with an intramuscular injection of Telazol (5mg/kg) based on an initial estimation of the animal's weight (Gehrt et al. 2001). Blood (5-10 ml) was collected from the femoral vein of selected raccoons to test for CDV (Yabsley et al. 2001). Blood samples were allowed to clot at room temperature and then centrifuged and separated. Serum was removed from each sample and aliquotted into cryovials and immediately frozen at $-10^{\circ}$ C until tested at the Animal Health Diagnostic Center at Cornell University, Ithaca, New York. Similar to Mitchell et al. (1999), a CDV serum neutralization test was used with a starting dilution of 1:4; raccoons were considered negative if no antibody was detected at this dilution. Individuals with higher titers (≥1:8) were considered exposed to CDV. Research was conducted in adherence with a university-approved animal care and use protocol.

## RESULTS

We found 276 latrine sites; of these, 61% (n = 168) were located at tree bases, 36% (n = 99) on downed logs, 2% (n = 5) on the ground, and 1% (n = 4) on stumps. Because downed logs and tree bases made up the vast majority of substrates used, further analysis was only conducted on these 2 substrates. Downed logs with larger diameter ($r = 0.219$, P

= 0.029) and greater length ($r = 0.435$; $P < 0.001$) contained more latrine sites. As dbh of tree bases used as latrine sites increased, the number of latrine sites at tree bases also increased ($r = 0.246$, $P < 0.002$).

We collected 100 fecal samples at latrine sites; of these, 16 samples (16%) exhibited *B. procyonis* eggs. Other parasites, such as whipworms (*Trichuris spp.*) and hookworms (*Ancylostoma spp.*), were observed in 28% of the samples. We collected blood from 35 raccoons (26 M, 9 F); 8 (23%) were seropositive for CDV. Four of the 9 F sampled (44%) were seropositive, while 4 of 26 M (15%) were positive.

## DISCUSSION

We report relatively low prevalence of *B. procyonis* (16%) and CDV (23%) in raccoons on the UCCA in southern Illinois. We expected slightly higher prevalence rates given that raccoon density on our study area was one of the highest reported in the literature at 1 raccoon/0.6 ha (range = 1 raccoon/0.4 ha to 1 raccoon/17.4 ha; Twitchell and Dill 1949, Kennedy et al. 1986). When host population density is high, disease prevalence rate may also be elevated (Anderson and May 1982), but our data do not necessarily indicate this. Canine distemper virus has a 4-year epizootic cycle (Hoff et al. 1974, Roscoe 1993) and we may have studied raccoons on UCCA during a period when seroprevalence was low. Herein, we compare our findings to others in the wildlife literature and discuss potential impacts of *B. procyonis* and CDV on raccoons and other wildlife in southern Illinois.

### Latrine Site Characteristics

Although we did not explicitly assess preference of latrine sites (via use vs. availability analysis), we provide information for comparison to other studies and elementary insight into raccoon behavior. Raccoon latrine sites have been documented on a variety of substrates (Page et al. 1998). Similar to other studies of raccoons at forested sites, we found latrine sites were most often associated with downed logs or tree bases (Kennedy et al. 1991, Page et al. 1998). We also noted that downed logs lacking bark were rarely used as latrine sites. This might result if bark provides a more stable contact surface for raccoons to travel along or if bark holds olfactory information necessary for raccoon communication (Ough 1982).

Relationships between latrine sites and characteristics of downed log and tree base substrates highlight the importance of forest structure to raccoons (Gehrt 2003). Tree bases were the most important latrine sites for raccoons on the UCCA, and were used almost twice as often as downed logs. Our results differ somewhat from Page et al. (1998), who reported that downed logs were used as latrine sites more than tree bases. Perhaps fewer downed logs existed on the UCCA relative to the west-central Indiana study site (Page et al. 1998). Large standing trees contained preferred raccoon den sites on the UCCA (Wilson and Nielsen 2007), thus raccoons were likely to be using these larger trees, and defecating at their bases before ascending. More latrine sites were found on larger and longer downed logs, which likely provide more surface area for raccoons to use.

### *B. procyonis*

Prevalence of *B. procyonis* varies across the distributional range of raccoons, and comparison of prevalence rates must consider (1) the seasonality of parasite sampling, (2) latitude, and (3) method of determining prevalence rate (i.e., using feces from animals, latrine sites, or upon necropsy). Page et al. (2005) found that although latrine site sampling is a useful estimator of zoonotic potential for *B. procyonis*, this measure likely underestimates prevalence rate. We appropriately primarily limit our comparisons to those studies that have assessed *B. procyonis* prevalence at latrine sites, except where noted otherwise (i.e., Birch et al. 1994).

We report a prevalence rate (16%) very similar to that of Page et al. (1998) in west-central Indiana (14%), and slightly less than Page et al. (2005) at 23% in northern Illinois. However, prevalence rates from these studies are relatively low compared to other Midwestern and Northeastern sites (>60% prevalence; Ermer and Fodge 1986, Kazacos and Boyce 1989), and our results support previous findings that prevalence rates of *B. procyonis* are generally lower in more southerly latitudes. Birch et al. (1994) found that only 5% of raccoons sampled via necropsy in Pope County, southern Illinois, were infected with *B. procyonis*. The relatively high density of raccoons on the UCCA (Wilson 2005) may explain the increased prevalence rate relative to raccoons studied by Birch et al. (1994); such is especially true given that prevalence rates are often underestimated when based on latrine site sampling (Page et al. 2005).

Although *B. procyonis* has a relatively low prevalence on the UCCA, other wildlife may be impacted via ingestion of infected raccoon feces (Page et al. 1998, LoGiudice 2001, Page et al. 2001a). Specifically, latrine sites on or close to the ground may affect several ground-dwelling species. Small vertebrates such as the white-footed mouse (*Peromyscus leucopus*) and eastern chipmunk (*Tamias striatus*) are more susceptible to contracting *B. procyonis* at the base of trees because these animals are known to be ground foragers (Page et al. 1998, LoGiudice 2001). Birds species present on the UCCA such as the white-breasted nuthatch (*Sitta carolinensis*), northern flicker (*Colaptes auratus*), and northern cardinal (*Cardinalis cardinalis*) are also documented foragers of raccoon feces (Page et al. 2001a); these species are potentially susceptible to fatal or severe CNS disease as a result of *B. procyonis* (Kazacos 2001).

*B. procyonis* may have contributed to the decline in woodrat populations in eastern North America (Birch et al. 1994; LoGiudice 2001, 2003). LoGiudice (2001) explored food caching behavior of Allegheny woodrats and found that carrying entire feces to food caches resulted in a greater risk of contamination of the entire food cache as opposed to white-footed mice, which only carried *B. procyonis* eggs to food caches. At the current low prevalence rate, the ongoing eastern woodrat recovery effort in southern Illinois is probably not hindered by *B. procyonis* (G. Feldhamer, Southern Illinois University Carbondale, personal communication); again, this is due in part to latitudinal concerns. Furthermore, the high density of raccoons on our study area (Wilson 2005) is not likely to occur in xeric forested habitats preferred by woodrats in southern Illinois.

Raccoons are rarely affected by *B. procyonis*. As stated by Roussere et al. (2003), *B. procyonis* causes little or no clinical disease in raccoons, except in uncommonly heavy infections in juveniles. We recorded no known mortalities related to *B. procyonis* infection in a radiomarked sample of >60 raccoons on UCCA (Wilson 2005).

### Canine Distemper Virus

Similar to *B. procyonis*, rates of CDV in raccoons reported in the wildlife literature vary considerably. Seroprevalence of CDV in our study was the same as Mitchell et al. (1999), who found a CDV seroprevalence of 23% in west-central Illinois raccoons. Other studies have reported higher rates of CDV in raccoon populations. For example, Davidson and Nettles (1997:147) indicated that 40-50% of all dead or sick Southeast raccoons studied had CDV, and CDV prevalence in Florida raccoons was 55% (Hoff et al. 1974). On the UCCA, we reported no known radiomarked raccoon mortalities due to CDV and no raccoons captured with obvious lesions associated with CDV (Wilson 2005).

Other wildlife species may be affected by high exposure risk to CDV. One carnivore species of concern in southern Illinois potentially affected by CDV is the gray fox. Others have shown that gray foxes can suffer significant mortality from epizootics of CDV; Nicholson and Hill (1984) reported that 7 of 25 study animals (28%) died from this disease. Gray fox populations appear to be declining in Illinois as evidenced by the Archery Deer Hunter Survey (ADHS) administered by the Illinois Department of Natural Resources. The ADHS has indicated a 68% decline in the statewide gray fox sighting index since the inception of the survey in 1992 (Bluett 2005). Although previous epizootics of CDV may have contributed to the gray fox decline, whether CDV is currently affecting gray foxes on the UCCA is unknown. Gray fox decline in southern Illinois may also be influenced by increasing competition from coyotes and bobcats (*Lynx rufus*), whose populations have increased in Illinois during the past 20 years (Woolf et al. 2000, Bluett 2005), or by habitat change to less preferred, older-aged forests.

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# If You Build It, They Will Come: Herpetofaunal Colonization of Constructed Wetlands and Adjacent Terrestrial Habitat in the Cache River Drainage of Southern Illinois

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## ABSTRACT

Agricultural lands within the Cache River drainage of southern Illinois are being acquired by both public and private conservation organizations and restored to native terrestrial and wetland natural community types. These efforts proceed under the untested assumption that constructed wetlands and adjacent reforested terrestrial habitat provide a suitable environment for local fauna. I examined this assumption for amphibians and reptiles at three newly constructed wetlands and adjacent terrestrial habitat in Johnson County, Illinois. A total of 35 species of amphibians and reptiles was observed, ranging from 22 to 28 per year. Frogs comprised 31.5% of the species observed, followed by snakes (26%), turtles (20%), salamanders (17%), and lizards (5.5%). Previously unrecorded species were observed each year, suggesting continued colonization by new species. Although most species observed are common in southern Illinois, four species of conservation concern were also encountered. When source populations occur nearby, constructed wetlands and associated terrestrial habitat are rapidly colonized by amphibians and reptiles. Constructed wetlands and adjacent reforested terrestrial habitat provide a habitable environment for amphibians and reptiles and have the potential to expand existing herpetofaunal populations, including those of species of conservation concern.

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## INTRODUCTION

Through the efforts of a diverse assemblage of conservation partners, agricultural lands within the Cache River drainage of southern Illinois are being acquired to link existing conservation lands and reduce sediment input into the Cache River. Former agricultural land is being reforested with native bottomland hardwood trees (principally *Quercus palustris,* but also *Q. bicolor*, *Q. lyrata*, *Q. macrocarpa*, *Q. michauxii*, *Q. pagodaefolia*, *Q. phellos*, *Q. shumardii*, and *Carya illinoensis*) and wetlands are being constructed to reduce effects of floods. Constructed wetlands and reforested terrestrial habitat are assumed to provide suitable habitat for local fauna (Kruse and Groninger 2003, Palmer et al. 1997). I examined this assumption by studying amphibian and reptile colonization of three newly-constructed wetlands and adjacent early-successional terrestrial habitat at

Grassy Slough Preserve (GSP), a Nature Conservancy property in Johnson County, Illinois. In addition to documenting immediate herpetological colonization of newly-created habitat, I assessed suitability of newly-created wetlands as amphibian reproductive habitat by sampling for larvae and metamorphs. I used repeatable, quantitative methods to collect baseline data with which to make future herpetofaunal community comparisons possible.

## STUDY AREA

The study area is an approximately 1123 ha former vegetable farm along the Cache River, Johnson County, Illinois. In 1999, The Nature Conservancy (TNC) purchased the land and designated it Grassy Slough Preserve. In 1999-2000, TNC constructed 15 Wetland Reserve Program wetlands designed by the Natural Resources Conservation Service, and planted former cropland to hardwood tree seedlings. The preserve is bisected by the Forman Floodway, a channelized portion of the Cache River, and is bordered by the Cache River State Natural Area (CRSNA), cropland, and the town of Belknap (Figure 1).

Following cessation of crop production, pioneering herbaceous vegetation, especially *Hordeum pusillum*, *Setaria* sp., *Erigeron canadensis*, *Erigeron* sp., and *Solidago* spp. colonized the former cropland. Planted hardwood tree seedlings are visually inconspicuous in this herbaceous-dominated "oldfield" habitat. In addition to extensive oldfield habitat, bottomland forest, comprised of *Acer saccharinum, Acer negundo*, *Acer rubrum*, *Fraxinus pennsylvanica*, *Platanus occidentalis*, *Celtis laevigata*, *Betula nigra*, *Quercus palustris*, *Ulmus Americana,* and *Liquidambar styraciflua* occurs in narrow riparian corridors along the Cache River and a former channel of the river, as well as adjacent to the southwest and northeast borders of GSP. Upland forest, dominated by *Quercus* spp. and *Carya* spp, occurs on hills on GSP and CRSNA. Aquatic habitats, in addition to the constructed wetlands, include roadside and drainage ditches, irrigation ponds, sewage lagoons, and the present and former channels (including an oxbow) of the Cache River (Figure 1).

Prior to the present study, I surveyed the herpetofauna of GSP and CRSNA from 23 February through 30 June 2000 (Palis 2000). The objective of the 2000 survey was to determine the composition of the herpetofauna of GSP at the initiation of restoration efforts and to determine the suite of potential colonist species inhabiting adjacent CRSNA. Wetland Reserve Program wetlands (including those studied from 2001-2004) were just completed or being constructed at the time of the 2000 survey; therefore they were not included in the 2000 survey. The 2000 survey documented 48 species of amphibian and reptiles on CRNSA, all but one also occurred on GSP.

I focused my 2001-2004 survey efforts on three constructed wetlands (1, 4, and 11; Figure 1) and adjacent terrestrial habitat. Wetland 1 (17.5 ha) and Wetland 11 (7.75 ha) were constructed in spring 2000, whereas Wetland 4 (8.0 ha) was constructed in fall 1999. Each wetland was created by impounding water behind an earthen dam constructed at the low end of a shallow, gently-sloping valley. Although the maximum depth of each wetland is approximately 1.5 m, water depth is generally is $\leq 0.5$ m. All three wetlands are permanent, and water levels and area inundated fluctuate with variations in precipitation.

During the study, all three wetlands were principally vegetated with algae, *Jussiaea repens*, and *Xanthium commune*.

Wetland 1 is within 150 m of Wetland 3, an oxbow in a former channel of the Cache River. During the 2000 survey, I observed 21 herpetofaunal species in Wetland 3 (before it was impounded in late spring 2000). Wetland 4 is within 800 m of forested wetlands and uplands on CRSNA where I encountered 10 herpetofaunal species in 2000. Wetland 11 is within 800 m of bottomland forest where, in 2000, I documented 9 herpetofaunal species.

## METHODS

I conducted three herpetofaunal surveys per year, once each in April, May, and June. I varied the order of visitation to the wetlands when employing all survey methods to avoid potential bias associated with time of day.

### Drift Fence Sampling

I constructed 21, 10-m long x 0.75 m-high drift fences from 0.9 m-wide x 30 m-long rolls of black silt-fence. I placed seven drift fences near each wetland, three in a y-shaped array in the adjacent terrestrial habitat, and four parallel to, and 8-12 m from, the shoreline of each wetland (two on the north side and two on the south side of each wetland; Figure 1). Fences in y-shaped arrays were 120° apart and radiated outward beginning 10 m from a central point. Each fence was supported by wood stakes, and the bottom of each fence was buried approximately 0.15 m in the ground to prevent animals from burrowing beneath. Due to excessive weathering, I replaced several drift fences each year. Prior to construction of drift fences, and at the beginning of each year, I cleared vegetation with a mechanical weed-eater or by hand up to 0.25 m away from each side of every fence.

I placed single-ended, cylindrical, aluminum window-screen funnel traps on both sides of each end of every fence (4 traps per fence). Funnel traps were 80 cm long x 20 cm wide and had an interior funnel opening 5 cm in diameter. The funnel of each trap faced toward the center of the fence. Each trap was molded to fit tight against the fence and ground, and was held in place by a 41-cm square tempered masonite shade board. Shade boards were leaned across each trap at an approximately 45 degree angle, from the ground to the fence. The shade board was held in place by a wood stake at the bottom and by the fence at the top. Each trap contained a moistened 7.5-cm x 12.5-cm cellulose sponge.

With the exception of May 2002, I trapped along drift fences for ten consecutive days per sample month. I split the May 2002 trapping period into two, 5-day periods (separated by 13 days) due to flooding that inundated nearshore traps. I inspected traps each day. I identified captures to species, and then marked cohorts by clipping a different toe on a hind foot (salamanders, frogs, and lizards), clipping a different ventral scute (snakes), or filing a different notch into a marginal scute of the carapace (turtles) each year. Scissors were dipped in alcohol between each use. I released all captures $\geq 1$ m away on the opposite side of the fence or off to the side of the fence. I closed traps between survey periods by everting and closing the funnels.

## Coverboard Sampling

I placed an array of 20 coverboards (0.6-m x 1.2-m x 0.6-cm thick chipboard) in the terrestrial habitat within 250 m each wetland (Figure 1). I arranged 10 boards, 10 m apart, in two parallel rows, 10 m apart. Due to excessive weathering, I replaced half of the boards at each wetland in 2004, alternating new boards with old boards. I checked boards irregularly in 2001 (220 board checks in April, 300 in May, and 180 in June; 700 board checks total), and six alternating days each in April, May, and June 2002-2004 (360 board checks per month per year; 1080 board checks total per year). At each check, I lifted one end of every board and captured, marked (as at drift fences), and released all amphibians and reptiles.

## Turtle Trapping

I trapped turtles from 2002-2004 with baited, 2.54-cm mesh, 76.2-cm diameter, single-throated nylon hoop nets. I placed one net in relatively deep water parallel to, and near, the dam of each wetland. The top of each net extended above the water. I baited each net with a partially open can of sardines packed in oil which I suspended near the rear of each net. I trapped for 7 days in May 2002 (21 trap-days) and for 3 consecutive days in May 2003 and 2004 (9 trap-days per year). I checked nets each day they were open. I marked and released turtles, and released other, non-target animals near the net.

## Visual Encounter Surveys

I conducted three diurnal wetland visual encounter surveys (WVES) per year by slowly wading through shallow, nearshore water and walking along the edge of each wetland, periodically scanning the substrate or water's surface with binoculars (10 x 40), dipnetting (4-mm mesh, 41-cm wide dipnet), and watching and listening for movement in the water and along the shore. I tallied the number of individuals of each species I encountered and recorded survey time. I surveyed each wetland a maximum of 2 hours per month. When positive identification was not possible (e.g., small *Pseudacris* larvae or briefly observed snakes or turtles), I recorded the lowest identifiable taxon.

I conducted three diurnal terrestrial visual encounter surveys (TVES) per year along predetermined linear transects near each wetland (see Figure 1). Transect length varied from 500 m near Wetland 4 to 800 m near Wetlands 1 and 11. I surveyed transects by slowly walking through the herbaceous vegetation, visually scanning and listening for movement, as well as turning cover (e.g., matted dead grass) with a long-handled potato rake. In terms of visibility, each transect was approximately 5 m wide. In June, however, visibility was often less than 5 m due to dense vegetative growth. I tallied the number of individuals of each species I encountered and recorded survey time.

## Anuran Vocalization Surveys

I conducted four nocturnal anuran vocalization surveys per year to account for differences in anuran calling phenology (2001-2003: twice in April and once each in May and June; 2004: once each in late March, April, May and June). I listened for 10-15 minutes at each site, identified the species calling, and scored the chorus of each species as follows: 1 = one or more individuals calling, but no overlap; 2 = overlapping calls; and 3 = chorus, calls overlapping and continuous.

### Incidental Encounters

From 2002-2004, I recorded species I encountered peripheral to other survey activities. In addition to recording direct observations of animals, I noted calling anurans.

## RESULTS

I observed a total of 21,148 individuals of 35 species of amphibians and reptiles -- all survey methods combined -- at, or near, all three wetlands combined from 2001-2004 (Tables 1 & 2). Because recapture rates of marked individuals was extremely low (1.6%), I included them in the total number of individuals observed. I observed 22 species in 2001, 26 in 2002, 25 in 2003, and 28 in 2004 (Table 1). I observed previously unrecorded species each year: six in 2002 (*Rana areolata*, *Chelydra serpentina*, *Agkistrodon piscivorus*, *Farancia abacura*, *Lampropeltis getula*, *Nerodia rhombifer*), two in 2003 (*Pseudemys concinna*, *Elaphe obsoleta*), and five in 2004 (*Siren intermedia*, *Kinosternon subrubrum*, *Sternotherus odoratus*, *Terrapene carolina*, *Eumeces fasciatus*). I observed 30 species and over 5,000 individuals at, or near, Wetland 1, including five species not observed elsewhere. I observed 8,000 individuals of 26 species at, or near, Wetland 4, and nearly 7,000 individuals of 24 species at, or near, Wetland 11 (Table 1).

Combined, WVES and drift fence trapping yielded the most species (N = 33; 94.3%) and individuals (N = 20,825; 98.5%) of all sampling methods (Table 2). Only two species were not recorded by these methods (*Eumeces fasciatus* and *Pseudemys concinna*). Six species comprised 89% of the WVES observations: *Acris crepitans*, *Bufo fowleri*, *Hyla chrysoscelis*, *Pseudacris crucifer*, *Pseudacris feriarum*, and *Rana sphenocephala*. Observations were principally of larvae and juveniles. The per-hour herpetofaunal encounter rate during the four-year period was 201.9 at Wetland 1, 304.0 at Wetland 4, and 247.6 at Wetland 11. The annual per-hour herpetofaunal encounter rate at all three wetlands combined was 247.7 in 2001, 250.4 in 2002, 224.9 in 2003, 289.5 in 2004 (253.8 overall).

Three amphibian species comprised nearly 82% of the total catch at all drift fences: *Rana sphenocephala* (44.0%), *Bufo fowleri* (19.6%), and *Acris crepitans* (18.1%). Captures at drift fences were dominated by juvenile amphibians: 96.4% in 2001, 94.5% in 2002, 77.0% in 2003, and 87.1% in 2004. The number of amphibians and reptiles captured at drift fences fluctuated among years (625 in 2001, 2255 in 2002, 451 in 2003, and 1277 in 2004). More herpetofaunal captures were made at Wetland 4 (N = 1782) than at Wetland 1 (N = 1477) or Wetland 11 (N = 1349).

Only 231 individuals of 12 species were encountered during coverboards checks and TVES (Table 2). *Bufo fowleri* (juveniles) and *Coluber constrictor* accounted for 75.6% of the observations during coverboard checks. The capture rate (per 100 coverboards) of individuals observed under coverboards was 0.28 in 2001, 4.44 in 2002, 1.94 in 2003, and 0.65 in 2004 (1.83 overall). Three amphibians (*Acris crepitans*, *Bufo fowleri*, and *Rana sphenocephala*) accounted for 93.5% of observations during TVES. The per-hour TVES herpetofaunal encounter rate during the four-year period was 5.71 near Wetland 1, 6.03 near Wetland 4, and 11.7 at Wetland 11. The annual per-hour encounter rate near all three wetlands combined was 6.13 in 2001, 14.9 in 2002, 9.3 in 2003, and 1.43 in 2004 (7.85 overall).

I captured 89 individuals of three turtle species, as well as one snake, in hoop nets during the four-year period (Table 2). The number of turtles and the turtle catch rate (number of turtles per trap-day) increased each year, from 16/0.7 in 2002, to 30/3.3 in 2003, and 43/4.7 in 2004. *Trachemys scripta* dominated the turtle catch (87.6%).

The number of anuran species documented by vocalization surveys at all three wetlands combined was 8 in 2001, 11 in 2002, 10 in 2003 and 10 in 2004. The three species added in 2002 include *Rana areolata*, *Rana catesbeiana*, and *Rana clamitans*. I did not hear *Rana areolata* in 2003 or *Rana clamitans* in 2004. The number of species with enough males to chorus increased from two in 2001 (*Acris crepitans*, *Hyla cinerea*) to five in 2002 (*Acris crepitans*, *Hyla chrysoscelis*, *Hyla cinerea*, *Pseudacris crucifer*, *Rana sphenocephala*), fell to four in 2003 (*Acris crepitans*, *Bufo fowleri*, *Hyla chrysoscelis*, *Hyla cinerea*), and rose to seven in 2004 (*Acris crepitans*, *Bufo americanus*, *Hyla chrysoscelis*, *Hyla cinerea*, *Pseudacris crucifer*, *Pseudacris feriarum*, *Rana sphenocephala*). Four species (*Acris crepitans*, *Bufo fowleri*, *Hyla chrysoscelis*, *Hyla cinerea*) chorused in at least one year in all three wetlands. Three species (*Rana areolata, Rana catesbeiana*, *Rana clamitans*) never chorused.

I observed a total of 15-20 herpetofaunal species per year incidental to other activities from 2002-2004 (Table 2). Two species, *Pseudemys concinna* and *Eumeces fasciatus*, were not encountered by any other survey method.

## DISCUSSION

Twenty-two species of amphibians and reptiles colonized the wetlands and adjacent early-successional terrestrial habitat within one year of wetland construction. Rapid colonization of GSP wetlands is consistent with observations of amphibian colonization elsewhere (Lehtinen and Galatowitsch 2001, Pechmann et al. 2001). Rapid colonization by amphibians may be the result of chance encounters of adults moving towards historic breeding sites and/or maturing juveniles dispersing from their natal wetlands. Reptile colonization may be the result of foraging behavior or terrestrial wandering. Many snakes have large home ranges (Maccartney et al. 1988) and turtles wander overland in search of nesting sites or mates (Obbard and Brooks 1980, Morreale et al. 1984). Eighteen herpetofaunal species were documented at, or near, all three wetlands suggesting they are especially adept at colonizing new habitat.

The cumulative total number of herpetofaunal species colonizing the new habitat continued to rise during the study, from 22 in 2001 to 35 in 2004. All species documented during this survey were, except for *Farancia abacura* and *Pseudemys concinna*, previously observed on GSP prior to wetland construction (Palis 2000). Given that pre-wetland construction surveys of GSP and adjacent CRSNA yielded a total of 48 herpetofaunal species, the number of species colonizing the wetlands and adjacent terrestrial habitat will likely increase as habitat conditions become more favorable for a greater variety of species.

My observation of large numbers of larval and juvenile amphibians suggests that the newly-created wetlands provide quality larval habitat. Canopy-free wetlands are highly productive systems (Moore 1970). Unimpeded input of solar radiation results in elevated water temperatures and abundant periphyton (Feminella et al. 1989, Petranka et al. 2003). Anuran larvae grow and develop quickly at warm water temperatures (Newman 1998, Skelly et al. 2002) and periphyton is a significant food of larval anurans (Dickman 1968, Seale 1980). Larval amphibians are also likely to benefit from the lack of established populations of predators and competitors in newly constructed wetlands (Hecnar and M'Closkey 1997, Smith 1983). The temporal increase in the number of anuran species abundant enough to chorus suggests that the wetlands and adjacent early-successional terrestrial habitat may be suitable for maturation of juvenile anurans.

I observed four Illinois species of conservation concern (Illinois Department of Natural Resources 2005) on GSP: *Rana areolata*, *Pseudemys concinna*, *Nerodia erythrogaster neglecta* and *Thamnophis sauritus*. *Rana areolata* successfully reproduced (produced metamorphs) in two of the newly created wetlands in two years. Both snake species appeared to be relatively common and widespread on GSP. With 42 and 22 individuals, respectively, *Thamnophis sauritus* and *Nerodia erythrogaster neglecta* were the third and fourth most commonly captured snakes at drift fences. Moreover, *Nerodia erythrogaster neglecta* was the most commonly observed snake during wetland visual encounter surveys (68.7% of all snakes observed at all three wetlands). With only one individual fortuitously encountered, *Pseudemys concinna* is likely a rare or transient occupant of GSP.

## SUMMARY

Newly-constructed wetlands and adjacent early-successional terrestrial habitat are rapidly colonized by herpetofauna when source populations occur nearby. Newly-constructed wetlands and associated terrestrial habitat in the Cache River drainage of southern Illinois can provide suitable habitat for amphibians and reptiles, and have the potential to expand populations of the indigenous herpetofauna, including those of species of conservation concern. Terrestrial habitat conditions at GSP are expected to change over time from herbaceous-dominated oldfield to closed-canopy forest. As the canopy closes, forest-dwelling amphibian and reptile species will likely colonize GSP whereas herpetofaunal species associated with early successional, open-canopied habitats will likely decline in abundance (Fitch 2006, Skelly et al. 1999).

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Table 1. Number of amphibians and reptiles observed at/near wetlands 1, 4, and 11 from 2001-2004, all sampling methods combined.

| SPECIES | WETLAND 1 | WETLAND 4 | WETLAND 11 | TOTAL |
|---|---|---|---|---|
| SALAMANDERS | | | | |
| *Ambystoma opacum* (marbled salamander) | 0 | 0 | 2 | 2 |
| *Ambystoma talpoideum* (mole salamander) | 5 | 12 | 0 | 17 |
| *Ambystoma texanum* (smallmouth salamander) | 93 | 58 | 33 | 184 |
| *Ambystoma tigrinum* (tiger salamander) | 6 | 2 | 0 | 8 |
| *Notophthalmus viridescens* (eastern newt) | 15 | 11 | 4 | 30 |
| *Siren intermedia* (lesser siren) | 0 | 5 | 0 | 5 |
| TOTAL | 119 | 88 | 39 | 246 |
| ANURANS | | | | |
| *Acris crepitans* (cricket frog) | 2607 | 2017 | 3183 | 7807 |
| *Bufo americanus* (American toad) | 107 | 0 | 0 | 107 |
| *Bufo fowleri* (Fowler's toad) | 322 | 1485 | 787 | 2594 |
| *Bufo* sp. (unidentified) | 50 | 100 | 300 | 450 |
| *Hyla chrysoscelis* (gray treefrog) | 199 | 930 | 250 | 1379 |
| *Hyla cinerea* (green treefrog) | 190 | 24 | 4 | 218 |
| *Pseudacris crucifer* (spring peeper) | 28 | 238 | 13 | 279 |
| *Pseudacris feriarum* (upland chorus frog) | 12 | 241 | 27 | 280 |
| *Pseudacris* sp. (unidentified) | 110 | 515 | 115 | 740 |
| *Rana areolata* (crawfish frog) | 2 | 10 | 0 | 12 |
| *Rana catesbeiana* (bullfrog) | 30 | 15 | 480 | 525 |
| *Rana clamitans* (green frog) | 2 | call | 3 | 5 |
| *Rana sphenocephala* (southern leopard frog) | 1436 | 2792 | 1618 | 5846 |
| *Rana* sp. (unidentified) | 2 | 7 | 4 | 13 |
| TOTAL | 5097 | 8374 | 6784 | 20255 |
| TURTLES | | | | |
| *Chelydra serpentina* (snapping turtle) | 3 | 4 | 4 | 11 |
| *Chrysemys picta* (painted turtle) | 8 | 1 | 3 | 12 |
| *Kinosternon subrubrum* (eastern mud turtle) | 1 | 0 | 0 | 1 |
| *Pseudemys concinna* (slider) | 1 | 0 | 0 | 1 |
| *Sternotherus odoratus* (stinkpot) | 1 | 0 | 0 | 1 |
| *Terrapene carolina* (eastern box turtle) | 0 | 1 | 0 | 1 |
| *Trachemys scripta* (red-eared slider) | 42 | 80 | 28 | 150 |
| Unidentified Turtle | 10 | 116 | 3 | 129 |
| TOTAL | 66 | 202 | 38 | 306 |
| LIZARDS | | | | |
| *Eumeces fasciatus* (five-lined skink) | 1 | 0 | 0 | 1 |
| *Scincella lateralis* (ground skink) | 1 | 0 | 1 | 2 |
| TOTAL | 2 | 0 | 1 | 3 |

Table 1, continued.

| SPECIES | WETLAND 1 | WETLAND 4 | WETLAND 11 | TOTAL |
|---|---|---|---|---|
| SNAKES | | | | |
| *Agkistrodon piscivorus* (cottonmouth) | 4 | 1 | 0 | 5 |
| *Coluber constrictor* (racer) | 31 | 20 | 31 | 82 |
| *Elaphe obsoleta* (rat snake) | 1 | 0 | 1 | 2 |
| *Farancia abacura* (mud snake) | 0 | 0 | 1 | 1 |
| *Lampropeltis getula* (common kingsnake) | 0 | 9 | 5 | 14 |
| *Nerodia erythrogaster* (plainbelly water snake) | 31 | 11 | 4 | 46 |
| *Nerodia rhombifer* (diamondback water snake) | 7 | 0 | 1 | 8 |
| *Thamnophis sauritus* (eastern ribbon snake) | 26 | 9 | 8 | 43 |
| *Thamnophis sirtalis* (eastern garter snake) | 26 | 49 | 57 | 132 |
| *Thamnophis* sp. (unidentified) | 1 | 0 | 0 | 1 |
| Unidentified Snake | 2 | 2 | 0 | 4 |
| TOTAL | 129 | 101 | 108 | 338 |
| | | | | |
| TOTAL INDIVIDUALS | 5413 | 8765 | 6970 | 21148 |
| TOTAL SPECIES | 30 | 26 | 24 | 35 |
| SPECIES UNIQUE TO WETLAND | 5 | 2 | 2 | |

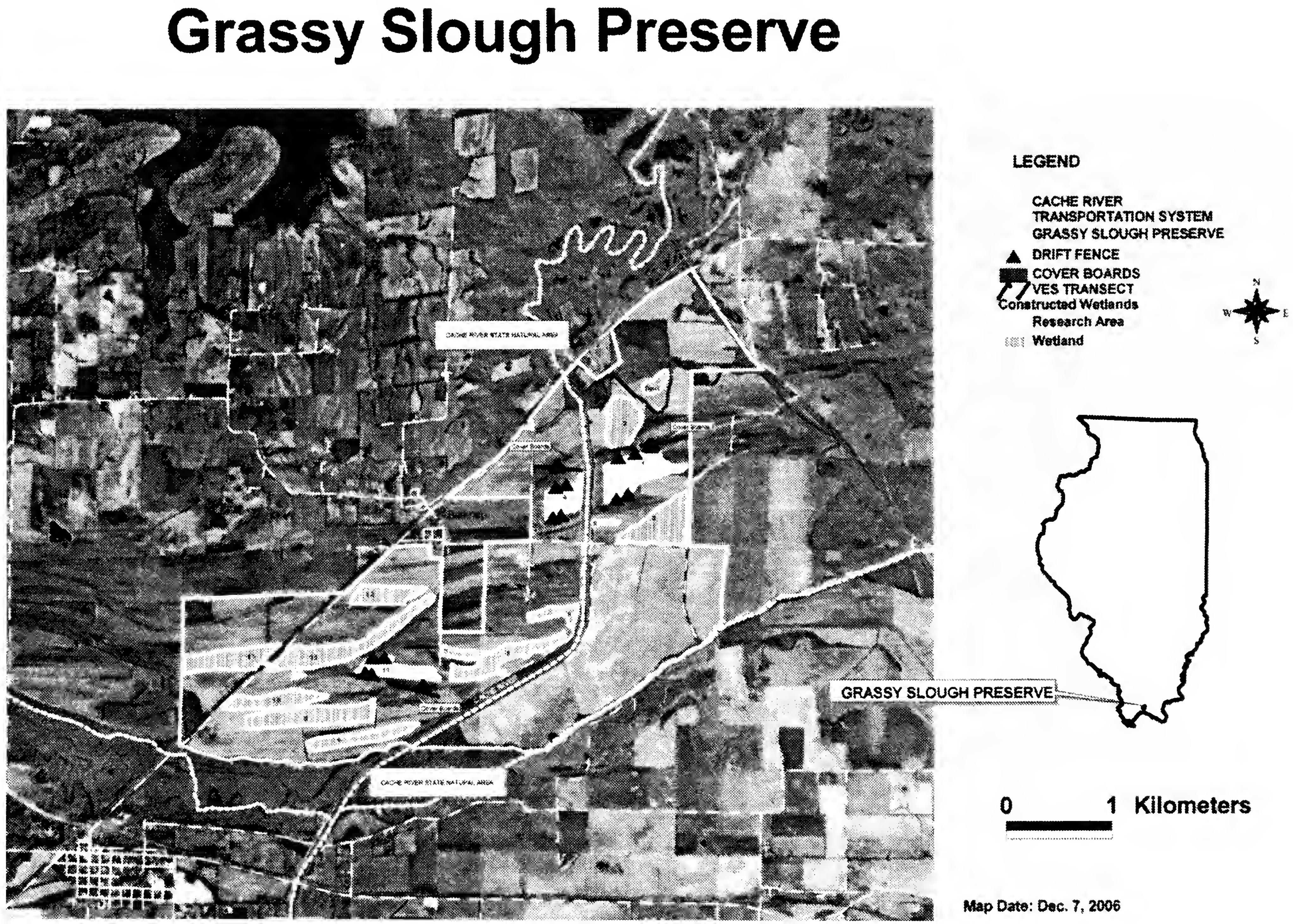
Table 2. Number of amphibians and reptiles observed at/near wetlands 1, 4, and 11 from 2001-2004, by sampling method. Dfence = drift fence, Cboard = coverboard, Hopnet = hoop net, WetVES = wetland visual encounter survey, TerVET = terrestrial visual encounter survey, Fvocal – frog vocalization survey, and Indntl = incidental observation. An “x” denotes a non-numeric observation.

| SPECIES | Dfence | Cboard | HopNet | WetVES | TerVES | Fvocal | Indntl |
|---|---|---|---|---|---|---|---|
| SALAMANDERS | | | | | | | |
| *Ambystoma opacum* | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| *Ambystoma talpoideum* | 3 | 0 | 0 | 14 | 0 | 0 | 0 |
| *Ambystoma texanum* | 90 | 2 | 0 | 91 | 1 | 0 | x |
| *Ambystoma tigrinum* | 7 | 0 | 0 | 1 | 0 | 0 | 0 |
| *Notophthalmus viridescens* | 1 | 0 | 0 | 29 | 0 | 0 | 0 |
| *Siren intermedia* | 0 | 0 | 0 | 5 | 0 | 0 | 0 |
| TOTAL | 102 | 2 | 0 | 141 | 1 | 0 | N/A |
| ANURANS | | | | | | | |
| *Acris crepitans* | 834 | 0 | 0 | 6940 | 33 | x | x |
| *Bufo americanus* | 0 | 0 | 0 | 107 | 0 | x | x |
| *Bufo fowleri* | 906 | 42 | 0 | 1552 | 94 | x | x |
| *Bufo* sp. (unidentified) | 0 | 0 | 0 | 450 | 0 | 0 | 0 |
| *Hyla chrysoscelis* | 250 | 0 | 0 | 1128 | 1 | x | x |
| *Hyla cinerea* | 2 | 0 | 0 | 216 | 0 | x | x |
| *Pseudacris crucifer* | 69 | 0 | 0 | 210 | 0 | x | x |
| *Pseudacris feriarum* | 95 | 0 | 0 | 184 | 1 | x | x |
| *Pseudacris* sp. (unidentified) | 5 | 0 | 0 | 735 | 0 | 0 | 0 |
| *Rana areolata* | 11 | 0 | 0 | 1 | 0 | x | 0 |
| *Rana catesbeiana* | 14 | 0 | 0 | 511 | 0 | x | x |
| *Rana clamitans* | 2 | 0 | 0 | 3 | 0 | x | x |
| *Rana sphenocephala* | 2029 | 2 | 0 | 3799 | 16 | x | x |
| *Rana* sp. (unidentified) | 1 | 0 | 0 | 12 | 0 | 0 | 0 |
| TOTAL | 4218 | 44 | 0 | 15848 | 145 | N/A | N/A |
| TURTLES | | | | | | | |
| *Chelydra serpentina* | 1 | 0 | 7 | 3 | 0 | 0 | x |
| *Chrysemys picta* | 2 | 0 | 4 | 6 | 0 | 0 | x |
| *Kinosternon subrubrum* | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Pseudemys concinna* | 0 | 0 | 0 | 0 | 0 | 0 | x |
| *Sternotherus odoratus* | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| *Terrapene carolina* | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| *Trachemys scripta* | 15 | 1 | 78 | 56 | 0 | 0 | x |
| Unidentified Turtle | 0 | 0 | 0 | 129 | 0 | 0 | x |
| TOTAL | 19 | 1 | 89 | 196 | 0 | 0 | N/A |
| LIZARDS | | | | | | | |
| *Eumeces fasciatus* | 0 | 0 | 0 | 0 | 0 | 0 | x |
| *Scincella lateralis* | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| TOTAL | 2 | 0 | 0 | 0 | 0 | 0 | N/A |

Table 2, continued.

| SPECIES | Dfence | Cboard | HopNet | WetVES | TerVES | Fvocal | Indntl |
|---|---|---|---|---|---|---|---|
| SNAKES | | | | | | | |
| *Agkistrodon piscivorus* | 5 | 0 | 0 | 0 | 0 | 0 | x |
| *Coluber constrictor* | 63 | 17 | 0 | 0 | 2 | 0 | x |
| *Elaphe obsoleta* | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| *Farancia abacura* | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Lampropeltis getula* | 5 | 7 | 0 | 0 | 2 | 0 | x |
| *Nerodia erythrogaster* | 22 | 0 | 1 | 22 | 1 | 0 | x |
| *Nerodia rhombifer* | 5 | 0 | 0 | 3 | 0 | 0 | x |
| *Thamnophis sauritus* | 42 | 0 | 0 | 1 | 0 | 0 | x |
| *Thamnophis sirtalis* | 123 | 6 | 0 | 1 | 2 | 0 | x |
| *Thamnophis* sp. (unidentified) | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Unidentified Snake | 0 | 0 | 0 | 4 | 0 | 0 | 0 |
| TOTAL | 267 | 31 | 1 | 32 | 7 | 0 | N/A |
| | | | | | | | |
| TOTAL INDIVIDUALS | 4608 | 78 | 90 | 16217 | 153 | N/A | N/A |
| TOTAL SPECIES | 29 | 8 | 4 | 26 | 10 | 11 | 23 |
| SPECIES UNIQUE TO SAMPLING METHOD | 1 | 0 | 0 | 3 | 0 | 0 | 2 |

Figure 1. Location of wetlands 1, 4, and 11, as well as drift fences, coverboard arrays, and terrestrial VES transects.



## BOOK REVIEW 2007 - #2

Evens, Jules, and Ian Tait. Introduction to California Birdlife. 2005. xii + 382 pp; 150 color photographs; illustrations; maps; checklist of California birds; glossary; references; index of birds; general index. California Natural History Guide Series No. 83. Hardcover ISBN 0-520-23861-3 Price: US $45.00. Softcover ISBN 0-520-24254-8 Price: US $16.95. Available from University of California Press, 2120 Berkeley Way, Berkeley, California 94704.

Lentz, Joan Easton. Introduction to Birds of the Southern California Coast. 2006. xiv + 316; color photographs; illustrations; maps; seasonal occurrence bar graphs; suggested reading; index of birds; general index. California Natural History Guide Series No. 84. Hardcover ISBN 0-520-23780-3 Price: US $55.00. Softcover ISBN 0-520-24321-8 Price: US $19.95. Available from University of California Press, 2120 Berkeley Way, Berkeley, California 94704.

Evens and Tait's noteworthy book, Introduction to California Birdlife (California Birdlife), provides a special insight into understanding bird behavior that could be applied to any state or region. Published as part of the California Natural History Guide Series, California Birdlife illustrates a method of examining the natural world that stresses avian ecological relationships over taxonomy and the details of species identifications.

In contrast, Lentz's excellent tome, Introduction to Birds of the Southern California Coast (Birds of the Southern California Coast), also published as part of the California Natural History Guide Series, offers a more typical field guide treatment to birds of a specific region. When carried together into the field, one may feel well prepared for discovery, especially if the first introductory chapters have been read beforehand.

In their "Preface" to California Birdlife, the authors clearly state that "This is not a field guide," even though the publisher promotes the book as a field guide to birds (web site address is www.ucpress.edu). The photographs by Ian Tait are all of excellent quality, but were included only for illustrative purposes rather than for field identification. The authors further suggest that the user have a true bird field guide near at hand to view species mentioned in the text that lack an accompanying photograph. Seven bioregions are designated for the state in California Birdlife; and each is given a separate chapter: Seabirds and the Marine Environment, Birds of the Shoreline, Birds of the Coastal Ranges, Birds of the Central Valley and Delta, Birds of the Mountains and Foothills, Birds of the Great Basin, and The Deserts' Birds.

Characteristic birds of each region are mentioned, but few, as warned in the "Preface," are illustrated with photographs. Certain species with an interesting story (e.g., California Condor; Marbled Murrelet) are occasionally given special attention. Bird habitats are mostly defined by plant communities, except in situations such as the open ocean. Typical bird species for each plant community (e.g., grassland, subalpine meadow, chaparral, lodgepole pine forest) are mentioned, but no plant illustrations are offered. Furthermore each chapter has a simplified map of California showing the location and aerial extent of a particular bioregion in relation to the state's boundaries. But these maps and a few other maps within the text are of limited value in locating specific sites mentioned in the text.

Thus, readers may wish to have a state atlas and a field guide to plants handy as well as a field guide to birds.

Putting these inconveniences aside, California Birdlife is well written and quite informative on a variety of subjects. The book may look and feel like a field guide (7 1/4 in x 4 1/2 in, durable backing, small type), but it is clearly a book that deserves to be carefully read from front to back. With the exception of beginning with the first chapter, "An Overview of California Birdlife," the book may be read in any order without loss of continuity. Occasional side bars (i.e., more in-depth discussion of special topics such as hybridization) and excerpts from Evens' personal field journal add a meaningful variety of information to the text.

California Birdlife is particularly interesting because Evens approaches the subject matter from an ecological or habitat perspective with birds as the focal organisms. For example, when covering seabird habitats, Evens includes a discussion of oceanography that covers topics such as El Niño and the Coriolis effect. Throughout the book, a wide selection of ecological concepts are introduced at appropriate times as related to birds in specific habitats; topics include: predator-prey relationships, habitat partitioning, niche, metapopulation dynamics, adaptive radiation, and the principle of competitive exclusion. Of course, when discussing birds and their habitat relationships as viewed in the wild, one must also consider evolutionary factors; that is, how current situations developed over long periods of time and over many generations. Evens certainly does this occasionally, but sometimes in a rather unscientific way, referring to "evolution's subtlety and ingenuity" or "evolution's creativity and genius."

When considering wildlife habitats within any region today, it is nearly always a given that human effects must be part of the discussion. If not, the author may be considered naive or out-of-touch with reality. Imagine discussing, for example, grassland bird habitats in Illinois without considering the effects of agriculture and habitat fragmentation. Therefore, Evens' frequent references to conservation issues (e.g., spotted owl and logging, wetland loss and waterfowl habitat, pesticides and raptor populations) are appropriate and even necessary.

California Birdlife offers much more than a simple introduction to the birds of California. The reader will gain knowledge of a variety of subjects that will enhance the field experience, although, as already mentioned, the identification of species in the field is not a strong point, nor is guiding the traveler to specific locations in which to view birds. It ends with a hopeful thought, which somewhat balances a slight scattering of negativity throughout when addressing conservation issues, that we may recognize our dependence, with birds and other wildlife, on maintaining the earth's natural processes for the benefit of all living organisms.

While California Birdlife may enhance one's field experience by explaining relationships among birds and their habitats, Birds of the Southern California Coast was designed to bring travelers to a destination and help them identify birds in the field while interpreting bird behavior. The book is divided into three major sections: the "Introduction," which contains basic information on bird habitats, behavior, and how to find and watch birds; "Species Accounts"; and "Birding Sites Along the Coast."

The 120 species accounts, arranged in taxonomic order (i.e., not by habitat as in California Birdlife), make-up the bulk of Birds of the Southern California Coast. Each account includes a high-quality color photograph of the highlighted species; a few short paragraphs with information on behavior, habitat needs, and other items of interest (e.g., conservation); and information on size, plumage, special identifying features, and status (resident, migrant, etc.). The photographs may be effective in helping to identify species that have highly distinctive plumage (e.g., male waterfowl). But for species where plumage differences are subtle, such as sparrows and sandpipers, nothing can take the place of detailed color artwork, as may be found in Sibley (2001), where small details can be emphasized without being limited by lighting conditions or other uncontrollable factors.

An important feature of Birds of the Southern California Coast is the section on birding sites. Simple, yet meaningful maps are provided for portions of six coastal counties with detailed directions to a number of birding sites, including tips on visitation, finding specific species, and traveling by boat. A special section entitled "Seasonal Occurrence Bar Graphs" is useful to determine beforehand whether or not a species should be present at a particular location during a certain period of the year. This can help in bird identification by eliminating species that should not be given consideration. The separate shorebird size chart and gull identification guide should help users on positive identifications within these two difficult groups.

If one is planning a bird-finding trip to the southern California coast, both Birds of the Southern California Coast and California Birdlife will be very useful references, although both would probably be most meaningful to birders or serious naturalists with a focus on birds, rather than ornithological researchers. However, bird enthusiasts, of other states not planning a trip to California, will still find it interesting to compare habitat affinities for similar species that occur in California but not in other states (e.g., California Towhee versus Eastern Towhee) or to note similar habitat choices for species with widespread distributions (e.g., colonial cliff swallows that build mud nests under overhanging rocky shelves or bridges). The bioregional approach works very well for a state such as California, where each bioregion is quite distinct; but for an agriculturally dominated state such as Illinois, similarities between some regions (Grand Prairie versus Southern Till Plain) may be more obvious than subtle differences. For Illinois and other midwestern states, the use of general types of habitats (e.g., forest, grassland, row-crop agriculture) rather than bioregions might be more meaningful for organizing bird populations than bioregions. Still, California Birdlife shows how such an approach can be applied.

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## Literature Cited

Sibley, D.A. 2001. The Sibley guide to birds. Alfred A. Knopf, New York. 543 pp.

# BOOK REVIEW 2007 - #3

Burger, William C. Flowers: How They Changed The World. 2006. 337 pages; line drawings; colored photographs; notes with references; glossary; index. Prometheus Books, Amherst, New York. Hard Cover (5 X 7 inches). ISBN 1-59102-4072. Price: US $23.00. Available from Prometheus Books, 59 John Glenn Drive, Amherst, New York 14228.

Burger has done it again! As with his previous tome (Burger, 2003), he has given us another first-rate, captivating, and exploratory read in natural history. In Flowers: How They Changed The World, Burger expertly takes the reader on a journey through the life history and evolution of flowering plants, their importance in the development and maintenance of ecosystems, and their influence on humankind's beginnings, social development, and well-being. Also, the author's life-long enthusiasm for botany and the sharing of his keen field observations add considerable appeal to the text.

Following a brief introduction about the global significance of flowering plants and a challenge to intelligent design, the author's treatment of the largest taxonomic group of photosynthetic plants, the flowering plants or angiosperms, is achieved in eight clearly written chapters. Each chapter is entitled with an intriguing question or phrase. They are by chapter: 1) "what, exactly is a flower?"; 2) "what are flowers for?"; 3) "flowers and their friends"; 4) "flowers and their enemies"; 5) "how are flowering plants distinguished?"; 6) "what makes the flowering plants so special?"; 7) "primates, people and the flowering plants"; and 8) "how flowers changed the world".

Subsequent to these chapters there are three sections preceding the subject index. The first section entitled "epilogue" is a concise essay on the long term development of relationships of humans and selected flowering plants, and the adverse impacts of these relationships on our planet's biosphere. The author then takes the reader to the disquieting question. What's next – changing our way of sharing the biosphere or another great extinction? We prefer the first option. The next section "notes" is essentially an annotated bibliography. Each chapter and section has its own set of "notes" and reference numbers that are referenced in the text by small subscript numbers. After the "notes" is the "glossary" where numerous technical terms applicable to plant biology are defined.

Flowers: How They Changed The World is not intended to be an introductory textbook. Thus, readers wishing to enlarge their knowledge of basic plant biology need to examine college level textbooks. In addition to the first-rate botanical books recommended by the author (p. 272), we recommend Graham, Graham, and Wilcox's (2006) excellent textbook entitled – Plant Biology. Chapter thirteen has noteworthy discussions and illustrations on the difficult concept of meiosis within the gametic, zygotic, and sporic life cycles. As a reminder, all plants (i.e., bryophytes, ferns, fern allies, gymnosperms, and angiosperms) and some algae have sporic life cycles. And during the sporic life cycles, spores (1n) are produced by meiosis, whereas gametes (1n) are produced by mitosis.

This book certainly fills a need in our society with respect to the transmission of scientific knowledge by scientists to the general public [In her recent article entitled – Who Is Science Writing For?, Margaret Wertheim (2006) expressed this social concern and challenges scientists to participate in popular science writing]. Besides the basic plant science information in the book, Burger's personal experiences and insights will be helpful to anyone teaching plant biology at all educational levels. Also, college students of biochemistry, botany, and zoology will find this book informative and fun to read along with the textbooks of their introductory courses. Buy or borrow it, read it, and discuss – Flowers: How They Changed The World.

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## Literature Cited

Burger, W.C. 2002. Perfect Planet, Clever Species: How Unique Are We? Prometheus Books, Amherst, New York. 345pp. (For a review of this book see: Transactions of the Illinois State Academy of Science 98(1&2): 83-85, 2005).

Graham, L.E., J.M. Graham, and L.W. Wilcox. 2006. Plant Biology. Second Edition. Pearson/Prentice Hall, Pearson Education, Inc. Upper Saddle River, New Jersey. 670 pp.

Wertheim, M. 2006. Who Is Science Writing For? BioScience 56(8): 640-641.

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3 5185 00342 2183

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**Transactions of the Illinois State Academy of Science** **Volume 100 (2007)**

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*Illinois State Academy of Science*

I·S·A·S

FOUNDED 1907

1868
1818

AUG. 26TH 1818

# *TRANSACTIONS* of the ILLINOIS STATE ACADEMY OF SCIENCE

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## ONE HUNDRED YEARS

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# Errata

## From Volume 99, #3&4 (2006)

Tables 6 and 7 of the paper by Raymond H. Brand – The Influence of Prescribed Burning on Spiders and Pseudoscorpions: Known Predators of Woodland Litter Springtails – incorrectly defined $X_m$ as “mean of individuals” rather than “mean weight of the litter.” Only the preceding tables should have had $X_m$ defined as “mean of individuals.” Corrected pages are reprinted following this notice. The reprinted pages include the original paper numbering for easy insertion into previously printed volumes.

## From Volume 100, #1 (2007)

The authorship of the paper by Mina A and Laurence Leff – A Case Study in Reuse: An XML-Editing Component and Contract Editor – inadvertently has Mina A listed as the second author, rather than as the principle author. Corrected pages are reprinted following this notice. The reprinted pages include the original paper numbering for easy insertion into previously printed volumes.

**From Volume 99, #3&4 (2006)**

**Correct pages 133 and 134 of the Brand article follow.**

Table 5. Effect of fire on pseudoscorpions ($X_m/m^2$).

| | Burned | | | Unburned | | | | |
|---|---|---|---|---|---|---|---|---|
| | N | $X_m$ | S.E. | N | $X_m$ | S.E. | Analysis | P Value |
| All samples | 81 | 5.6 | 1.09 | 81 | 7.11 | 1.12 | F = 0.99 | p = 0.32 |
| Annual Variation | | | | | | | | |
| 1987 | 18 | 3.78 | 1.28 | 18 | 6.56 | 2.36 | KW = 19.4 | p < .001** |
| 1989 | 27 | 6.15 | 2.07 | 9 | 6.01 | 3.06 | KW = 0.01 | p = 0.18 |
| 1997 | 27 | 5.7 | 2.21 | 27 | 3.15 | 0.92 | KW = 0.07 | p = 0.80 |
| 1998 | 9 | 7.22 | 3.01 | 27 | 11.93 | 2.41 | F = 1.08 | p = 0.31 |
| Seasonal Variation | | | | | | | | |
| Spring | 18 | 7.72 | 2.82 | 36 | 6.5 | 1.8 | F = 0.14 | p = 0.71 |
| Summer | 27 | 4.74 | 1.96 | 9 | 6 | 3.06 | F = 0.11 | p = 0.74 |
| Autumn | 36 | 5.17 | 1.39 | 36 | 8.08 | 1.62 | F = 1.87 | p = 0.18 |

N = number of samples; $X_m$ = mean of individuals; S.E. = standard error

Table 6. Dry weight of litter for all samples plus annual and seasonal variation ($kg/m^2$).

| | N | $X_m$ | S.E. | | N | $X_m$ | S.E. |
|---|---|---|---|---|---|---|---|
| Annual Variation | | | | Seasonal Variation | | | |
| KW – 2.21 p < 0.33 | | | | KW = 57.0 p < 0.01** | | | |
| 1989 | 36 | 2 | 0.2 | Spring | 54 | 2.8 | 0.1 |
| 1997 | 54 | 2.3 | 0.2 | Summer | 36 | 1.3 | 0.1 |
| 1998 | 36 | 1.9 | 0.1 | Autumn | 72 | 1.9 | 0.1 |
| All Samples | 126 | 2.1 | 0.1 | | | | |

N = number of samples; $X_m$ = mean weight of litter; S.E. = standard error

Table 7. Effect of fire on litter ($X_m/m^2$).

|  | Burned |  |  | Unburned |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
|  | N | $X_m$ | S.E. | N | $X_m$ | S.E. | Analysis | P Value |
| All samples | 72 | 1.92 | 0.11 | 54 | 2.39 | 0.15 | KW = 7.22 | p < 0.01* |
| Annual Variation |  |  |  |  |  |  |  |  |
| 1989 | 18 | 1.51 | 0.23 | 9 | 2.22 | 0.21 | KW = 4.81 | p < .03* |
| 1997 | 27 | 1.81 | 0.21 | 27 | 2.85 | 0.21 | F = 12.83 | p < 0.001* |
| 1998 | 27 | 1.53 | 0.11 | 27 | 2.12 | 0.15 | KW = 5.88 | p < 0.02* |
| Seasonal Variation |  |  |  |  |  |  |  |  |
| Spring | 18 | 2.8 | 0.19 | 36 | 2.79 | 0.18 | F = 0.0 | p = 0.98 |
| Summer | 27 | 1.35 | 0.16 | 9 | 1.32 | 0.12 | KW = 0.49 | p = 0.49 |
| Autumn | 18 | 1.98 | 0.2 | 36 | 1.79 | 0.13 | F = 0.61 | p = 0.44 |

N = number of samples; $X_m$ = mean weight of litter; S.E. = standard error

**From Volume 100, #1 (2007)**

**Correct pages 71 and 72 of the A and Leff article follow.**

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# A Case Study in Reuse: An XML-Editing Component and Contract Editor

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## I. INTRODUCTION AND OVERVIEW

Many decades ago, Bill Joy developed the first full-screen editor for UNIX, **vi**. Users could edit files on ASCII terminals by moving the cursor up, down, backwards and forwards with the **h**, **j**, **k**, **l** keys (the home keys) and press other sequences to delete lines, words, sentences and insert text. On a slow connection on an ASCII terminal, a few lines might be displayed; if one enjoyed a relatively high speed connection, one would be able to edit using a full screen. Note that this was before "WIMP" interfaces, such as the Xerox Star, Macintosh, and Windows, were widely available.

This worked using the "escape codes" on the terminal. When a computer program sent a sequence of characters to the terminal, it might move the cursor, clear the screen, delete a line or ring the bell. Unfortunately, this was different for each brand of terminal. So Bill Joy "abstracted" the problem. A file named **termcap** contained the sequences needed for each operation. The users would set an environment variable to indicate which terminal they were using. **vi** would read the **termcap** file and issue the correct sequence of escape codes to implement the user's editing request. (Gaughan, 2003) This was called optimal cursor movement, as the logic in vi will determine the sequence of escape codes with the fewest, or close to the fewest, number of characters needed to change the display.

Ken Arnold created a library called **curses** by "simply lifting nearly intact" the routines to implement "optimal cursor movement" from Bill Joy's editor. (Arnold), (Arnold and Amir). This was used for many full-screen programs, most notably, an "adventure game" called Rogue (Wichman, 1997). Wichman indicated that his group, which originally implemented Rogue, simply used it after "it made the rounds to other Universities." Some web sites, however, including (die.net) (Foldoc, 1993), indicate that **curses** was developed specifically to support games.

In this article, we report an analogous sequence, over two decades later. Mr. Go Eguchi developed a Graphical User Interface (GUI) to create rule-base for transforming XML files (Eguchi and Leff, 2002) (Tong, et. al., 2005). Those works define two expert systems that would examine XML files. It would match this information against the XML appearing in the left-hand side of the rule. These expert systems would then generate the XML designated by the right-hand side of the rule, transferring information from the input. The standard (Leff, 2002) also defined additions to the XML so that when the expert system is run, information that was in the input file being matched is transferred

into the output XML. The goal of the editor was to allow the rule-writer or user to create the XML defining the transformations to occur.

That editor's user interface had two panes, a menu bar and three sets of buttons. The user, or rule writer, develops the XML rule-base in the right-hand pane. The rule-writer loads samples of the XML to be transformed in the left-hand pane. They use the left-hand set of arrow buttons to move within that XML. Then, using the right-hand set of arrow buttons, the rule-writer moves within the rule-base to indicate which rule to create or modify. In the middle set of buttons, there is a "Move From Sample" button. The user presses this to set up the example. Then, the user has to modify the XML moved to the left hand set of the rules to add the special markup. The rule writer moves within the rule-base (again with the right set of buttons) and inserts the special markup to indicate how to recognize the inputs that are considered similar. Lastly, the user loads a sample of the XML to be produced when the input is recognized, and similarly, they move some of the XML to the "right hand side" of the rule. The reader of this paper does not have to be concerned with the above detail; only to realize that Mr. Eguchi implemented code to allow transformation of XML for the specific purpose of implementing the above-described system, and he embedded that within his system without planning for any reusability.

The first author extracted this into a Java Swing "component" for general use. Swing is a package, provided by Sun, which programmers use to develop GUIs using the Java programming language. The items on one of these implemented GUIs which includes other panels, edit boxes, buttons, sliders, and menus are all components (Walrath and Campione, 1998) derived from the class **Component** (Java, 2004). The programmer sets up a "containment hierarchy" in their GUI; for example, a main screen might contain several panels, some of which may have buttons or edit boxes.

The XML-Editing **Component** which is the subject of this report contains a panel in which XML is displayed with a set of four arrow buttons; the user uses these to navigate the XML. One element or "tag" is always highlighted in red. That is, when the user clicks the left arrow, the containing tag is highlighted; when the user clicks the right arrow, the highlight changes from the current tag to the immediate child on which the mouse is selected. The Up and Down arrows move the cursor from the current tag to the subsequent, or previous tag at the same level.

The programmer creates the XML editing component using its constructor and adds it to the frame or another panel using the **add** method of the frame. This is precisely how they would add an ordinary built-in edit box or button. Then they can use **setParser** to load an XML file, which is displayed. The programmer can retrieve a **parser** object. This allows the user to add or otherwise manipulate elements. It also supports the operation **getPointer** so the programmer can get the node that the user has highlighted. For example, assume the user selected an element that represents an "if," and selected a button to add a "then" part. The logic for a button would use the **getPointer** method to get a pointer to this element and then use the XML manipulation methods that are part of the packages that come with the Java programming language to add the new information.

The senior author developed an XML standard for legal contracts (Leff, 2000). It was proposed to the Legal XML standards organization. A legal contract can be viewed as a

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# Response of *Ipomoea batatas* (L.) Lam. to Soil Fertilization with Filter Cake

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## ABSTRACT

Filter cake is a waste product from sugarcane (*Saccharum officinarum* L.) processing. Filter cake is often found as a waste product near locations of sugar mills. Currently, sweetpotato [*Ipomoea batatas* (L.) Lam.] farmers do not use filter cake as fertilizer. If the benefits of filter cake as a soil-improvement material for sweetpotato could be demonstrated, sweetpotato farmers could obtain and use this waste product. Five soil-improvement materials (no filter cake; 10,000 kg $ha^{-1}$ filter cake; 20,000 kg $ha^{-1}$ filter cake; 40,000 kg $ha^{-1}$ filter cake; and 600 kg $ha^{-1}$ compound fertilizer) were assessed in a randomized complete block design that was replicated five times. The objective of this study was to assess the influence of filter cake on yield and yield components of sweetpotato, soil temperature, and weed infestation. Results showed that yields were highest (13,427.4 kg $ha^{-1}$) with 10,000 kg $ha^{-1}$ of filter cake application, and lowest (11,686.0 kg $ha^{-1}$) with 40,000 kg $ha^{-1}$. Mass of tuber/plant made 28.1% ($r = 0.530$; $n = 25$) contribution to increased yield; tuber length contributed 3.5% ($r = 0.186$; $n = 25$) to yield. Weed infestation was negatively, but non-significantly correlated ($r = - 0.161$; $n = 25$) with storage root yield. Soil temperatures did not significantly vary among the treatments, though 5-cm depth temperatures were higher than temperatures at 10-cm depth and soil surface. Based upon the results of this experiment, it is recommended that 10,000 kg $ha^{-1}$ of filter cake be applied to sweetpotato.

Keywords: Filter cake, sweetpotato, soil fertilization, soil temperatures, weed infestation, yield components.

## INTRODUCTION

Filter cake is the main solid waste obtained by filtration of the mud, which settles out in the process of clarification of juice from sugarcane processing (Barnes, 1974). It was reported (FAO, 2004) that filter cake could increase soil fertility and supplement inorganic fertilizers. Filter cake or filter mud was described (Blackburn, 1984) as a useful fertilizer, especially when applied to phosphate-deficient soils and to fields in which the topsoil was removed. This beneficial aspect of filter cake could make it useful where attempts are required to restore or increase the fertility of eroded, clay-textured, or strip-mined land. In addition, using filter cake rather than artificial fertilizer would be one way of promoting organic gardening.

Sweetpotato is the most important storage root crop in Swaziland. Its importance in Swazi cuisine is now becoming more prominent as it is being realized that sweetpotato could play a useful role in ameliorating the health conditions of those afflicted with diabetes, HIV or AIDS (Mzileni, P., Nursing Sister, University of Swaziland, Personal Communication, 2005). Usually planted on ridges, sweetpotato takes about 4-6 months to mature; during the growing period, the young leaves can also be harvested and cooked for food.

In Swaziland, the country's four sugar mills produce large quantities of waste, including filter cake. These sugar mills are expected to declare their production of halogenated filter cakes and spent absorbents (Anon., 2004b). The Swaziland Environmental Authority is expected to oversee these declarations; however, it is believed that these reports are imprecise and thus the exact quantity produced is unknown. Swaziland is not alone in its problem of waste management. In a workshop to identify the problems facing the sugar sub-sector in Kenya, the participants declared that Kenya sugar industry made no progress in diversifying its operations and product base from sugar. Among the suggestions to improve the situation was the need to use bagasse (fiber) to produce newsprint, paper, building hardboard, and putting filter cake into an economic use as an organic fertilizer or soil ameliorate (Odek et al., 2003).

The world's population is growing tremendously. The United States Census Bureau (2006) reported that the world's population would increase from 6.5 billion in July 2006 to 6.8 billion by July 2010. This increased population demand will require more food production in order to feed the increasing world population. This is likely to require the farming population to use more inorganic fertilizers to achieve higher crop yields. However, these inorganic fertilizers are expensive whereas organic fertilizers are cheap. If the benefits of filter cake as a fertilizer in sweetpotato production could be demonstrated, Swaziland farmers could obtain filter cake from sugar mills and use this as a soil-improvement material on their farms. The objectives of the investigation were to determine the effects of filter cake on yield and yield components, soil temperature, and weed infestation in sweetpotato.

## METHODS

### Location and experimental design

The field trial was conducted at Malkerns Research Station (altitude, 740 m above sea level; rainfall, 800-1460 mm; mean temperature, 7.3°C to 26.6°C) from January to June 2006. The soil was an Oxisol (Murdoch, 1968). Five treatments were replicated five times in a randomized complete block design. The treatments (T) were: no filter cake (control); 10,000 kg ha$^{-1}$ of filter cake; 20,000 kg ha$^{-1}$ of filter cake; 40,000 kg ha$^{-1}$ of filter cake; and 600 kg ha$^{-1}$ of compound fertilizer. The amount of filter cake applied was similar to that typically added when applying compost. Plot dimensions were 5.0 m x 7.0 m, with eight ridges per plot. The crop spacing was 30.0 cm within rows, and 100.0 cm between rows, giving a plant population of 33,333 plants ha$^{-1}$ (Ossom et al., 2005). A 200-cm space was allowed between replicates; treatments within the same replicates were spaced 100 cm apart.

### Fertilizer application and planting

Initial land preparation consisted of moldboard plowing followed by disking with a tractor-mounted disk harrow. Thereafter, ridge-construction (for 100-cm ridges) was done using tractor-mounted ridgers. Filter cake and fertilizer application was made one day before planting. The fertilizer consisted of 300 kg ha$^{-1}$ of N:P:K [2:3:2: (22) + Zn] mixed with 100 kg ha$^{-1}$ single superphosphate and 100 kg ha$^{-1}$ of muriate of potash (Anon., 1991). At 6 weeks after planting (WAP), 100 kg ha$^{-1}$ of limestone ammonium nitrate (LAN, 28% N) was applied to the fertilizer treatment. Both fertilizer and filter cake were banded and incorporated. The sweetpotato variety used was 'Kenya' that was obtained from Malkerns Research Station. Planting was done on January 9, 2006, by hand, using young vines that were 30 cm in length, at the rate of one vine/planting station. The experiment was not irrigated to simulate small-scale farming activities that typically have no irrigation.

### Data Collection

Data were collected on soil temperature, weed infestation and yield and yield components. Alternate ridges were used as guard rows from which no data were taken.

### Soil Temperature

Soil temperature was taken every four weeks on bright, sunny days without rain, and between 1400 and 1600 hours. The temperature was recorded using the Fisher brand bimetal-dial thermometers having a gauge diameter of 4.5 cm, a stem length of 20.3 cm, and an accuracy of ± 1.0% of dial range at any point on the dial (Ossom et al., 2001; Ossom et al., 2006). The temperature readings were taken at a distance of 10 cm from the plant rows, and at three depths: soil surface, 5-cm, and 10-cm depths. Three readings were made in each depth/plot, totaling nine readings/plot. A 30-second interval was allowed to elapse before readings were taken in order to allow the thermometers to stabilize.

### Weed Infestation

General weeding was done at 4 weeks after planting (WAP) by the use of hand hoes. Weed infestation was assessed at 12 WAP. To assess weed density, a 90-cm square quadrat was used and three assessments/plot were made on each occasion. The descriptions of the range of scores (1-6) that indicated the degree of weed density were: 1, zero weeds within the quadrat; 2, sparse weed coverage of soil within the quadrat; 3, intermediate weed coverage of soil within the quadrat; 4, general weed coverage of soil within the quadrat; 5, severe weed coverage of soil within the quadrat; and 6, complete weed coverage of soil within the quadrat. A similar method of estimating weed density had earlier been used by other workers (Daisley et al., 1988; Ossom et al., 2001; and Ossom et al., 2006). The weed species were also identified and classified (Botha, 2001) within the quadrat at each determination; the presence or absence of weed species was noted to determine if any weed species would be confined to any particular soil-improvement materials. After identification, the dry matter of each weed species was determined by oven drying (Tafaj et al., 2006). Weed sub-samples weighing 300-400 g were dried; where the weeds weighed below 300 g, the entire mass was dried.

### Harvesting and Yield data

The crop was manually harvested at 20 WAP, using garden forks. Two lines/plot were used for yield determination, and the fresh mass/plot was converted to kg $ha^{-1}$. Yield components were determined as follows: petiole length was measured by taking the linear measurements from 10 petioles randomly selected from each of 5 plants/plot; the length of marketable tubers was measured from the proximal end of the tuber to its distal end using a plastic tape measure. Tuber diameter was measured by means of a vernier caliper, measurements being made at the widest part of every marketable tuber from each of 5 plants/plot.

### Data analysis

Data were analyzed using MSTAT-C package, version 1.3 (Nissen, 1983). The least significant difference (LSD) test (Steel and Torrie, 1980) was used for mean separation at 5% probability level.

## RESULTS AND DISCUSSION

### Meteorological Information

Climatic factors that influence crop growth and performance include rainfall distribution and amounts as well as air and soil temperatures. Table 1 shows the meteorological information during the period of the investigation. The air temperatures ranged from a low of 8°C in June (harvest month), to a high of 28.8°C (one month after planting). The total rainfall during the period was 833.4 mm, with a range of 1.7 mm (in May 2006) to 295.5 mm (in January 2006).

### Soil Properties

Initial chemical properties of the soil during the investigation were: pH, 5.8; total N, 1.3%; P, 4.54 mg P $kg^{-1}$ soil; K, 1,599 mg K $kg^{-1}$ soil; exchangeable acidity, 0.29 cmol $kg^{-1}$; and organic matter, 2.4%. The soil appeared low in nitrogen, with moderate concentrations of P and K. The chemical properties of the filter cake were as follows: pH, 7.9; total N, 1.15%; P, 1,289 mg P $kg^{-1}$ soil; K, 1,614 mg K $kg^{-1}$ soil; Mg, 1,305 ppm; and organic matter, 27.1 %. As noted, the pH of the filter cake was in the alkaline range that would have complemented the acid soil. Perry (1997) reported the optimum pH range for sweetpotato to be 5.2-6.0; on this account, the soil pH of 5.8 was adequate for the performance of the crop.

### Soil Temperature

Data on soil temperature (Table 2) show that the general trend in temperature values was 5-cm depth > soil surface > 10-cm depth. Slightly lower soil temperatures were recorded at 16 WAP because this period coincided with the onset of winter, when low and fluctuating air and soil temperatures are usually experienced. Yet 20 WAP, the temperatures increased again. However, there were no significant differences between the treatments. That soil temperatures are higher at 5-cm depth than at the soil surface and at 10- and 15-

cm depths agree with earlier observations (Ossom et al., 2001; Ossom, 2003; Thwala, 2004; Ossom and Dlamini, 2006; Ossom et al., 2006) who also reported that same trend in soil temperatures. Soil temperature is reported to influence some physiological processes including seed dormancy, germination (Relf, 1997), seedling emergence, and growth (Anon., 2004a). The soil temperature range (14.7-35.3°C) recorded in our investigation is consistent with soil temperatures in tropical areas (Sanchez, 1976; Ossom et al., 2001; Ossom et al., 2006). Increased physiological activities in the topsoil being a consequence of the greater number of living organisms are given (Ossom et al., 2006; Ossom and Dlamini, 2006) as among the reasons for higher temperatures in the upper layers of the soil (such as 5-cm depth) than in lower depths (such as 10-cm depth).

### Weed infestation

Table 3 shows the weed species that were encountered at 12 WAP. The weeds are common weeds of the Luyengo area (Ossom, 2005); no new weed species were introduced through the use of soil-improvement materials. A few edible species (such as *Amaranthus hybridus* L., and *Bidens pilosa* L.) were among the weeds; both species are commonly eaten as vegetables in Swaziland. Weed density showed no significant differences among soil-improvement materials. Weed density was negatively, but non-significantly correlated ($r = - 0.161$; $n = 25$) with storage root yield. The coefficient of determination ($R^2$) of 0.0259 indicates that 2.6% of the variation in tuber yield/ha can be attributed to the adverse effect of weed density at 12 WAP. The species were distributed over 13 genera and 11 families. The distribution was as follows: no filter cake, 12 genera and nine families; 10,000 kg ha$^{-1}$ of filter cake, 13 genera and nine families; 20,000 kg ha$^{-1}$ of filter cake, 10 genera and eight families; 40,000 kg ha$^{-1}$ of filter cake, 13 genera and nine families; and inorganic fertilizer, 13 genera and 11 families of weeds. Based on biomass production, *Bidens pilosa* (L.) and *Richardia brasiliensis* (Gomes.) were the two most troublesome weed species. Our results are consistent with previous reports (Zimdahl, 1993; Thwala, 2004; Ossom et al., 2001; Kelly et al., 2006; and Ossom et al., 2006) that associated crop yield reductions with increased weed infestation. Kelly et al. (2006) observed that the benefits from increased yields by controlling sweetpotato weeds more than outweighed the expense in the exercise.

### Yield and yield components

Table 4 shows the influence of soil-improvement materials on yield and yield components in sweetpotato. All yield components are positively correlated with tuber yield, with mass of tuber/plant making the largest (28.1%) contribution to yield. Tuber length contributed the least (3.5%) to tuber yield. Generally, the storage root yields were low compared to yields from previous sweetpotato investigations (Development Associates, Inc., 2003). Previous workers (Hartermink et al., 2000; Ossom et al., 2003) show yields of sweetpotato to be variable and inconsistent.

The 10,000 kg ha$^{-1}$ filter cake yielded highest and the other four treatments were lower than the highest yield by the following percentages: no filter cake, 10.5%; 20,000 kg ha$^{-1}$ filter cake, 10.8%; 40,000 kg ha$^{-1}$ filter cake, 13.0%; and fertilizer, 0.8%. Thus, filter cake at 20,000 kg ha$^{-1}$ resulted in a higher tuber yield than when 40,000 kg ha$^{-1}$ was applied. This is in agreement with the findings of Ossom and Nxumalo (Unpublished data, 2006) on the effects of filter cake on yields of maize (*Zea mays* L.); they indicated a lower grain yield of maize from 40,000 kg ha$^{-1}$ of filter cake than when 20,000 kg ha$^{-1}$ was applied.

Fertilizing soil with filter cake has been investigated in other crops besides sugarcane and maize, and found to have no detrimental effects. Srinarong and Panchaban (2003) investigated the influence of filter cake and other soil-improvement materials on the growth performance of rice and found that filter cake and sludge cake significantly increased soil pH and soil organic matter, but slightly decreased soil electrical conductivity whereas Tzeng et al. (2001) reported no adverse effects of filter cake on soils.

The fact that the application of 10,000 kg $ha^{-1}$ of filter cake produced a tuber yield equivalent to the application of 600 kg $ha^{-1}$ of a compound fertilizer as applied in this experiment is not surprising considering that the chemical properties of this filter cake were: pH 7.9, total N 1.15%, P 1,289 mg P $kg^{-1}$ soil, K 1,614 mg K $kg^{-1}$ soil, Mg 1,305 mg Mg $kg^{-1}$ soil, and organic matter 27.1%. The surprising result was the fact that 20,000 and 40,000 kg $ha^{-1}$ of filter cake produced no increase in yield of sweetpotato tubers compared to the control plots (no filter cake). Long-term studies will be needed to more clearly elucidate the response of sweetpotato to the application of rates of filter cake above 10,000 kg $ha^{-1}$ as a source of fertilizer mineral elements and organic matter.

## CONCLUSION AND RECOMMENDATION

Findings from this investigation are that tuber yields were highest when filter cake was applied at the rate of 10,000 kg $ha^{-1}$. Filter cake did not significantly influence soil temperature in sweetpotato plots. Weed species distribution varied among the soil-improvement materials, but no species could be expressly associated with the use or non-use of filter cake.

While there is need for further long-term investigations into the use of filter cake in sweetpotato production, it is reasoned that if 10,000 kg $ha^{-1}$ filter could give a higher tuber yield than higher rates of filter cake, then sweetpotato farmers who have access to filter cake should adopt this rate of application.

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Table 1. Meteorological data during the period of the investigation.

| Month | Mean air temperatures (°C) | | Monthly rainfall (mm) | Mean monthly rainfall[1] (mm) |
|---|---|---|---|---|
| | Maximum | Minimum | | |
| January 2006 | 27.8 | 19.1 | 295.5 | 192.5 |
| February 2006 | 28.8 | 18.9 | 200.6 | 187.5 |
| March 2006 | 25.7 | 16.3 | 271.2 | 116.8 |
| April 2006 | 27.0 | 11.4 | 58.3 | 56.7 |
| May 2006 | 23.2 | 10.2 | 1.7 | 40.9 |
| June 2006 | 21.6 | 8.0 | 6.1 | 15.2 |
| Totals | 154.1 | 83.9 | 833.4 | 609.6 |
| **Means** | **25.7** | **14.0** | **138.9** | **101.6** |

[1] Mean monthly rainfall from 1996-2005.

Table 2. Influence of soil-improvement materials on soil temperatures in sweetpotato.

| Type of soil fertilizer material | Soil depth | Weeks after planting | | | | | Means |
|---|---|---|---|---|---|---|---|
| | | 4 | 8 | 12 | 16 | 20 | |
| | | °C | | | | | |
| No filter cake | Surface | 34.3 | 23.6 | 29.2 | 14.7 | 27.9 | 25.9 |
| | 5-cm | 33.7 | 24.6 | 29.5 | 18.0 | 26.6 | 26.5 |
| | 10-cm | 28.9 | 23.5 | 26.2 | 18.7 | 22.9 | 24.0 |
| 10,000 kg $ha^{-1}$ filter cake | Surface | 32.0 | 24.4 | 27.9 | 12.0 | 26.5 | 24.6 |
| | 5-cm | 32.0 | 24.2 | 28.0 | 18.7 | 25.5 | 25.5 |
| | 10-cm | 28.4 | 23.3 | 26.7 | 18.7 | 22.8 | 24.0 |
| 20,000 kg $ha^{-1}$ filter cake | Surface | 35.3 | 24.3 | 28.3 | 12.7 | 25.7 | 25.3 |
| | 5-cm | 31.7 | 24.4 | 30.5 | 16.0 | 25.3 | 25.6 |
| | 10-cm | 28.0 | 23.2 | 28.2 | 18.0 | 21.4 | 18.4 |
| 40,000 kg $ha^{-1}$ filter cake | Surface | 29.3 | 24.8 | 27.9 | 12.7 | 26.5 | 24.2 |
| | 5-cm | 33.0 | 24.5 | 29.3 | 18.0 | 26.2 | 26.2 |
| | 10-cm | 28.5 | 23.6 | 26.5 | 18.0 | 22.9 | 23.9 |
| 600 kg $ha^{-1}$ fertilizer | Surface | 34.7 | 24.5 | 27.7 | 15.4 | 27.2 | 25.9 |
| | 5-cm | 32.8 | 24.3 | 30.3 | 18.0 | 27.7 | 26.6 |
| | 10-cm | 28.6 | 23.2 | 27.3 | 19.3 | 21.8 | 24.0 |
| Means | Surface | 33.1 | 24.3 | 28.2 | 13.5 | 26.7 | 25.2 |
| | 5-cm | 32.7 | 24.4 | 29.5 | 17.8 | 26.2 | 26.1 |
| | 10-cm | 28.6 | 23.3 | 27.0 | 18.5 | 22.4 | 24.0 |
| [1]LSD (0.05) | Surface | 6.77 | 1.48 | 3.35 | 3.48 | 2.91 | - |
| | 5-cm | 2.03 | 0.52 | 3.90 | 3.32 | 3.11 | - |
| | 10-cm | 1.48 | 0.77 | 2.33 | 2.05 | 2.63 | - |
| Significance ($P < 0.05$) | Surface | Ns | Ns | Ns | Ns | Ns | - |
| | 5-cm | Ns | Ns | Ns | Ns | Ns | - |
| | 10-cm | Ns | Ns | Ns | Ns | Ns | - |
| [2]Correlation | Surface | 0.042Ns | -0.224Ns | - 0.107Ns | - 0.311Ns | 0.075Ns | - |
| | 5-cm | - 0.550* | - 0.071Ns | - 0.392Ns | - 0.512* | 0.389 Ns | - |
| | 10-cm | - 0.611* | - 0.221Ns | - 0.414* | - 0.427* | 0.230 Ns | - |

[1] Least significant difference;

Ns, Not significant at $P > 0.05$; *, Significant at $P < 0.05$;

[2] Correlation coefficient of soil temperature with tuber yield.

Table 3. Effects of fertilizer materials on weed species distribution in sweetpotato.

| Family name | Scientific name | Common name | Soil-improvement materials and weed species dry matter accumulation | | | | |
|---|---|---|---|---|---|---|---|
| | | | No filter cake | 10,000 kg $ha^{-1}$ filter cake | 20,000 kg $ha^{-1}$ filter cake | 40,000 kg $ha^{-1}$ filter cake | 600 kg $ha^{-1}$ fertilizer |
| Amaranthaceae | *Amaranthus hybridus* L. | Common pigweed | A | A | A | 7.9 | A |
| Asteraceae | *Galinsoga parviflora* Cav. | Gallant soldier | 26.4 | 47.9 | 17.5 | 64.5 | 7.3 |
| Asteraceae | *Bidens pilosa* L. | Black jack | 551.6 | 309.6 | 415.3 | 281.4 | 613.8 |
| Asteraceae | *Acanthospermum hispidum* DC. | Upright starbur | A | A | A | A | 22.6 |
| Capparaceae | *Cleome gynandra* L. | Spider flower | A | A | A | A | 6.2 |
| Commelinaceae | *Commelina benghalensis* L. | Benghal wandering Jew | 92.0 | 88.0 | 26.9 | 57.8 | 7.2 |
| Convolvulaceae | *Convolvulus arvensis* L. | Field bindweed | 0.4 | A | A | A | 10.5 |
| Cyperaceae | *Cyperus rotundus* L. | Purple nutsedge | 11.5 | 13.2 | 21.7 | 4.0 | 19.8 |
| Labiataceae | *Leucas martinicensis* (Jacq.) R. Br. | Bobbin weed | A | 6.1 | 82.4 | 4.8 | A |
| Malvaceae | *Sida cordifolia* L. | Heartleaf Sida | A | 1.6 | A | A | 18.2 |
| Oxalidaceae | *Oxalis latifolia* H.B.K. | Red garden sorrel | 10.7 | 5.5 | 17.3 | 13.2 | 2.6 |
| Poaceae | *Elusine africana* L. | African goose grass | 46.7 | 0.4 | 37.4 | 74.9 | 32.4 |
| Poaceae | *Panicum maximum* Jacq. | Common buffalo grass | 29.7 | 71.3 | A | 7.2 | A |
| Poaceae | *Digitaria senquinalis* L. | Crab finger grass | 16.2 | A | 6.3 | 11.4 | 13.3 |
| Poaceae | *Echinochloa crus-galli* (L.) Beauv | Barnyard grass | A | 5.5 | A | A | A |
| Poaceae | *Cynodon dactylon* L. | Bermuda grass | A | 7.7 | A | A | A |
| Poaceae | *Chloris virgata* Sw. | Feather-top chloris | A | A | A | 10.7 | A |
| Polygonaceae | *Rumex crispus* L. | Curly dock | 9.9 | A | A | A | A |
| Rubiaceae | *Richardia brasiliensis* Gomes. | Tropical Richardia | 379.0 | 403.7 | 139.7 | 247.0 | 137.8 |
| Solanaceae | *Nicandra physalodes* (L.) Gaertn. | Apple of Peru | 4.1 | 38.1 | 28.6 | 43.9 | 17.5 |
| Weed density | NA | NA | 3.2 | 3.9 | 3.1 | 3.7 | 3.6 |
| [1]LSD $_{(0.05)}$ density | NA | NA | ---------------------- 0.82 ---------------------- | | | | |

[1]Least significant difference; A, species absent;
NA, Not applicable

Table 4. Effects of soil-improvement materials on yield and yield components in sweetpotato.

| Type of fertilizer material | Tuber yield (kg $ha^{-1}$) | Number of tubers $plant^{-1}$ | Mass of tuber $plant^{-1}$ (g) | Petiole length (cm) | Tuber length (cm) | Tuber diameter (cm) |
|---|---|---|---|---|---|---|
| No filter cake | 12017.4 | 3.8 | 650 | 16.2 | 18.7 | 4.3 |
| 10,000 kg $ha^{-1}$ filter cake | 13427.4 | 4.4 | 674 | 16.9 | 20.6 | 4.0 |
| 20,000 kg $ha^{-1}$ filter cake | 11973.1 | 4.5 | 918 | 18.5 | 18.7 | 4.0 |
| 40,000 kg $ha^{-1}$ filter cake | 11686.0 | 4.0 | 730 | 17.0 | 19.7 | 4.1 |
| 600 kg $ha^{-1}$ fertilizer | 13320.2 | 3.8 | 696 | 16.9 | 19.2 | 4.0 |
| Means | 12484.8 | 4.1 | 734 | 17.1 | 19.4 | 4.1 |
| [1]LSD $_{(0.05)}$ | 3010.73 | 0.89 | 274 | 2.70 | 3.07 | 0.41 |
| Significance ($P < 0.05$) | Ns | Ns | Ns | Ns | Ns | Ns |
| Correlation coefficient with tuber yield | - | 0.419 | 0.530 | 0.607 | 0.186 | 0.335 |
| $R^2$ | - | 17.6 | 28.1 | 36.8 | 3.5 | 11.2 |

[1]Least significant difference;
Ns, Not significant at $P > 0.05$;
$R^2$, Coefficient of determination for tuber yield (%).

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# Fire Maintained, Closed Canopy Barren Communities in Western Illinois

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## ABSTRACT

Barrens were common in Illinois at the time of European settlement. These communities were fire-maintained, had an open canopy, and a grass-dominated ground layer containing both forest and prairie species. Barrens were commonly underlain by nutrient poor, clayey soils, and were found on rolling topography. Fire suppression following the arrival of European settlers resulted in canopy closure and the loss of many prairie species. The barrens studied are currently being managed by fire. *Quercus alba* (white oak) dominated the overstory and accounted for more than 65% of the importance value on both barrens. Other overstory species were *Carya tomentosa* (mockernut hickory), *Q. stellata* (post oak), and *Q. velutina* (black oak). Woody seedlings were common, but few shrubs and saplings were present, probably due to recurring fires. Overstory cover at Argyle Hollow Barrens Nature Preserve averaged 77%, while cover at McKee Creek Barrens averaged 85%. Numerous prairie species were found on these barrens but most were restricted to canopy openings.

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## INTRODUCTION

Barrens were described as open forest communities with a ground layer of prairie grasses and forbs, but also with an unusually high proportion of forest herbs (Ellsworth 1838, Vestal 1936). The woody vegetation of barrens consisted of stunted trees of *Quercus stellata* (post oak), *Q. alba* (white oak), *Carya* spp. (hickories), with the common shrubs being *Corylus americana* (hazel), *Rhus glabra* (smooth sumac), and *R. copallina* (winged sumac) (Peck 1837, Worthen 1868). Grubs, commonly described as brushy trees that had been repeatedly top-killed by recurring fires, were common (Peck 1837). In some instances the grubs were more than 100 years old and consisted of numerous basal branches that sometimes exceeded 3 meters in height (Curtis 1959).

Barrens were fire maintained communities. Bourne (1820) describes the disappearance of barrens after Native Americans left and fires were stopped. Worthen (1868, 1870) also described barrens as fire maintained communities, and Peck (1837) described the growth of vigorous sprouts from grubs once there were no more fires. By the 1860s it was realized that barrens were transient communities and, due to fire suppression, would soon be replaced by forest (Engelmann 1863). Presently few good quality examples of barrens exist in Illinois (Edgin 2000, Taft 2003, Edgin et al. 2005, McClain et al. 2007). Most have been degraded due to fire suppression and currently retain little of the species diversity and community structure that existed in the early 1800s.

In general, the few remaining barrens have been subjected to occasional fires, have very poor quality soils, have been relatively undisturbed by human activity, and are restricted to regions of rolling topography (Bowles and McBride 1994, Bowles et al. 1994, Ebinger et al. 1994, Homoya 1994, Taft 2003, Edgin et al. 2005). As this community is uncommon, attempts are being made to re-establish barrens where they previously existed. The present study was undertaken to determine the composition and structure of the vegetation of two barrens in western Illinois that are presently being managed as barren communities. According to Government Land Office (GLO) survey records, these two areas were barrens in early settlement times (Hutchinson 1988).

## DESCRIPTION OF THE STUDY AREA

The barrens examined were located in the Western Forest-Prairie Natural Division, a strongly dissected glacial till plain subjected to the Illinoian stage of Pleistocene Glaciation approximately 125,000 years ago (Schwegman 1973). At the time of European settlement oak-hickory forests, woodlands, and barrens dominated the rugged topography associated with the well developed and extensive drainage systems of this Division (Anderson 1991). Prairies were also common, but mostly restricted to the level uplands (Anderson 1991).

The barrens studied were located on rolling topography and had many floristic similarities to woodlands and forests on dry-mesic to xeric sites. Both barrens were on steep, southwest-facing hillsides, were less than 2 ha in size, and had small canopy openings in which some prairie vegetation was present. Both would presently be classified as mature second-growth dry to dry-mesic upland forests using the classification of White and Madany (1978). The more open canopy, which varied from 77 to 85%, and the open understory were probably the result of recent fire management.

### Argyle Hollow Barrens

This dedicated nature preserve is within Lake Argyle State Park about 2 kms north of Colchester, McDonough County, Illinois (NE1/4 S36 T6N R4W). The barrens community was located on the rolling uplands on the east side of Argyle Lake. Sandstone and shale outcrops were common on the steep slope with a sandstone cliff at the edge of the lake. The soils were classified as Hickory loam with 10 to 18% slope (Walker 1997).

**McKee Creek Barrens**
This natural area was in Siloam Springs State Park about 18 kms south of Clayton, Adams County, Illinois (SE1/4 S24 T2S R5W). The barren overlooks McKee Creek that forms the southern boundary of the park. A cliff at the base of the barrens was about 15 meters high. The soils were classified as Marseilles silt loam with 18 to 35% slope (Tegeler 2003).

The climate is continental, characterized by humid, hot summers and cold winters. Weather records for Quincy, Illinois, gives an average annual precipitation of 98 cm that falls mostly as rain from March through October (www.sws.uiuc.edu 2005). January is the coldest month with an average high temperature of 0°C and an average low of –9°C. July is the hottest month with an average low of 19’C and an average high of 30°C. The frost-free growing period averages 191 days with a low of 166 and a high of 232 days.

## MATERIALS AND METHODS

The study sites were visited throughout the growing seasons of 1995 and 1996, and at least once each growing season since that time to complete the vascular plant species list. Voucher specimens of each species were collected, identified, and deposited in the Stover-Ebinger Herbarium of Eastern Illinois University, Charleston, Illinois (EIU). Criteria for designating exotic species followed Mohlenbrock (2002), and Gleason and Cronquist (1991), while nomenclature follows Mohlenbrock (2002).

During the late summer of 1996 the woody overstory was surveyed using a 25 m x 50 m plot. This plot was placed as near the middle of the site as possible to eliminate edge effect. In each quadrate all living woody individuals ≥10.0 cm dbh were identified and their diameters recorded. From these data, the living-stem density (stems/ha), basal area ($m^2$/ha), relative density, relative dominance, importance value (IV), and average diameter (cm) were calculated for each species. The IV was the sum of the relative density and relative dominance (basal area) (McIntosh 1957). Overstory cover was determined by photographing the canopy and projecting the photo onto a 100 point grid.

To study ground layer vegetation, two transects 25 m long were located randomly in each study area. Along each transect, 1 $m^2$ quadrates were located at 1 m intervals (n=25/transect), odd-numbered quadrates to the right even-numbered to the left. A random numbers table was used to determine the number of meters (0 to 9) a quadrate was located from the transect line. Cover was determined by using the Daubenmire cover class system (Daubenmire 1959) as modified by Bailey and Poulton (1968). The modified Daubenmire cover scale is as follows: class 1 = 0 to 1%; class 2 = >1 to 5%; class 3 = >5 to 25%; class 4 = >25 to 50%; class 5 = >50 to 75%; class 6 = >75 to 95%; class 7 = >95 to 100%. Importance value (IV) for ground layer species was determined by summing relative cover and relative frequency.

## RESULTS

Within the barrens studied a total of 139 plant species representing 46 families and 98 genera were documented (Appendix I). Only one fern species was encountered, while 40 were monocots in eight families, and 98 were dicots in 37 families. Seven exotic species were found, none being common in the plots. Of the species encountered 114 were found on Argyle Hollow Barrens, 104 were collected from McKee Creek Barrens, and 82 were found on both barrens. Nearly 25% of the herbaceous species collected were associated with prairie vegetation (Appendix I).

*Quercus alba* dominated the overstories of both barrens, accounting for more than 65% of the IV (Table 1). At Argyle Hollow Barrens *Carya tomentosa* was second in IV, while on McKee Creek Barrens *Q. stellata* was second in IV. *Quercus velutina* (black oak) was third in IV on both barrens. The slightly more mesic McKee Creek Barrens had higher species diversity in the overstory, and a canopy closure of 85%. Very few dead-standing trees were encountered.

As a result of management with periodic fires, both barrens had a park-like appearance; the understory was open. Small saplings averaging between 800 and 1375 stems/ha and large saplings averaged 120 to 288 stems/ha on the barrens (Table 2). Numerous tree seedlings were present, however, and averaged between 15,000 and 17,500 stems/ha. Management fires top-killed most seedlings, but many had an enlarged caudex indicating that they re-sprouted after each fire. These sprouts rarely reached the sapling layer.

Ground layer vegetation was sparse on the study sites. Bare ground and litter had cover values of 62.14 and 67.09 on Argyle Hollow and McKee Creek barrens respectively (Table 3). On Argyle Hollow Barrens *Parthenocissus quinquefolia* (IV of 54.) dominated with *Carex pensylvanica, Rubus flagellaris, Solidago ulmifolia,* and *Helianthus divaricatus* being the common species encountered, having a combined IV of 148.0 (possible 200). Similar results were obtained on McKee Creek Barrens except these species differed somewhat in IV and *Rubus flagellaris* was replaced by *Muhlenbergia sobolifera.* On this barren the five dominant species had a combined IV of 110.2. The ground layer of both barrens consisted of a mixture of forest and prairie grasses and forbs (Table 3, Appendix I). Forest species were, by far, the most important, and the few species listed as "others" in the table included many of the prairie species encountered. Other prairie species were growing near the barren edges, or in very low frequencies on the barrens, and did not occurr in the survey quadrates.

## DISCUSSION

At the time of European settlement in the early 1800s a broad mosaic of prairie and open- to closed-canopy oak-dominated communities (forest, woodland, savanna, barren) existed in Illinois (Davies 1977, Anderson 1983). Most forested areas persisted on the lee side of topographic and wetland fire breaks. Fire frequency and intensity were important in determining the composition and structure of these wooded areas. Intense and frequent fires created prairie and savanna, less intense and less frequent fires causing barrens and woodlands, while low intensity, infrequent fires allowed closed forests to persist (Ebinger and McClain 1991).

Based on early literature and GLO survey notes, it is evident that most upland forests in Illinois had open canopies (Vestal 1936, Anderson and Anderson 1975, Ebinger and McClain 1991). These open canopy forests (woodlands, barrens, savannas) represented a transition between prairies and closed-canopy forests of the dissected terrain of river valleys. These open woodlands, savannas, and barrens were fashioned by climate, topography, edaphic factors, and periodic fires (Heikens and Robertson 1994, McClain and Elzinga 1994). With the cessation of landscape fires soon after the arrival of European settlers, woody plant encroachment usually resulted in canopy closure except where edaphic factors slowed tree growth. Native aborigines were probably responsible for most of these fires (Williams 1989, Davies 1994, McClain and Elzinga 1994).

During the past 15 years attempts wave been underway to re-create the barren aspect at both Argyle Hollow and McKee Creek barrens. Occasional prescribed fires are being used to slowly open the canopy. Presently the ground layer is dominated by species associated with forest communities. Very few of the herbaceous species presently found in the ground layer of these two barrens are prairie species (Table 3). Also the shrub layer of sumac, hazel, and the stunted trees reported by the early GLO surveyors are lacking, as are the dense oak grubs (Vestal 1936). It is possible that under the present management of occasional prescribed fires, the "barrens of the early 1800s" cannot be attained on these sites. It is likely that more intense, landscape fires are necessary; the slow moving ground fires presently being used are not hot enough or intense enough. These ground fires are not killing the large canopy trees, and the canopy is still mostly closed. The continued management with fire, however, will slowly open the canopy and promote an increase in some prairie species. The year after the 1996 fire at the McKee Creek Barrens, *Trifolium reflexum* (buffalo clover) was found. Apparently the seeds of this Illinois endangered species had been lying dormant in the soil and the heat from the fire promoted germination.

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Table 1. Density (#/ha), basal area ($m^2$/ha), relative values, importance values, and average diameters (cm) of the tree species encountered at Argyle Hollow Barrens, McDonough County, and McKee Creek Barrens, Adams County, Illinois.

| Species | Density (#/ha) | Basal Area ($m^2$/ha) | Rel. Den. | Rel. Dom. | I.V. | Average Diameter (cm) |
|---|---|---|---|---|---|---|
| **Argyle Hollow Barrens** | | | | | | |
| *Quercus alba* | 144 | 20.2 | 69.2 | 94.6 | 163.8 | 41.4 |
| *Carya tomentosa* | 32 | 0.7 | 15.4 | 3.3 | 18.7 | 16.1 |
| *Quercus velutina* | 16 | 0.2 | 7.7 | 1.1 | 8.8 | 13.7 |
| *Carya ovata* | 16 | 0.2 | 7.7 | 1.0 | 8.7 | 13.3 |
| Totals | 208 | 21.3 | 100.0 | 100.0 | 200.0 | |
| **McKee Creek Barrens** | | | | | | |
| *Quercus alba* | 128 | 21.7 | 50.0 | 82.0 | 132.0 | 45.7 |
| *Quercus stellata* | 48 | 3.7 | 18.8 | 14.0 | 32.8 | 31.0 |
| *Quercus velutina* | 24 | 0.5 | 9.4 | 1.9 | 11.3 | 15.8 |
| *Acer saccharum* | 24 | 0.2 | 9.4 | 0.8 | 10.2 | 10.7 |
| *Juglans nigra* | 8 | 0.1 | 3.1 | 0.4 | 3.5 | 13.4 |
| *Ostrya virginiana* | 8 | 0.1 | 3.1 | 0.3 | 3.4 | 10.5 |
| *Carya ovata* | 8 | 0.1 | 3.1 | 0.3 | 3.4 | 12.0 |
| *Fraxinus americana* | 8 | 0.1 | 3.1 | 0.3 | 3.4 | 10.5 |
| Totals | 256 | 26.5 | 100.0 | 100.0 | 200.0 | |

Table 2. Density (stems/ha) of woody seedlings, shrubs, small saplings, and large saplings encountered at the Argyle Hollow Barrens, McDonough County, and the McKee Greek Barrens, Adams County, Illinois.

| Species | Seedlings | Small Saplings | Large Saplings |
|---|---|---|---|
| **Argyle Hollow Barrens** | | | |
| *Quercus alba* | 11250 | 125 | -- |
| *Quercus imbricaria* | 1250 | -- | -- |
| *Viburnum prunifolium* | 1250 | -- | -- |
| *Quercus velutina* | 833 | 208 | 8 |
| *Prunus serotina* | 833 | 542 | -- |
| *Amelanchier arborea* | 833 | -- | -- |
| *Sassafras albidum* | 833 | -- | -- |
| *Carya tomentosa* | 417 | 125 | 56 |
| *Ostrya virginiana* | -- | 125 | -- |
| *Fraxinus americana* | -- | 125 | -- |
| *Carya ovata* | -- | 83 | 40 |
| *Cercis canadensis* | -- | 42 | -- |
| *Acer saccharum* | -- | -- | 16 |
| Totals | 17499 | 1375 | 120 |
| **McKee Creek Barrens** | | | |
| *Viburnum prunifolium* | 4000 | -- | -- |
| *Quercus alba* | 2333 | 100 | -- |
| *Quercus stellata* | 1667 | 100 | 8 |
| *Carya ovata* | 1667 | 133 | 64 |
| *Ostrya virginiana* | 1667 | -- | 120 |
| *Ulmus rubra* | 1333 | 33 | 8 |
| *Quercus velutina* | 1000 | 167 | 32 |
| *Sassafras albidum* | 667 | -- | -- |
| *Acer saccharum* | 333 | 167 | 40 |
| *Amelanchier arborea* | 333 | -- | 16 |
| *Prunus serotina* | -- | 100 | -- |
| Totals | 15000 | 800 | 288 |

Table 3. Frequency (%), average cover, and importance values of the ground layer species encountered at the Argyle Hollow Barrens, McDonough County, and the McKee Greek Barrens, Adams County, Illinois. (*exotic species)

| Species | Argyle Hollow Barrens | | | McKee Creek Barrens | | |
|---|---|---|---|---|---|---|
| | Freq. | Mean Cover | I.V. | Freq. | Mean Cover | I.V. |
| *Parthenocissus quinquefolia* | 74 | 13.76 | 54.0 | 28 | 2.04 | 12.0 |
| *Carex pensylvanica* | 84 | 10.88 | 48.5 | 62 | 3.00 | 21.5 |
| *Rubus flagellaris* | 42 | 3.80 | 19.8 | 4 | 0.60 | 2.8 |
| *Solidago ulmifolia* | 30 | 3.17 | 15.4 | 82 | 5.93 | 34.9 |
| *Helianthus divaricatus* | 26 | 1.64 | 10.3 | 22 | 4.54 | 19.0 |
| *Dichanthelium acuminatum* | 36 | 0.33 | 9.1 | 4 | 0.02 | 0.9 |
| *Antennaria plantaginifolia* | 20 | 0.64 | 6.2 | -- | -- | -- |
| *Viola pedata* | 20 | 0.35 | 5.4 | -- | -- | -- |
| *Danthonia spicata* | 10 | 0.25 | 3.0 | 6 | 0.08 | 1.4 |
| *Toxicodendron radicans* | 8 | 0.38 | 2.8 | 2 | 0.06 | 0.6 |
| *Smilacina racemosa* | 6 | 0.42 | 2.5 | 2 | 0.06 | 0.6 |
| *Rosa carolina* | 8 | 0.19 | 2.3 | 16 | 0.48 | 4.6 |
| *Potentilla simplex* | 4 | 0.36 | 2.0 | 4 | 0.12 | 1.2 |
| *Aster turbinellus* | 6 | 0.18 | 1.9 | -- | -- | -- |
| *Anemonella thalictroides* | 8 | 0.04 | 1.9 | 10 | 0.10 | 2.2 |
| *Carex hirsutella* | 6 | 0.08 | 1.6 | 12 | 0.16 | 2.8 |
| *Galium concinnum* | 6 | 0.08 | 1.6 | 20 | 1.08 | 7.3 |
| *Hieracium gronovii* | 6 | 0.03 | 1.5 | -- | -- | -- |
| *Elymus virginicus* | 4 | 0.07 | 1.2 | 8 | 0.04 | 1.6 |
| *Galium circaezans* | 4 | 0.07 | 1.2 | 10 | 0.30 | 2.8 |
| *Carex muhlenbergii* | 4 | 0.02 | 1.1 | 16 | 0.13 | 3.4 |
| *Acalypha virginica* | 4 | 0.02 | 1.1 | 16 | 0.08 | 3.3 |
| **Poa compressa* | 4 | 0.02 | 1.1 | -- | -- | -- |
| *Muhlenberegia sobolifera* | -- | -- | -- | 32 | 5.13 | 22.8 |
| *Desmodium glutinosum* | -- | -- | -- | 20 | 1.51 | 8.7 |
| *Aster anomalus* | -- | -- | -- | 24 | 1.20 | 8.4 |
| *Phlox divaricata* | -- | -- | -- | 22 | 1.09 | 7.8 |
| *Bromus pubescens* | -- | -- | -- | 14 | 0.42 | 4.0 |
| *Festuca subverticillata* | -- | -- | -- | 16 | 0.18 | 3.6 |
| *Sanicula canadensis* | -- | -- | -- | 16 | 0.18 | 3.6 |
| *Amphicarpaea bracteata* | -- | -- | -- | 10 | 0.49 | 3.5 |
| *Ageratina altissima* | -- | -- | -- | 10 | 0.49 | 3.5 |
| *Tradescantia ohiensis* | -- | -- | -- | 12 | 0.31 | 3.3 |
| *Lactuca canadensis* | -- | -- | -- | 4 | 0.31 | 1.8 |
| *Geum canadense* | -- | -- | -- | 6 | 0.13 | 1.5 |
| *Lespedeza intermedia* | -- | -- | -- | 4 | 0.07 | 1.0 |
| Others | -- | 0.20 | 4.5 | -- | 0.28 | 3.6 |
| Totals | | 36.98 | 200.0 | | 30.61 | 200.0 |
| Bare ground and litter | | 62.14 | | | 67.09 | |

## APPENDIX I.

Vascular taxa encountered at the western Illinois barren communities listed alphabetically by family under major plant groups. An asterisk indicates non-native (exotic) species. For each species the author's collection number (JEE) is given followed by the barrens in which each species was collected (a = Argyle Hollow Barrens, m = McKee Creek Barrens. Nomenclature follows Mohlenbrock (2002).

FERN AND FERN-ALLIES
Ophioglossaceae
*Botrychium virginianum* (L.) Sw., 29643a, 29652m

MONOCOTS
Amaryllidaceae
*Hyposis hirsuta* (L.) Coville, 29644a

Araceae
*Arisaema dracontium* (L.) Schott., 30097a
*Arisaema triphyllum* (L.) Schott., 30794a, 30776m

Commelinaceae
*Tradescantia ohiensis* Raf., 30098a, 26181m

Cyperaceae
*Carex albicans* Willd., 26189m
*Carex blanda* Dewey, 30795a, 26187m
*Carex cristatella* Britt., 29651a
*Carex hirsutella* Mack., 26303a, 26190m
*Carex muhlenbergii* Schk., 26308a, 26192m
*Carex pensylvanica* Lam., 29457a, 29662m
*Carex rosea* Schk., 26191m

Juncuaceae
*Juncus tenuis* Willd., 30099a, 30106m

Liliaceae
*Allium canadense* L., 30796a
*Smilacina racemosa* (L.) Desf., 30797a, 29667m
*Trillium recurvatum* Beck, 29450a

Poaceae
*Agrostis perennans* (Walt.) Tuckerm., 30509a, 30491m
*Andropogon gerardii* Vitman, 30510a, 30492m
*Bromus pubescens* Muhl., 30100a, 30107m
*Cinna arundinacea* L., 31001a, 30493m
**Dactylis glomerata* L., 30798a, 30777m
*Danthonia spicata* (L.) Roem. & Schultes, 26297a, 26173m
*Dichanthelium acuminatum* (Sw.) Gould & Clark, 26305a, 30111m
*Dichanthelium latifolium* (L.) Gould & Clark, 30104a, 26174m
*Dichanthelium linearifolium* (Scribn.) Gould, 26299a, 30781m
*Elymus hystrix* L., 30101a, 30108m
*Elymus villosus* Muhl., 30511a
*Elymus virginicus* L., 30102a, 30109m
**Festuca pratensis* Huds., 30799a, 30778m
*Festuca subverticillata* (Pers.) E.B. Alexeev., 30103a, 30110m
*Glyceria striata* (Lam.) Hitchc., 30801a, 30780m
*Muhlenbergia schreberi* J.F. Gmel., 30512a, 30494m
*Muhlenbergia sobolifera* (Muhl.) Trin., 30513a, 30495m
**Poa compressa* L. 30105a, 30112m
**Poa pratensis* L. 29650a, 26172m
*Poa sylvestris* Gray, 26176m
*Schizachyrium scoparium* (Michx.) Nash, 30514a, 30496m
*Sphenopholus obtusata* (Michx.) Scribn, 30802a, 26175m
*Tridens flavus* (L.) Hitchc. 31191a, 30497m
*Vulpia octoflora* (Walt.) Rydb., 30782m

Smilacaceae
*Smilax tamnoides* L., 30515a, 30783m

DICOTS
Acanthaceae
*Ruellia humilis* Nutt., 30516a, 30113m

Anacardiaceae
*Rhus aromatica* Ait., 29663m
*Rhus glabra* L., 31014m
*Toxicodendron radicans* (L.) Kuntze, 30803a, 30784m

Apiaceae
*Sanicula canadensis L.*, 30075a, 30114m
*Taenidia integerrima* (L.) Drude, 30813a, 29658m

Aristolochiaceae
*Aristolochia serpentaria* L., 31008a

Asclepiaadaceae
*Asclepias quadrifolia* Jacq., 26300a, 26182m

Asteraceae
*Ageratina altissima* (L.) King & Robins., 30522a, 30501m
*Antennaria plataginifolia* (L.) Hook., 29453a, 29653m
*Aster anomalus* Engelm., 30517a, 30498m
*Aster lateriflorus* (L.) Britt., 30519a, 30499m
*Aster pilosus* Willd., 30520a
*Aster turbinellus* Lindl., 30521a, 30500m
*Aster urophyllus* Lindl., 30518a
*Coreopsis palmata* Nutt., 30117m
*Erigeron annuus* (L.) Pers., 30077a, 30115m
*Erigeron philadelphicus* L., 30804a, 30785m
*Eupatorium serotinum* Michx., 31192a
*Helianthus divaricatus* L., 30076a, 30116m
*Hieracium gronovii* L., 31005a
*Krigia biflora* (Walt.) Blake, 29645a
*Lactuca canadensis* L., 31007a
*Lactuca floridana* (L.) Gaertn., 31009m
*Liatris aspera* Michx., 30523a, 30502m
*Prenanthes alba* L., 30524a
*Solidago nemoralis* Ait., 30526a, 30503m
*Solidago speciosa* Nutt., 31193a
*Solidago ulmifolia* Muhl., 30525a, 30504m

Berberidaceae
*Podophyllum peltatum* L., 30810a, 29665m

Boraginaceae
*Hackelia virginiana* (L.) I.M.Johnston, 30078a

Brassicaceae
*Arabis canadensis* L., 30805a, 29654m
*Arabis laevigata* (Willd.) Poir., 30079a

Caesalpiniaceae
*Chamaecrista fasciculata* (Michx.) Greene, 30082a

Campanulaceae
*Campanulastrum americanum* (L.) Small, 30080a, 31010m
*Lobelia inflata* L., 30081a, 30118m
*Lobelia spicata* Lam., 26311a, 30119m
*Triodanis perfoliata* (L.) Nieuwl., 30807a, 30786m

Caprifoliaceae
**Lonicera maackii* (Rupr.) Maxim., 30527a
*Viburnum prunifolium* L., 30528a, 30505m

Caryophyllaceae
**Cerastium glomeratum* Thuill., 26183m

Convolvulaceae
*Calystegia spithamaea* (L.) Pursh, 30806a

Corylaceae
*Corylus americana* Walt., 30083a

Elaeagnaceae
**Elaeagnus umbellata* Thunb., 30529a, 30506m

Eupohorbiaceae
*Acalypha virginica* L., 31003a, 30507m
*Euphorbia corollata* L., 31002a, 31011m

Fabaceae
*Amorpha canescens* Pursh, 26307a, 30120m
*Amphicarpaea bracteata* (L.) Fern., 30787m
*Dalea candida* (Michx.) Willd., 26312a, 30123m
*Desmodium glutinosum* (Muhl.) A. Wood, 30084a, 30122m
*Desmodium nudiflorum* (L.) DC., 30121m
*Lespedeza intermedia* (S. Wats.) Britt., 31196m
*Lespedeza virginica* (L.) Britt., 31194a, 30608m
*Tephrosia virginiana* (L.) Pers., 30126m
*Trifolium reflexum* L., 26186m

Grossulariaceae
*Ribes missouriense* Nutt., 29449a

Hypericaceae
*Hypericum punctatum* Lam., 26310a

Lamiaceae
*Pycnanthemum pilosum* Nutt., 30530a
*Pycnanthemum tenuifolium* Schrad., 26306a, 30124m
*Teucrium canadense* L., 30085a

Menispermaceae
*Menispermum canadense* L., 30808a

Onagraceae
*Circaea lutetiana* L., 30086a

Oxalidaceae
*Oxalis fontana* Bunge, 30087a
*Oxalis violacea* L., 29452a, 29656m

Phrymaceae
*Phryma leptostachya* L., 30088a, 30125m

Polygalaceae
*Polygala sanguinea* L., 30089a

Portulacaceae
*Claytonia virginica* L., 29456a

Ranunculaceae
*Anemone virginiana* L., 30090a, 30127m
*Anemonella thalictroides* (L.) Spach, 29455a, 26179m
*Ranunculus abortivus* L., 30809a
*Ranunculus micranthus* Torr. & Gray, 29655m

Rhamnaceae
*Ceanothus americanus* L., 30128m

Rosaceae
*Agrimonia gryposepala* Wallr., 30091a, 30129m
*Geum canadense* Jacq., 30092a, 30130m
*Potentilla simplex* Michx., 26304a, 26184m
*Rosa carolina* L., 30093a, 30131m
*Rubus allegheniensis* Porter, 29647a
*Rubus flagellaris* Willd., 29646a, 29666m
*Rubus occidentalis* L., 30811a, 30788m
*Rubus pensilvanicus* Poir., 29670m

Rubiaceae
*Galium aparine* L., 29648a, 26185m
*Galium circaezans* Michx., 26301a, 30789m
*Galium concinnum* Torr. & Gray, 26298a, 30133m
*Galium pilosum* Ait., 30132m
*Galium triflorum* Michx., 31006m

Rutaceae
*Ptelea trifoliata* L., 31013m
*Zanthoxylum americanum* Mill., 30094a

Santalaceae
*Comandra umbellata* (L.) Nutt., 30095a

Scrophulariaceae
*Agalinus tenuifolia* (Vahl) Raf.,30531a, 31197m
*Aureolaria grandiflora* (Benth.) Pennell, 30532a, S31012m
*Penstemon pallidus* Small, 29649a, 26178m
**Veronica arvensis* L., 30812a, 30790m

Solanaceae
*Physalis subglabrata* Mack. & Bush, 26180m
*Physalis virginiana* Mill., 29668m

Violaceae
*Viola palmata* L., 31004a, 30793m
*Viola pedata* L., 29454a, 30791m
*Viola sororia* Willd., 29451a, 30792m

Vitaceae
*Parthenocissus quinquefolia* (L.) Planch, 30096a, 30134m

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# *Glyceria maxima* (Poaceae), Sweet Reed Grass, an Exotic Grass New to the Illinois Flora

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## ABSTRACT

*Glyceria maxima* (Hartman) Holmberg (Poaceae, sweet reed grass) is reported for Illinois based on recently collected specimens from Illinois Beach State Park, Lake County, Illinois.

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Since the publication of the Vascular Flora of Illinois (Mohlenbrock 2002), new state records have continued to appear. In 2005, one of us (Nelson) noted a large vegetative grass in a natural area of Illinois Beach State Park, Lake Co., Illinois. A specimen was collected on 20 May 2006 (*Nelson s.n.*, EIU 71133) and was subsequently identified (Tucker). The compressed sheaths with a rough texture suggested *Glyceria maxima* (Hartman) Holmberg. This Eurasian grass, sometimes considered synonymous with the native *Glyceria grandis* S. Wats. (Dore and McNeill 1980; Tucker 1996) has been reported only from Connecticut, Massachusetts and Wisconsin (USDA, NRCS 2007; Tucker, 2007). In the field, *G. maxima* can be distinguished from *G. grandis* by the rough sheaths of the introduced species. Further identification information is provided in the treatment by Barkworth and Anderton (2007) for *Flora of North America.*

Later in the season, on 4 August 2006, Nelson collected flowering material of *Glyceria maxima* (*Nelson s.n.,* EIU 71381) from which Tucker and Ebinger confirmed the identification previously based on vegetative specimens. An image of the flowering specimen was sent to Stephen Darbyshire (DAO), who also confirmed the identification. A duplicate of this specimen was deposited at the Illinois Natural History Survey Herbarium (ILLS).

Though first collected in 2006 at Illinois Beach State Park, *Glyceria maxima* had been at that site for at least a quarter-century. An oddly different, circular patch has shown up on aerial photos since 1982. Until recently it was thought to be reed canary grass and did not receive management attention. It has apparently been expanding in a circular pattern from around a manhole cover that was installed many years ago as a part of a sanitary sewer project. Perhaps it was brought to the site by workers or equipment during one of many repairs on the sanitary sewer line. It seems likely that the original source of this population, whether from seeds, rhizomes, or sod, was from nearby Wisconsin, where it is known from four counties in the vicinity of Milwaukee and Kenosha (USDA, NRCS 2007). Sweet reed grass has not been found in any other part of the park.

Based on the diameter of the patch compared to the width of the road, the population of sweet reed grass has approximately quadrupled in area from 1982 to 2005. This grass is clearly an aggressive invasive wetland species, as it has displaced a dense stand of cattails. In 2006, it covered ca. 1.35 acres (0.5 ha) within the cattail stand. This is a clear example of why it is important to insist that all construction equipment be pressure washed before being allowed entry into high quality natural areas.

The population of sweet reed grass was treated with 3% Glypro (aquatic approved Glyphosate) in early August of 2006. Several weeks later, the treated areas were completely brown, but a second application will be made in 2007, if there are any remaining plants.

## ACKNOWLEDGMENTS

We thank Stephen Darbyshire (Agriculture Canada, Ottawa) for providing a confirmation of the identification of *Glyceria maxima.*

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# Unusual Spring 2007 Weather Conditions Destroy Illinois' Peach Crop

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## ABSTRACT

An unusually long warm period in late March and early April followed by several days with low temperatures in the low to mid 20s spelled doom for Illinois' 2007 peach crop. Dating back to 1899 there has been great inter-annual variability in Illinois peach harvests; however only four years—1982, 1985, 1990, and 2007—registered 'zero' harvests (< 1 million pounds). Examination of previous temperature conditions in these 'zero' harvest years identified that winters characterized by a large number of cold days ($T_{min} \leq$ 0°F) and/or early spring temperature extremes, consisting of long (>10 days) extremely warm periods (average daily growing degree day, base 40°F, ≥ 15°F) followed by a multi-day cold period ($T_{min} \leq$ 27°F), are capable of causing peach bud, blossom, and/or tree kill in Illinois. The statistical relationship between the number of winter days with $T_{min} \leq$ 0°F and Illinois' annual peach harvest was r = -0.40, suggesting that better yields can be expected following warmer winters.

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## INTRODUCTION

In mid-April 2007 fruit experts proclaimed that the spring weather conditions in Illinois had destroyed much of the berry, grape, and orchard crops in Illinois (Grant, 2007). Fruit experts also indicated it was the most devastating loss since the 1950s. The goal of this research is to identify the peach-damage weather conditions in 2007 and to assess past critical weather conditions associated with other years when little or no peach harvest occurred in Illinois.

Most of the fruit crops in Illinois are grown in the southern third of the state, where production developed for several environmental and economic reasons. The soils of the region were not as rich as the prairie soils of the northern two-thirds of the state, and the southern topography is rolling and hilly, making it much harder to cultivate for grain crops. The region's climate in winter and spring is milder than in areas further north, a preferred climate for fruit crops.

The initiation of fruit growing in the southern region of Illinois was promoted by the Illinois Central Railroad (IC), which had been built during the period from 1851 to 1856 when the state was largely unsettled. Funding to build this north-south oriented, 702-mile railroad by eastern financiers was induced by awarding them a federal charter of six square miles of land (then federally owned) for each mile of rail line built. Thus, to regain their investment, the owners had to sell these lands. After 1856 they were having trouble selling the hilly, poorer soil lands along their lines in southern Illinois. IC leaders also realized the need for fresh fruits and produce for a rapidly growing Chicago population. Thus, they saw an opportunity to promote fruit growing in southern Illinois in order to sell the land and obtain products to sell in Chicago (Stover, 1975). Fruit crops did not have to be planted and cultivated each year as did grain crops, and were thus better suited for the hilly terrain in southern Illinois. The IC promoted the fruit production and offered reduced shipping rates for fruit growers. Then, in 1857, the IC sponsored the Illinois State Fair held in Centralia, a rail hub of the IC. There the IC actively promoted fruit production in the areas along their lines south of Effingham and Vandalia. As a result, the growing of strawberries, grapes, apples, and peaches developed from Cairo northward. By the late 1860s, the IC was operating special daily "peach" trains consisting of 20 cars loaded with peaches from southern Illinois locales to Chicago on every day of the peach harvest (Stover, 1975). More than 95% percent of all peaches in Illinois are grown south of a line from Hannibal, Missouri, to Terre Haute, Indiana (Fig. 1).

Illinois' peach harvest levels peaked prior to World War II, decreasing into the early 1960s before leveling off at an average of approximately 15 million pounds per year to the present (Fig. 2). Dramatic inter-annual variability exists throughout the record suggesting that yields in some years were influenced by anomalous weather conditions.

Weather conditions affecting different fruits vary to some extent, and for this study, the state's peach crop was chosen for evaluating the weather of 2007 and conditions in past years. Weather conditions in peach growing areas during the late summer 2006 (July through September), a time when buds are typically set on peach trees, was generally average both in terms of precipitation (i.e., ranging from 75% to 150% of average) and temperature (i.e., ranging from -1°F to 1°F) and thus did not appear to have an influence on the 2007 harvest. Peach crops are vulnerable in winter and spring to two conditions (Gardner et al., 1952; Kramer and Kozlowski, 1960). One is to extremely low temperatures in winter (November-March), typically daily minimum temperatures ($T_{min}$) at or below 0°F, and the other is abnormally cold temperatures in spring ($T_{min} \leq 27°F$—a "hard" freeze) after the buds and/or blossoms have emerged (Chaplin, 1948; Grant, 2007; Wahle, 2007). Extreme cold in the winter damages the trees, roots, and buds, and reduces yields (Kramer and Kozlowski, 1960). Peach blooming in Illinois normally occurs from mid April to early May depending on variety (Wahle, 2007). A period with two or more cold days ($T_{min} \leq 27°F$) in the spring when the peach buds are blooming kills the blooms and destroys the crop (Chaplin, 1948; Gardner et al., 1952; Wahle, 2007).

The weather oddity of 2007 was the prolonged period of much above-average temperatures in March through early April that led to blooming of many fruit crops in late March, about a month earlier than normal (Fig. 3). Ensuing days with quite low temperatures occurred in early to mid April, not a frequent outcome, but one that devastated the early blooms (Grant, 2007; Wahle, 2007).

## DATA AND APPROACH

Illinois Agricultural Statistics were used to assess annual peach harvest totals (National Agricultural Survey Statistics, 2007). The unit used to measure the quantity of harvested peaches changed twice between 1899 and the present, going from number of bushels to number of pounds to number of tons. For a uniform study all annual values were changed to number of pounds (Fig. 2). The top peach producing Illinois counties were identified (Fig. 1). Since the interest in this study focused on understanding the weather conditions that could devastate the Illinois peach harvest such as occurred in 2007, those years with less than one million pounds harvested (1982, 1985, 1990, and 2007)—*zero years*—were analyzed.

The winter and spring temperature conditions in Illinois's peach growing region were assessed using five long-term climate stations with good quality daily records: Anna, Du Quoin, Mt. Vernon, Effingham, and Jerseyville (Fig. 1). Daily minimum ($T_{min}$), maximum ($T_{max}$), and mean temperatures ($T_{mean}$) were assessed for these sites.

The number of cold season (November through March) days, defined as days with minimum temperatures ($T_{min}$) ≤ 0°F, were counted for each of the five stations and then related, using least-squares regression, to annual Illinois peach harvests (1899-2005). Pearson correlation coefficients (r-values) were determined.

For all "zero" harvest years, days with $T_{min} \leq 27$°F (i.e., "hard" freeze) after March 1st were identified. The number of hard freeze days was determined for each spring "cold" period, a period that began and ended with a hard freeze day. March and April "warm" periods, those periods between days/periods with hard freezes were also examined. Using a base of 40°F, the number of Growing Degree Days (value determined by averaging the daily maximum and minimum temperatures and subtracting 40° from daily average temperatures greater than 40°F) was determined on a daily basis and accumulated in each warm period; an average daily $GDD_{40}$ was then determined for each warm period. Based on the distribution of average daily $GDD_{40}$, an arbitrary "intensity" was assigned to each spring warm period. Those warm periods with an average $GDD_{40} \leq 12°$ (average daily temperature of 52°F or less) were considered "weak," those between 12° and 15° were considered "moderate," and those ≥ 15° "intense." The length of spring warm periods was examined and noted. Those warm periods that lasted more than 10 days were separated from those lasting fewer days. An example of how a warm period average $GDD_{40}$ was determined is shown in Table I and was based on daily temperatures from Effingham for the period March 19 through April 7, 2007 (Fig. 3).

## RESULTS

### Impact of cold winter days on peach harvests

The relationship of the number of cold winter days ($T_{min} \leq 0°F$) experienced at Mt. Vernon to annual peach harvests (Fig. 2) was examined for the period 1899 through 2005 using the Pearson correlation coefficient (r-value). For Mt. Vernon, the r-value for peach harvest to the number of cold winter days was -0.40; about 16 percent of the variation in annual peach harvests was explained by number of winter cold days. For Effingham the r-value was -0.42, for Jerseyville it was -0.38, for Du Quoin it was -0.39, and for Anna it was -0.39. The negative correlation coefficients indicate that as the number of winter cold days increases, the amount of peaches harvested the next summer decreases.

Winter temperature drops to $T_{min} \leq 0°F$ or several days/periods with $T_{min}$ at that level can kill trees (especially young ones) or kill the dormant buds (Wahle, 2007). For the "zero" peach harvest years, the number of winter cold days experienced at Mt. Vernon varied from zero to 10 days (Table II). In contrast, the average number of winter cold days at Mt. Vernon for the period 1899-2005 was three. Three of the zero-year winters experienced two to three times the average number of winter cold days. The low number of winter cold days during 2006/07 suggested that other weather conditions were the primary reason for the loss of the 2007 peach crop.

### Impact of spring warm and cold periods on peach harvests

The winter of 1981/82 was quite severe in Illinois producing 10 cold days at Mt. Vernon (Table II). The winter cold experienced at the northern two locations must have been enough to kill trees and buds as the spring conditions there did not suggest a significant temperature problem (Table III). Effingham and Jerseyville experienced two weak (average daily $GDD_{40} \leq 12°$) warm periods followed by multi-day (≥ 2 day) cold ($T_{min} \leq 27°F$) periods. For example, in spring 1982, Effingham experienced a 16-day warm period with an average daily $GDD_{40}$ of 8.1°, followed by a cold period that had two cold days, then a second eight-day warm period (average daily $GDD_{40}$ of 8.8°), followed by a cold period with five cold days. Whether these warm periods were intense or long enough to have buds emerge and bloom is doubtful (Wahle, 2007). The three southern locations experienced similar winter conditions as well as one long (> 10 day) moderate (average daily $GDD_{40}$ between 12° and 15°) and intense (average daily $GDD_{40} \geq 15°$) warm period followed by a multi-day cold period. If the winter cold of 1981/82 did not kill the trees or buds and ruin the peach crop in these locations these spring temperature extremes surely would have completely killed any blossoms that had emerged, eliminating any chance of a peach harvest.

The total loss of a peach crop in 1985 must be related to conditions primarily experienced during the winter as the spring temperature conditions (warm followed by freezing conditions) were not unusual (Table III). All sites experienced three or four weak warm periods (average daily $GDD_{40}$ ranging from 4.7° to 10°), periods that would normally be too short, at the described intensity, to expose the peach bud or blossom to a significant freeze. The number of hard freeze days following these warm periods were generally one or two, generally too short to create significant damage to all varieties. If this crop's failure was related to unusually cold temperatures, the killing of buds and trees must have occurred due to the large number of very cold days in January and February of 1985.

Once again, severe winter cold conditions probably led to the failure of the state peach crop by killing trees and/or buds in 1990. However, if that wasn't enough, spring 1990 temperature extremes would have ended any hope of a crop across the entire region. Each station in the peach growing region experienced at least one long (> 10 days) and intense warm (average daily $GDD_{40}$ ranging from 16.4° to 19.0°) period followed by a multi-day cold period, with the number of hard freeze days ranging from three to seven (Table III). These warm periods would have allowed buds to break and blossom (Wahle, 2007) before the period of freezing temperatures prevented any opportunity for the tree to set fruit.

The 2007 total peach crop failure was not at all related to the occurrence of winter cold periods as Mt. Vernon did not experience one day with $T_{min} \leq 0°F$. Peach trees and buds that safely made it through winter experienced two unusual warm periods, each followed by cold periods, the second of which was characterized by four or more cold, or hard freeze days ($T_{min} \leq 27°F$) at all sites (Table III). The first warm period lasted eight days and was of weak intensity at the two northern sites (Fig. 3) and moderate intensity at the three southern sites before a two day cold period occurred. Due to the intensity of the warm period, buds likely emerged at the southern sites for some varieties, but few if any emerged at the northern sites (Wahle, 2007). Then the second intense (average daily $GDD_{40}$ ranging between 20.0° and 21.4°) warm period, which lasted between 16 and 19 days across the region, brought out most if not all blossoms that were then killed by the long cold period (each period experiencing between 4 and 6 cold "hard freeze" days) that followed in early April (Fig. 3). Of all years examined, this was the most intense warm period experienced. Only a handful of late variety peaches survived in Calhoun County, located between the Illinois and Mississippi River near the mouth of the Illinois River (University of Illinois, 2007). This minor victory in an otherwise "zero" year in Illinois may have been attributed to the fact that the buds and/or blossoms for some late varieties did not become totally exposed in the first or second warm period and thus survived the second long freezing period (Wahle, 2007).

## SUMMARY

In 2007, Illinois suffered only its fourth year without a peach crop (harvest < one million pounds) since 1899. The key to the 2007 peach crop disaster is the fact that the prolonged high March and early April temperatures matched those normally occurring in late April/early May, and thus brought peach trees to their budding and blooming stages a month early. Normally these stages occur between mid April and early May when there is very little chance of below-freezing temperatures. But, cold days ($T_{min} \leq 27°F$) do commonly occur in late March and early April, and thus the early spring warmth of 2007 and early blooms were put in a highly vulnerable position for experiencing cold days which did occur in early April. Other crops including apples, grapes, strawberries, blackberries, and winter wheat also suffered major losses across the state due to these conditions.

The combination of a long (> 10 days) moderate to intense spring warm period followed by a multi-day ($\geq$ 2 day) cold ($T_{min} \leq 27°F$) period in parts of, if not all, the peach growing areas has occurred in other zero (1982 and 1990) peach harvest years examined in this study. In years when twice or more the average number of cold winter days ($T_{min} \leq$

0°F) occurred (1982, 1985, and 1990) prior to the spring, enough damage to either the trees and/or buds occurred to dramatically reduce the statewide peach harvest.

Of the four zero peach harvest years in Illinois, 2007 stands alone as unique as it was not impacted by winter cold days. Other growing season weather conditions such as drought, high winds, hail, and others can further alter the quality and/or quantity of the harvests; however, extreme winter and spring temperature conditions as described in the text serve as the primary factors contributing to whether a peach tree puts fruit on in the spring.

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Figure 1. Location of primary peach growing counties (shaded) and five climate stations used in the study. Area south of line from Hannibal, Missouri, and Terre Haute, Indiana, is region where 95% of the peach crop in Illinois is harvested.

Figure 2. Annual Illinois peach harvests (million of pounds) and number of winter days when $T_{min} \leq 0°F$, 1899-2005.

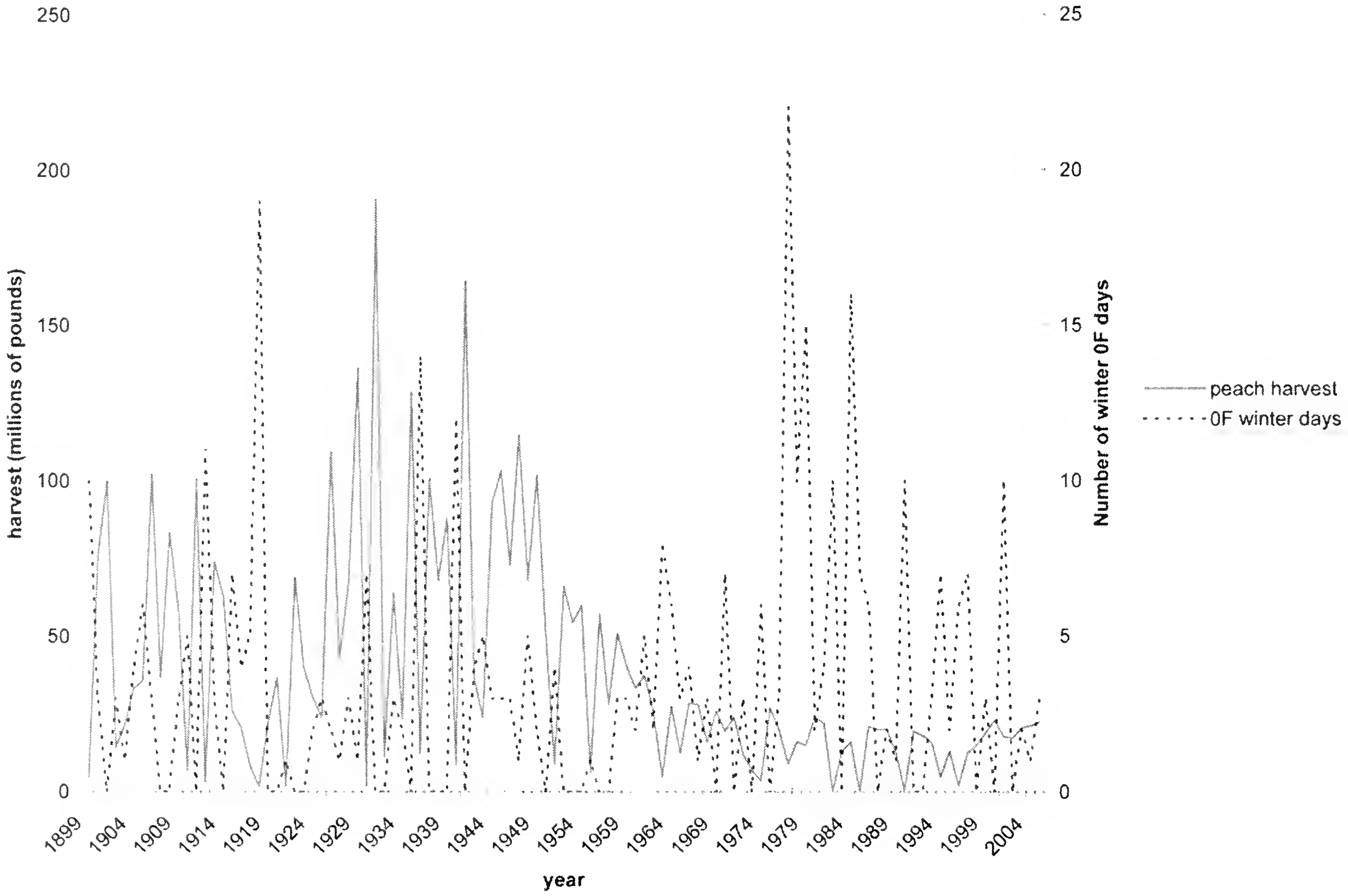

Figure 3. Observed and average daily temperatures ($T_{max}$, $T_{min}$, and $T_{mean}$) for Effingham, Illinois, between March 1, 2007 and April 20, 2007. When the observed daily $T_{mean}$ is above 40°F, that day is accumulating GDDs.

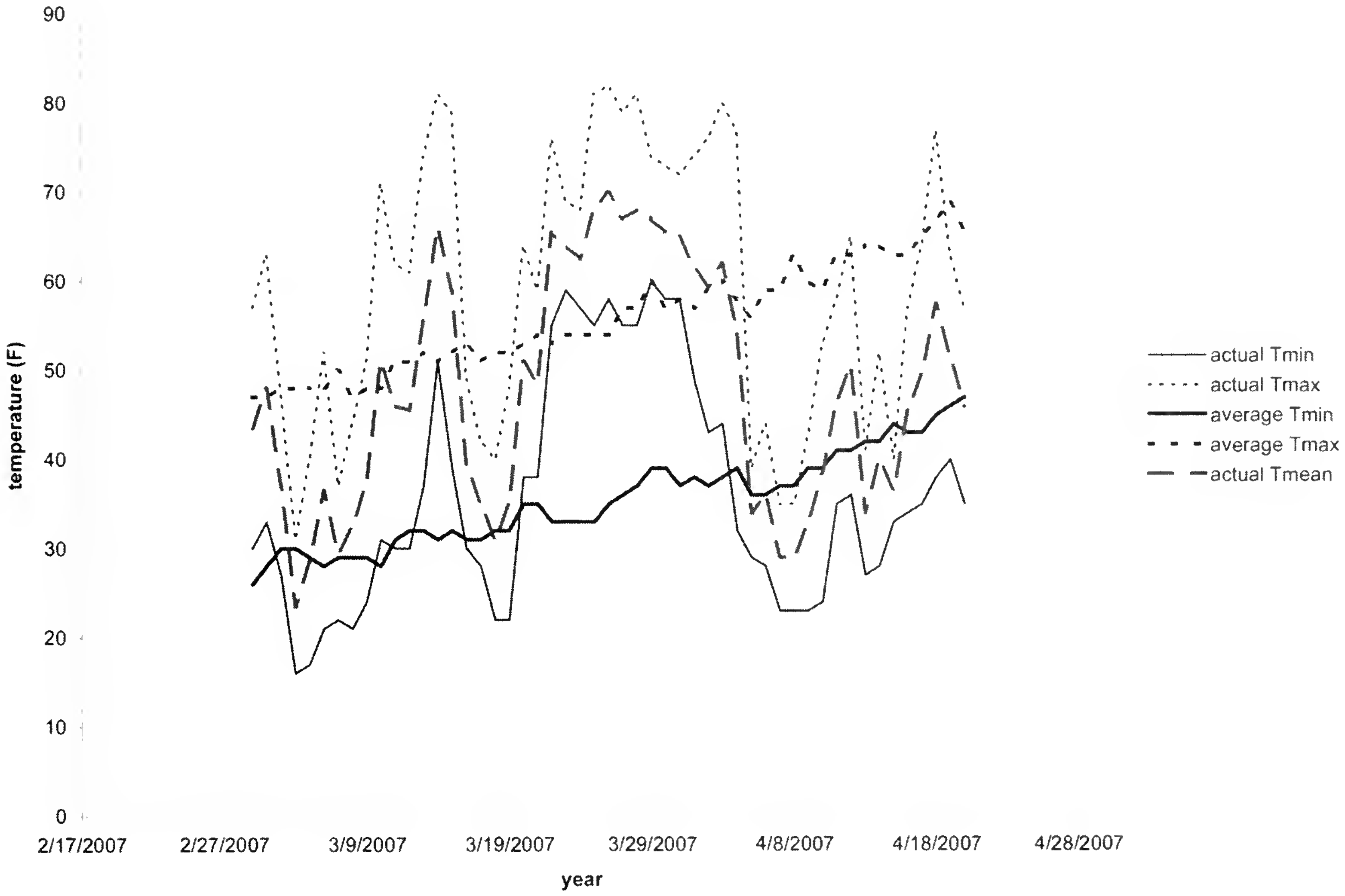

Table I. Daily temperatures ($T_{max}$, $T_{min}$, and $T_{mean}$) and $GDD_{40}$ values are shown for Effingham for the period March 19 through April 7, 2007. $T_{min} \leq 27°F$ are underlined as they represent “hard freeze” days. All values in degrees (°F).

| Date | $T_{max}$ | $T_{min}$ | $T_{mean}$ | $GDD_{40}$ | Status |
|---|---|---|---|---|---|
| March 19, 2007 | 48 | 22 | 35 | 0 | hard freeze |
| March 20, 2007 | 64 | 38 | 51 | 11 | warm period |
| March 21, 2007 | 59 | 38 | 48.5 | 8.5 | “ |
| March 22, 2007 | 76 | 55 | 65.5 | 25.5 | “ |
| March 23, 2007 | 69 | 59 | 64 | 24 | “ |
| March 24, 2007 | 68 | 57 | 62.5 | 22.5 | “ |
| March 25, 2007 | 81 | 55 | 68 | 28 | “ |
| March 26, 2007 | 82 | 58 | 70 | 30 | “ |
| March 27, 2007 | 79 | 55 | 67 | 27 | “ |
| March 28, 2007 | 81 | 55 | 68 | 28 | “ |
| March 29, 2007 | 74 | 60 | 67 | 27 | “ |
| March 30, 2007 | 73 | 58 | 65.5 | 25.5 | “ |
| March 31, 2007 | 72 | 58 | 65 | 25 | “ |
| April 1, 2007 | 74 | 49 | 61.5 | 21.5 | “ |
| April 2, 2007 | 76 | 43 | 59.5 | 19.5 | “ |
| April 3, 2007 | 80 | 44 | 62 | 22 | “ |
| April 4, 2007 | 77 | 32 | 54.5 | 14.5 | “ |
| April 5, 2007 | 39 | 29 | 34 | 0 | “ |
| April 6, 2007 | 44 | 28 | 36 | 0 | “ |
| April 7, 2007 | 35 | 22 | 29 | 0 | hard freeze |

Total warm period $GDD_{40}$ = 359.5°

Average daily $GDD_{40}$ for 18 day warm period = 20.0°, an intense warm period.

Table II. Number of winter cold days ($T_{min} \leq 0°F$) observed at Mt. Vernon, Illinois, for each of the “zero” Illinois peach harvest years.

| Winter | Number of Days |
|---|---|
| 1981/82 | 10 |
| 1984/85 | 7 |
| 1989/90 | 10 |
| 2006/07 | 0 |

Table III. Number of spring warm periods, length of each warm period (days) during the spring (bold are warm periods longer than 10 days), average daily $GDD_{40}$ for each warm period (bold is moderate and italics is intense warm periods), number of spring cold days ($T_{min} \leq 27°F$) following each warm period (2 or more cold days are in bold), at each station during each "zero" year.

| Year | Station | # Warm Periods | Warm Length | Average Daily GDDs (°) | Cold Days |
|---|---|---|---|---|---|
| 1982: | Anna | 4 | **11**, 6, **17**, 8 | 6.9, 7, *16.4*, **14.9** | 1, **4**, **2**, **4** |
| | DuQuoin | 3 | 10, **17**, 7 | 3.9, **13.7**, *15.1* | **8**, **2**, **5** |
| | Mt.Vernon | 3 | 3, **12**, 6 | 5.3, *15.3*, **13.7** | **6**, **3**, **4** |
| | Effingham | 2 | **16**, 8 | 8.1, 8.8 | **2**, **5** |
| | Jerseyville | 2 | **12**, 8 | 8.4, 9.6 | **3**, **5** |
| 1985: | Anna | 3 | 8, 5, **11** | 8.3, 7.8, 10 | 1, 1, 1 |
| | DuQuoin | 3 | 7, 4, **11** | 9.4, 8, 7.8 | **2**, **2**, 1 |
| | Mt.Vernon | 3 | 7, 4, 10 | 8.1, 8, 6.8 | **3**, **2**, 1 |
| | Effingham | 3 | 6, 10, **20** | 6.5, 4.7, 9.7 | **6**, **2**, 1 |
| | Jerseyville | 4 | 7, 4, **11**, **21** | 5.3, 5.3, 5.6, 9.4 | **2**, **2**, 1, 1 |
| 1990: | Anna | 3 | 10, **15**, **12** | 9.8, *17.9*, 9.8 | **5**, **3**, 1 |
| | DuQuoin | 3 | **11**, **14**, **11** | 6.6, *19*, 9.8 | **9**, **5**, 1 |
| | Mt.Vernon | 3 | **13**, 10, 4 | *17.3*, 7.5, 7.5 | **6**, 1, 1 |
| | Effingham | 3 | **13**, 10, 3 | *17.5*, 6.6, 10 | **7**, **3**, 1 |
| | Jerseyville | 4 | **13**, 3, 9, 4 | *16.4*, 7.7, 5.7, 9.5 | **3**, **4**, **2**, 1 |
| 2007: | Anna | 2 | 8, **19** | **13.9**, *20.7* | **2**, **4** |
| | DuQuoin | 2 | 8, **19** | **13.9**, *20.7* | **2**, **4** |
| | Mt.Vernon | 2 | 8, **19** | **13.6**, *20.8* | **2**, **4** |
| | Effingham | 2 | 8, **18** | 10.5, *20.0* | **2**, **5** |
| | Jerseyville | 2 | 8, **16** | 10.5, *21.4* | **2**, **6** |

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# Distribution of Woodchucks (*Marmota monax*) in Illinois

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## ABSTRACT

The woodchuck is important ecologically and because of its interactions with humans. We speculated that its abundance declined from historic levels and determined its current range to compare to past studies. Personal observations, sightings by hunters, and permits issued for removal indicated a statewide distribution as in the past. Range is a coarse indicator of abundance, so we recommend a systematic monitoring program and a study of demographics along an urban-rural gradient to determine relative values and risks of contemporary habitats.

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## INTRODUCTION

Woodchucks (*Marmota monax*) occur at low elevations from eastern Alaska to Labrador, south through the eastern United States to northern Georgia and Louisiana, and west to eastern Nebraska, Kansas, and North Dakota (Kwiecinski 1998, Armitage 2003). They are important ecologically as prey (Grizzell 1955, Meier 1985, Warner and Ver Steeg 1995) and because they modify their environment through burrowing, herbivory, and defecation (Merriam and Merriam 1965, Swihart 1991a, Swihart and Picone 1991, English and Bowers 1994). Abandoned dens provide shelter for many vertebrates, including opossum (*Didelphis virginiana*), river otter (*Lontra canadensis*), raccoon (*Procyon lotor*), eastern cottontail (*Sylvilagus floridanus*), and meadow vole (*Microtus pennsylvanicus*) (Hamilton 1934, Grizzell 1955, Schmeltz and Whitaker 1977, Hossler et al. 1994, Swihart 1995, Gorman et al. 2006).

The woodchucks's status is also a concern because of its interactions with people. It is pursued by hunters and trappers for meat and pelts (Hamilton 1934, Anderson et al. 1996, Anderson and David 1997) and causes damage to crops (Hamilton 1934, Swihart 1991b), cultural resources (Bruleigh and Vandruff 1998), human residences, and other structures (Miller et al. 2001, Bluett et al. 2003). This species also serves as a model for medical research on human diseases such as hepatitis (Wright et al. 1987, Dandri et al. 1996, Zhou et al. 2003).

The woodchuck is characterized as a forest-edge species (Kwiecinski 1998, Armitage 2003). We speculated that its abundance declined from historic levels as documented for other edge species such as northern bobwhite (*Colinus virginianus*; Roseberry and Sudkamp 1998, Dimmick et al. 2002) and eastern cottontail (Roseberry 1998). We determined the woodchuck's current distribution in Illinois to compare to past studies (e.g., Mohr 1943, Hoffmeister 1989); a range contraction of 20-50% was considered indicative of a change in status (e.g., Ceballos and Ehrlich 2002, Laliberte and Ripple 2004).

## METHODS

We used three sources to document distribution: personal observations, Nuisance Animal Removal Permits issued by the Illinois Department of Natural Resources (IDNR), and sightings reported by archery deer hunters who participated in a survey administered by IDNR. Nuisance Animal Removal Permits were issued to landowners and tenants to authorize removal of wildlife after an investigation by IDNR confirmed the existence of damage and a lack of effective alternatives. We examined all permits issued during 2003 through 2006 ($n$ = 2,771) to determine county-level locations of properties with damage caused by woodchucks ($n$ = 420). We eliminated some of these ($n$ = 90) because we were less confident about correct identification of the offending animal when a permit allowed removal of multiple species (including woodchucks) than those issued only for woodchucks ($n$ = 330).

The Archer Survey offers an economical and statistically robust means of monitoring the relative abundance of several species of terrestrial mammals (Hamilton et al. 1989, Winchcombe and Ostfeld 2001). IDNR first administered this survey in 1991 (Ver Steeg and Warner 1997). Data were collected by archery deer hunters who volunteered to keep standardized daily logs of their efforts (number of hours afield) and wildlife observations from 1 October through 14 November. We examined 5,120 surveys returned during 2003 through 2006 to determine county-level locations of woodchucks. We also recorded authors' incidental observations of woodchucks from April through October 2006.

## RESULTS

The Archer Survey provided 168 observations of woodchucks in 62 counties. Nuisance Animal Removal Permits were issued for properties in 52 counties. We observed 28 woodchucks at 26 locations in 16 counties. Altogether, we documented occurrences in 80 counties; 39 had observations from two or more sources (Fig. 1).

## DISCUSSION

Woodchucks were distributed statewide in 2003-2006. Their range was the same as historical reports by Kennicott (1855), Mohr (1943), who observed woodchucks in 81 of Illinois' 102 counties during 1931-1942, and Hoffmeister (1982), who examined 44 specimens from 23 counties. Our findings suggest the woodchuck's status is secure. However, we acknowledge that range is a coarse metric (Goehring et al. 2007) best suited for detecting major changes in abundance, especially when supported by other data (e.g., Martin et al. 2003, Gompper and Hackett 2005).

Monitoring programs allow managers to evaluate and adjust strategies for wildlife conservation (Lancia et al. 2005). Unfortunately, methods to monitor the abundance of woodchucks at large spatial scales are lacking. We have doubts about reliability of the Archer Survey as an index of relative abundance because the sampling period (1 Oct - 14 Nov) coincides with onset of hibernation (Bronson 1962, Ferron 1996). Thus, annual variations in climatic conditions might affect sightings and mask population effects. We suggest that a road-kill index might be useful for detecting trends in relative abundance, as it has for white-tailed deer (*Odocoileus virginianus*; McCaffery 1973), raccoons (Gehrt 2002, Gehrt et al. 2002), Virginia opossums, and striped skunks (*Mephitis mephitis*; Gehrt et al. 2006).

We detected woodchucks in residential, industrial, agricultural, and natural areas. Woodchucks prefer fencerows and woodlands for their hibernacula (Hamilton 1934, Twichell 1939, Grizzell 1955, Meier 1985). Densities are greatest where such areas adjoin crop fields, pastures, orchards, and other sources of abundant and palatable foods (de Vos and Gillespie 1960, Henderson and Gilbert 1978, Swihart 1992). Interspersion of these habitats has declined in Midwestern landscapes (e.g., Illinois Department of Energy and Natural Resources 1994, Warner 1994, Ribic et al. 1998), as have mammals that are dependent on them such as eastern cottontail (Roseberry 1998) and gray squirrel (*Sciurus carolinensis*; Rosenblatt et al. 1999, Swihart et al. 2007). The same might be true for woodchucks. On the other hand, woodchucks have adapted to residential and other human-modified habitats (Anthony 1962, Woodward 1990, Kwiecinski 1998), which are increasingly available. Studying populations along an urban-rural gradient would be useful for management and monitoring programs because demographic characteristics might differ among land uses as was the case for other habitat generalists like raccoon (Prange et al. 2003) and red fox (*Vulpes vulpes*; Gosselink 2002).

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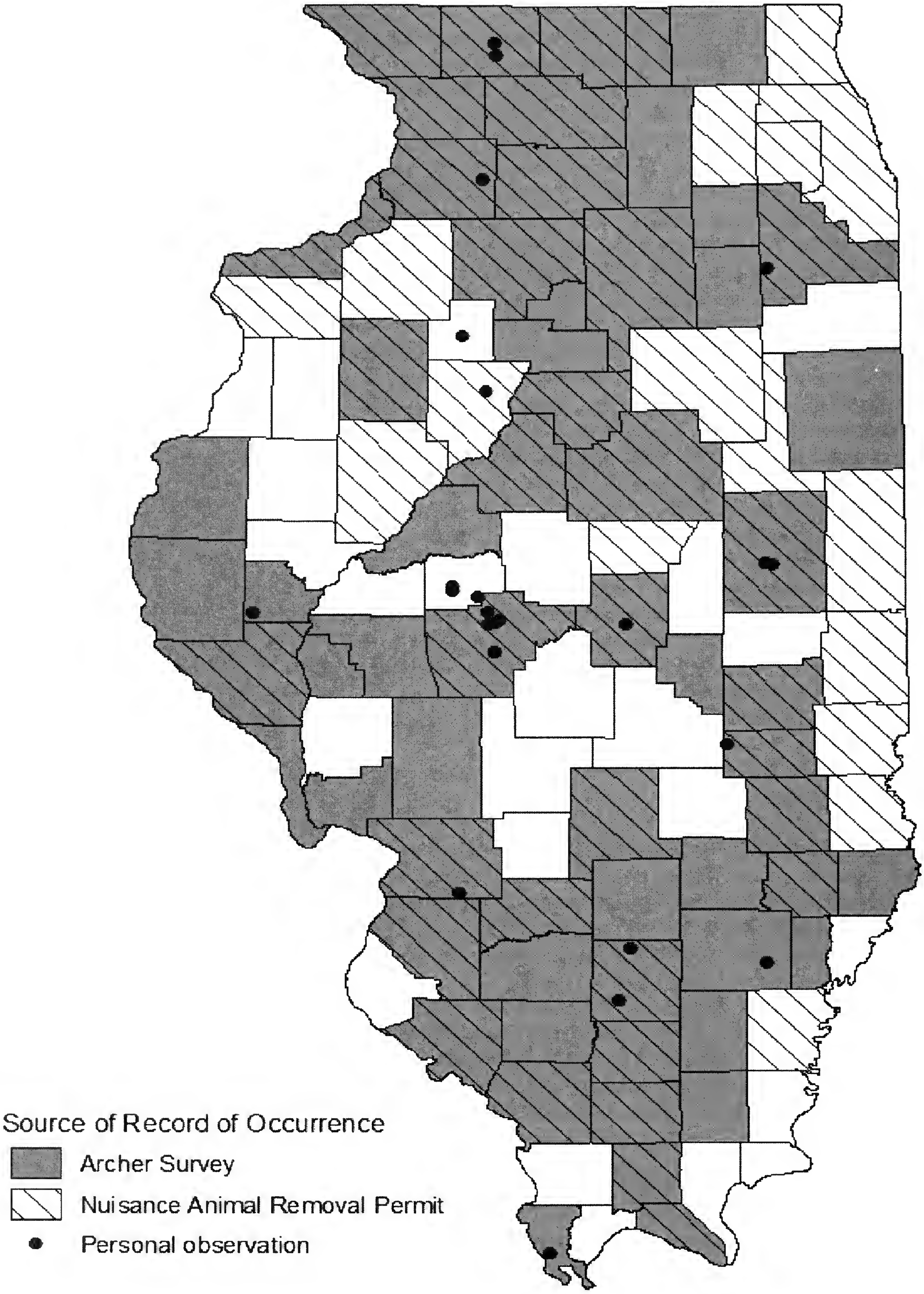
Figure 1. Distribution of woodchucks (*Marmota monax*) in Illinois, 2003-2006.



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# Food Choices by Northern Bobwhites in Illinois

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## ABSTRACT

Food choices of the northern bobwhite (*Colinus virginianus*) were determined by evaluating 209 crops collected between 1 November 2003 and 15 January 2004 in Clay, Richland, and Wayne Counties of southern Illinois. Plant materials composed 98.9% of the volume and animal matter 1.1%. Grit occurred in 6.2% of the crops, and 14.4% of the crops were empty. Only 5 food items made up 1.0% or more by volume. These included soybean 56.8%, corn 34.1%, acorn 1.4%, sorghum 1.2%, and leaves 1.1%. The 5 food items with the highest frequency of occurrence were soybean 47.9%, corn 40.7%, leaves 40.7%, slugs 14.8%, and ragweed 8.1%.

## INTRODUCTION

The northern bobwhite (*Colinus virginianus*) is a game bird well studied throughout its wide range (Brennan 1991, Roseberry 1979, Weber et al. 2002). The bobwhite is an early successional species and prefers the moderately disturbed habitat provided by activities like farming and the Conservation Reserve Program (Roseberry and Klimstra 1984). However, the bobwhite continues to decline in distribution and abundance in Illinois. Estimated hunter harvest of bobwhite in Illinois have decreased from 2,503,000 in 1956 to 844,000 in 1994 and 263,292 in 2004 (Roseberry and Cole 2006). Wildlife managers seek to determine the best food and cover to meet the bobwhite's survival needs. Continued study of the bobwhite during all seasons in various habitats is important, as every new piece of knowledge contributes to the conservation of the bobwhite.

The objectives of this project were to (1) determine the main food choices of bobwhites, and (2) compare food choices in each month of the hunting season. Research findings were then compared with results of a previous study (Larimer 1960) on bobwhite food choices in Illinois. He collected 4606 bobwhite crops in 1950 and 1951 from the 34 southernmost counties of Illinois. Farming practices have changed since 1950, with an increase in soybeans and sorghum and a decrease in wheat and hay; therefore, we hypothesized that bobwhite food choices had changed as well. In 1950, the hunting season only lasted from 11 November to 11 December, and the farmland in southern Illinois counties consisted of the following: 20-31% corn, 9-6% soybeans, 4-20% wheat, and 5-9% hay (Larimer 1960).

Our study focused on 3 counties: Clay, Richland, and Wayne Counties. According to the Illinois Department of Agriculture (2003), Clay County farmland is 46% soybeans, 28.9% corn, 3.8% wheat, 2.6% hay, 1.3% sorghum, and 17.4% other. Richland County farmland is 49.8% soybeans, 36% corn, 5.2% wheat, and 9% other. Wayne County farmland is 41.2% soybeans, 25.4% corn, 3.2% wheat, 4.4% sorghum, and 25.8 % other. Wayne produces more sorghum than any other county in Illinois. Corn appears to have stayed relatively stable over the years.

The average growing season in southern Illinois, from the last spring frost to the first fall frost, is approximately 200 days. The mean minimum temperatures for this study area are 7°C during fall and -5°C during winter. The mean maximum temperatures are about 18°C during fall and 3°C during winter. Southern Illinois has a mean annual rainfall of 116.8 cm, and winter, with a mean precipitation of 25.4 cm, is the driest season (Hollinger 2003).

## MATERIALS AND METHODS

Bobwhite crops were collected from hunters between 1 November 2003 and 15 January 2004, in Wayne, Richland, and Clay Counties. Data from all counties were pooled. Materials given to the hunters included a permanent marker, freezer bags, information tags, and a sheet of instructions. The tags were small squares of durable paper with a string tied through a hole in the paper. Each tag asked for the date, time, location, and sex of the bird harvested. While hunting in the field, hunters filled out the appropriate information and tied the tag onto the leg of the bobwhite. When the hunters got home and cleaned their birds, they removed the tags and extracted the crops. They placed each crop and its respective tag into a bag and then froze the sample. Unfortunately, because of the limitations on how the crops were collected, post-mortem digestion might have caused a misrepresentation of vegetation and invertebrates. Given that invertebrates are not generally eaten by gallinaceous birds in the winter, the effect on the data should have been minimal.

Crops were analyzed after the hunting season. Tag information was recorded, and after thawing, the crop was cut open and its contents were separated into like groups. Each group was placed into a graduated cylinder and measured using the water displacement method. Any unknown contents were placed in a separate bag to be identified later. Landers and Johnson (1976) and Uva and others (1997) were helpful resources for identifying seeds commonly eaten by bobwhites. Southern Illinois University and the Cooperative Wildlife Research Laboratory also provided assistance in identifying seeds.

Plant and animal nomenclature was based on Larimer's findings (1960) to facilitate comparison between the two studies. Seeds were identified to the species level if possible, but leaf material was simply labeled as "leaves." Recognizable animal parts were identified to the order, and in some cases, the family level. Some plant and animal materials were labeled as "unknown." Grit volume was measured the same as described above. Some crops were recorded as empty. For each food, percent frequency of occurrence and percent volume of total crop contents were calculated as described by Larimer (1960). In short, frequency of occurrence is the number of crops in which the food was found divided by the total number of crops. The percent volume of a food is determined by dividing the total volume of that food by the total volume of all crop contents. The volumes of food categories in our study were compared to Larimer's (1960) using a Fisher Exact Test. We also compared volumes of foods in the crops between the months using a Fisher Exact Test (Sokal 1969). For both tests a p value of less than 0.05 was considered to indicate a significant difference.

## RESULTS

Out of 209 crops, 34 different food items were identified (Table 1), of which 98.9% were plant materials and 1.1% were animal material. The legume family, Leguminosae, made up 57.1% of the volume of all crop contents, and the grass family, Graminae, made up 36.8%. All animal material was identified to the orders Insecta and Gastropoda. Grit occurred in 6.2% of the crops, and 14.4% of the crops were empty. Only 5 food items made up 1.0% or more by volume. These included soybeans 56.8%, corn 34.1%, acorns 1.4%, sorghum 1.2%, and leaves 1.1%. The 5 food items with the highest frequency of occurrence were soybeans 47.9%, corn 40.7%, leaves 40.7%, slugs 14.8%, and ragweed 8.1%.

Findings by Larimer (1960) were compared to the top 15 food choices from this study (Table 2). Food choices of bobwhites harvested during the 3 months were compared (Table 3). In November, 52 crops were collected, 108 in December, and 49 in January.

Using the Fisher Exact Test, we compared the top 4 foods by volume from Larimer's study (1960) with our study. We found a significant difference in soybean (G adjusted = 21.9, df = 1, p value <0.001), acorn (G adjusted = 4.6, df=1, p value of 0.03), and lespedeza (G adjusted = 11.9, df=1, p value < 0.001).

Using the Fisher Exact Test, we also tested the difference in November, December, and January foods. We found a significant difference in November corn compared to January corn (G adjusted = 7.6, df=1, p value = 0.006). Also, there was a significant difference between December and January soybeans (G adjusted = 18.9, df=1, p value < 0.001).

## DISCUSSION

In 1950 and 1951, Larimer (1960) found that cultivated grains, including corn, soybean, and wheat, comprised nearly 56% of the bobwhite's diet. In this study, cultivated grains comprised 92% of the diet. This suggests a change in the food availability of the bobwhite in Illinois over the past 50 years. We would expect this given the changes in agricultural practices in the state in the same time period.

Within this study, differences were present between the 3 months of the hunting season. In November, corn ranked above soybeans in percent volume, but soybean ranked first during the other 2 months. Cultivated grains (corn, soybean, and sorghum) made up 83.5% of food items in November, but that increased to 94.3% in both December and January.

The importance of this change in diet from past studies and within the winter months of our study may be more behavioral than physiological. More time spent in open fields feeding on waste grain exposes the bobwhite to more predators and more winter elements. Previous studies have shown 70% of waste soybeans and 40% of waste corn disappearing by late fall (Dec.1) in Illinois agricultural fields. By early spring (April 1), only 15% of waste soybeans are left in these fields (Warner et al. 1989), meaning the bobwhite is forced to forage longer to obtain its needed energy requirements. When cold-stress is added to this equation, survival in the Illinois' winter agricultural landscape may be arduous.

As we've stated, the importance of cultivated grains to bobwhites has increased in the past fifty years. This increase may not be a choice but a result of limited options. A decline of the bobwhite across the state of Illinois (Kleen 2004, Roseberry and Cole 2006) suggests this change in bobwhite foraging activity may be detrimental. Fencerows along fields or nearby woody patches may be essential for bobwhites to escape predation. Although microhabitats are integral, consideration of landscape structure is necessary when assessing habitat suitability (Weber et al. 2002). An adequate combination of food and cover is essential for survival. More research is needed to determine if the changing food availability or the change in cover are responsible for the decline of the bobwhite in Illinois.

## ACKNOWLEDGEMENTS

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Table 1. Percent volume and percent frequency of occurrence of all foods in crops.

| Food Group | % Volume | % Frequency of occurrence |
|---|---|---|
| Legume family (Leguminosae) | | |
| Soybean (*Glycine max*) | 56.84 (1) | 47.85 (1) |
| Small wild bean (*Strophostyles leiosperma*) | 0.17 (14) | 2.39 (21) |
| Lespedezas (*Lespedeza*) | 0.04 (21) | 1.91 (22) |
| Grass family (Graminae) | | |
| Corn (*Zea mays*) | 34.14 (2) | 40.67 (2) |
| Sorghum (*Sorghum*) | 1.22 (4) | 3.83 (15) |
| Switchgrass (*Panicum virgatum*) | 0.61 (9) | 8.13 (6) |
| Smooth crabgrass (*Digitaria ischaemum*) | 0.34 (12) | 3.35 (19) |
| Faber's foxtail (*Setaria faberii*) | 0.02 (23) | 4.31 (13) |
| Wheat (*Triticum aestivum*) | 0.01 (27) | 0.48 (34) |
| Barnyard grass (*Echinochloa crusgalli*) | 0.01 (27) | 0.96 (27) |
| Unknown graminae seed | 0.41 (11) | 4.31 (13) |
| Beech family (Fagaceae) | | |
| Oak acorns (*Quercus*) | 1.40 (3) | 5.74 (10) |
| Honeysuckle family (Caprifoliaceae) | | |
| Japanese honeysuckle (*Lonicera japonica*) | 0.80 (6) | 6.70 (8) |
| Composite family (Compositae) | | |
| Common ragweed (*Ambrosia elatior*) | 0.69 (7) | 8.13 (6) |
| Cashew family (Anacardiaceae) | | |
| Poison ivy (*Rhus radicans*) | 0.29 (13) | 1.91 (22) |
| Spiderwort family (Commelinaeceae) | | |
| Dayflower (*Commelina diffusa*) | 0.16 (16) | 5.26 (12) |
| Buckwheat family (Polygonaceae) | | |
| Climbing false buckwheat (*Polygonum scandens*) | 0.05 (18) | 1.91 (22) |
| Pennsylvania smartweed (*Polygonum pennsylvanicum*) | 0.01 (27) | 0.48 (34) |
| Amaranth family (Amaranthaceae) | | |
| Pigweed (*Amaranthus*) | 0.02 (23) | 3.83 (15) |
| Mallow family (Malvaceae) | | |
| Prickly sida (*Sida spinosa*) | 0.02 (23) | 3.83 (15) |
| Rose family (Rosaceae) | | |
| White avens (*Geum canadense*) | 0.01 (27) | 1.44 (25) |
| Pine family (Pinaeceae) | | |
| Red cedar (*Juniperus virginiana*) | 0.01 (27) | 0.96 (27) |
| Leaves | 1.07 (5) | 40.67 (2) |
| Unknown Materials | 0.49 (10) | 12.92 (5) |
| Grit Slugs & Snails (Gastropoda) | 0.04 (21) | 6.22 (9) |
| Slugs (Philomycidae) | 0.69 (7) | 14.83 (4) |
| Amber snails (Succinia) | 0.01 (27) | 0.96 (27) |
| Insects (Insecta) | | |
| Short-horned grasshoppers (Acrididae) | 0.17 (14) | 1.44 (25) |
| Orthoptera parts (Orthoptera) | 0.01 (27) | 0.96 (27) |
| Beetles (Coleoptera) | 0.12 (17) | 5.74 (10) |
| Ants (Formicidae) | 0.05 (18) | 3.35 (18) |
| Hymenoptera parts | 0.02 (23) | 2.39 (21) |
| Hemiptera parts | 0.01 (27) | 0.96 (27) |
| Flies (Diptera) | 0.05 (18) | 0.96 (27) |
| Animal parts | 0.01 (27) | 3.83 (15) |

Table 2. Top 15 food items in this study compared to Larimer's study.

| This study (2004) | | | Larimer (1960) | | |
|---|---|---|---|---|---|
| Food Item | % Volume | % Frequency of occurrence | Food Item | % Volume | % Frequency of occurrence |
| Soybeans | 56.84 | 47.85 | Corn | 27.79 | 28.85 |
| Corn | 34.14 | 40.67 | Soybeans | 22.43 | 22.08 |
| Acorns | 1.40 | 5.74 | Lespedezas | 8.66 | 42.23 |
| Sorghum | 1.22 | 3.83 | Acorns | 7.19 | 9.55 |
| Leaves | 1.07 | 40.67 | Wheat | 5.45 | 4.54 |
| Japanese honeysuckle | 0.80 | 6.70 | Ragweed | 4.58 | 26.40 |
| Slugs | 0.69 | 14.83 | White sassafras | 3.80 | 5.23 |
| Ragweed | 0.69 | 8.13 | Desmodium | 2.94 | 12.11 |
| Switchgrass | 0.61 | 3.35 | Slugs | 2.81 | 6.84 |
| Grass seed | 0.41 | 4.31 | Jewelweed | 1.82 | 8.66 |
| Smooth crabgrass | 0.34 | 3.35 | Bidens | 1.38 | 18.98 |
| Poison ivy | 0.29 | 1.91 | Cowpea | 1.36 | 1.73 |
| Small wild bean | 0.17 | 2.39 | Grasshoppers | 1.32 | 4.54 |
| Grasshoppers | 0.17 | 1.44 | Small wild bean | 1.00 | 12.53 |
| Dayflower | 0.16 | 5.26 | Yellow foxtail | 0.86 | 9.12 |

Table 3. Comparison by months of top ten food items consumed by bobwhites in Clay, Richland, and Wayne Counties, 2003-2004.

| November (52 crops) | | December (108 crops) | | January (49 crops) | |
|---|---|---|---|---|---|
| Food Item | % Volume | Food Item | % Volume | Food Item | % Volume |
| Corn | 40.09 | Soybeans | 58.58 | Soybeans | 69.66 |
| Soybeans | 39.14 | Corn | 35.22 | Corn | 24.37 |
| Acorns | 4.28 | Ragweed | 0.93 | Leaves | 2.72 |
| Sorghum | 4.28 | Switchgrass | 0.81 | Slugs | 1.24 |
| Japanese honeysuckle | 2.53 | Leaves | 0.71 | Acorns | 0.90 |
| Grass seed | 1.96 | Acorns | 0.64 | Japanese honeysuckle | 0.35 |
| Slugs | 1.63 | Sorghum | 0.53 | Sorghum | 0.30 |
| Smooth crabgrass | 1.62 | Japanese honeysuckle | 0.38 | Beetles | 0.16 |
| Grasshoppers | 0.87 | Small wild bean | 0.28 | Grass seed | 0.06 |
| Poison ivy | 0.71 | Poison ivy | 0.24 | Dayflower | 0.05 |

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# Demographics of Coyotes (*Canis latrans*) During the Late 1970s and 1990s in Southwestern Illinois

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## ABSTRACT

We collected sex, age, and reproductive data from 100 coyotes harvested by fur-takers during the late-1970s and another 200 in the late-1990s from southwestern Illinois. The two samples had nearly identical male-female sex ratios (0.89:1 and 0.87:1, respectively), and neither differed significantly from parity. The percentage of juveniles (<1 year of age) for the 1970s sample (69%) differed significantly from that of the 1990s sample (46%). The high percentage of juveniles in southwestern Illinois during the late-1970s affected breeding rates. Among adult (>1 year of age) females, breeding rates were 53% and 72% for the 1970s and 1990s samples, respectively. The mean number of placental scars (PS) per breeding female of the 1970s sample (4.0) was lower, but did not differ significantly from that of the 1990s sample (4.9). The number of coyotes in southwestern Illinois, as elsewhere in the state increased during the late-1970s. Twenty years later, the coyote population in this area of the state and statewide had stabilized. During both time periods, the mean PS counts in this region of the state were lower than those reported for coyotes in more northern latitudes of Illinois.

Key words: coyote, *Canis latrans*, age structure, placental scars, reproduction, sex ratio

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## INTRODUCTION

Coyotes (*Canis latrans*) have always been present in Illinois, but densities were low until the 1970s when the population began to grow rapidly (Hoffmeister 1989, Nelson and Lloyd 2005). During the late-1970s, fur prices and harvest rates of all furbearers, including coyotes, also increased from previous levels. The number of coyote pelts purchased by fur buyers rose from 2,833 in 1975-76 to 9,831 pelts in 1979-80 (Hubert 1976, 1980).

We analyzed and compared the demographics of two samples of coyotes collected in southwestern Illinois: One from the late-1970s, a time of increasing coyote numbers (Hoffmeister 1989, Nelson and Lloyd 2005) and increased harvests (Hubert 1976, 1980), and the second during the late-1990s, when the population had apparently stabilized (Nelson and Lloyd 2005). The two samples were compared with previous coyote studies in Illinois: Hubert (1978, 1979) and Nelson and Lloyd (2005).

## MATERIALS AND METHODS

We collected 36 coyote carcasses from fur buyers in Randolph County, Illinois from December 1976 to January 1977 and another 64 specimens from December 1979 to January 1980. The animals had been harvested by trappers and hunters in Randolph and surrounding counties. During the winters (November - February) of 1997-2001, a second sample of 200 coyotes was obtained from the same fur buyers and from several coyote hunters in Randolph, Monroe, and St. Clair Counties.

We recorded the sex of each specimen and removed the uterus from females. Placental scars (PS) were counted following Gier (1968) and Kennelly (1978), and female reproductive rates and mean PS counts were calculated for each sample.

After boiling for about 20 minutes, the upper canine teeth of each of the 1970s specimens were extracted from the skulls (1976-77) or rostrums which had been removed with a hand saw (1979-80). One canine tooth was sawed off at the gumline using a Dremel$^{TM}$ Roto-drill equipped with a 1-mm thick, 25-mm diameter carborundum disk. (Mention of a product does not imply endorsement by Illinois Department of Natural Resources.) For each of the coyotes collected in 1997-2001, one upper canine was sawed off at the gumline *in situ*.

Each canine tooth crown's maximum pulp cavity width (a) and maximum tooth width (b) was measured with a calibrated binocular dissecting scope, and a pulp cavity width ratio (a/b) was calculated for each specimen. Juveniles (<1 year of age) were separated from adults (>1 year of age) by their relatively larger canine tooth pulp cavity (Knowlton and Whittemore 2001, Nelson and Lloyd 2005, and others).

We used Chi-square ($x^2$) tests to determine if male-female ratios differed significantly from 1:1 and if our samples' sex and juvenile-adult ratios differed significantly from each other and from those of other Illinois studies. We used a two-tailed *t*-test to find any significant difference between the samples' mean PS counts. A *P*-value $\leq 0.05$ was used to determine significance.

## RESULTS

Males made up less than half (47%) of both the late-1970s and the late-1990s collections. Neither sample's male-female sex ratio was significantly different from parity; 0.89:1 and 0.87:1 ($x^2$=0.250 and 0.845), respectively (Table 1). The percentage of juveniles (69%) in the 1970s sample differed significantly from that of the 1997-2001 sample (46%; $x^2$=21.333).

Breeding rates among adult females were 53% and 72% for the 1970s and 1990s samples, respectively. The mean number of PS per breeding female of the late-1970s sample

(4.0, range 1-6, N=9) did not differ (*P*=0.186) from the late-1990s sample (4.9, range 1-10, N=39).

## DISCUSSION

Hubert (1978, 1979) collected coyote specimens during the late-1970s, and recorded significantly more males than females (Table 1). While our 1970s sample was made during the same time period, our sample's sex ratio did not differ from 1:1 (Table 1). Several coyote researchers have noted balanced sex ratios in lightly harvested coyote populations (Knowlton 1972, Todd, Keith, and Fischer 1981, Windberg 1995). Our results suggest that coyote harvests in southwestern Illinois during the late-1970s were low despite increasing statewide harvest rates (Hubert 1976, 1980).

Hoffmeister (1986) and Nelson and Lloyd (2005) indicated that the statewide coyote population was increasing rapidly in the 1970s. This also occurred in southwestern Illinois at that time and is supported by anecdotal reports of hunters, trappers, fur buyers, and the lay public. Coyote harvest rates in this part of the state were relatively low and slow to increase, however, due to lack of interest and knowledge among fur-takers about trapping and hunting coyotes.

Most coyotes purchased by fur buyers in the area during the late-1970s were from persons who inadvertently took them while trapping or hunting for other species (fur buyers, C. Zanders and H. Schaffner, personal communication). Interest in coyote hunting did not increase markedly in the region until the early- to mid-1980s when individuals began purchasing equipment and dogs used specifically to hunt coyotes (C. Zanders and H. Schaffner and coyote hunters, M. Albert and C. Barlow, personal communication).

We also did not find a significant difference from parity between sexes in our 1990s sample (Table 1). In a mid-1990s statewide study, Nelson and Lloyd (2005) recorded a preponderance of males (Table 1). Specifically, they noted significantly more adult (>2 years of age) males, and reported that their yearling (1-2 years of age) and juvenile age classes showed a balanced sex ratio. They suggested that adult males were more vulnerable to harvest, especially hunting.

To allow direct comparison with our 1990s sample, we combined Nelson and Lloyd's (2005) adult and yearling age classes. The resulting male-female ratio of this combined adult (>1 year of age) age class, 1.26:1, differed significantly from 1:1 ($x^2$=5.643). Although the number of adult males was slightly higher in our late-1990s sample (more of these coyotes were likely harvested via hunting), in neither of our samples — late-1970s nor late-1990s — did adult males predominate (Table 1). This probably reflects the less intense harvest rates in southwestern Illinois compared to elsewhere in the state during either time period.

Juveniles made up 69% of our late-1970s sample. Subsequent age analysis of 99 of the specimens collected by Hubert (1978, 1979) from the same time period revealed that 75% were juveniles (G. Hubert, unpublished data). Other researchers have recorded more juveniles in samples of coyotes from areas of high harvest rates (Mathwig 1973, Jean and Bergeron 1984, and Anderson, Stoneberg, Newell, and Schladweiler 2001). The high percentages of juveniles in Hubert's studies of the late-1970s probably resulted in part from increasing harvest rates and an expanding population — high recruitment of young coyotes and/or immigration of young individuals. Harvests of juveniles were high due to their lack of experience with human-caused threats, lack of familiarity of the local habitat, and possibly, exclusion from choice cover by territorial and socially dominant adults (Van Deelen and Gosselink 2006).

In southwestern Illinois, where coyote harvests appear to not have been as intense at the time and slow to increase, the large numbers of juveniles in the sample reflects an expanding population due to high recruitment of young coyotes and/or immigration of young individuals into the area.

By contrast, 20 years later, our collection of 200 coyotes from southwestern Illinois consisted of only 46% juveniles. And, while Nelson and Lloyd (2005) noted 55% juveniles in their mid-1990s statewide study, only 46% of the coyotes they collected from southern Illinois were juveniles, identical to what we found. Windberg (1995) reported that coyote populations near carrying capacity have a lower percentage of juveniles. The results from both Nelson and Lloyd's (2005) study and our late-1990s sample suggest that the Illinois coyote population was stabilizing at that time. This is supported by the nearly level coyote sighting indices from the Illinois Department of Natural Resources' annual Archery Deer Hunter Survey during the same time period (Bluett 2005).

High pregnancy rates among female coyotes in areas with high harvest rates have been reported (Dumond and Villard 2000, Anderson et al. 2001). In our late-1970s sample, a total of 53% of the adult females had PS. This somewhat low pregnancy rate suggests that at the time, coyote harvests in southwestern Illinois were not particularly high.

While Hubert (1978, 1979) reported breeding rates of 10% and 31%, extrapolating from the age data of 99 of his specimens (see above), only 33 of the 132 female coyotes examined by him were adults, and of these, 14 had PS giving a breeding rate of over 42%. Hubert's and our studies' pregnancy rates are still not particularly high when compared to those of other coyote studies (Gier 1968, Knowlton 1972, Jean and Bergeron 1984, Windberg 1995), and are lower than expected given the increasing coyote population during the 1970s.

Younger age classes of coyotes typically have lower ovulation and pregnancy rates (Clark 1972, Kennelly 1978, Todd and Keith 1983, Windberg 1995). The aforementioned high percentages of younger coyotes found in the statewide population, and in southwestern Illinois in particular, during the late-1970s explain the lower pregnancy rates noted by both Hubert (1978, 1979) and us. High recruitment of juveniles and immigration of young coyotes into the state from areas of higher coyote concentrations at that time is likely a major factor for such an increase in the population which occurred in the 1970s. The higher numbers of young coyotes depressed the population's reproductive rates.

Knowlton (1972) and Windberg (1995) stated that coyote populations at or near carrying capacity have low breeding rates. While the juvenile-adult percentages of our late-1990s sample suggested that the coyote population in southwestern Illinois was at or near carrying capacity, we noted a pregnancy rate of over 70%. Nelson and Lloyd (2005) found a breeding rate of 57% among the females in their statewide study involving a much larger sample. The relationship between the abundance of food to greater coyote pregnancy rates has been well documented (Gier 1968, Clark 1972, Todd and Keith 1983, and others). The high breeding rate noted in our late-1990s sample from southwestern Illinois suggests that food availability, related to the increasingly mild winters at the time (unpublished data), was not a problem for female coyotes during the reproductive seasons sampled.

Windberg (1995) felt that reduction of coyote populations via harvesting releases internal social constraints that stimulate compensatory population growth. During their mid-1990s statewide study, Nelson and Lloyd (2005) attributed the high breeding rate they found to food availability and high levels of exploitation. In southwestern Illinois during the 1990s, it appears that food availability, somewhat higher harvest rates, and possibly coyote social factors resulted in high pregnancy rates.

Larger litter sizes among female coyotes in areas of high harvest rates have been reported (Knowlton 1972, Anderson et al. 2001). While Hubert (1978, 1979) recorded mean PS counts of 6.8 and 6.9 per breeding female during the late-1970s, we noted a mean PS count of only 4.0 in our 1970s sample. Again, this suggests that relatively lower harvest rates occurred in southwestern Illinois at the time as compared to elsewhere in the state. Areas of lower coyote harvest rates often have lower litter sizes (Windberg 1995).

The mean PS count of our late-1990s sample (4.9 PS per breeding female) was slightly higher, possibly as a result of a greater percentage of adult females, but was not significantly different from that of our late-1970s sample. The figure is identical to that found by Nelson and Lloyd (2005) in their mid-1990s statewide study.

In his original study, Lloyd (1998) found no significant difference among the mean PS counts for female coyotes from northern, central, and southern Illinois. He felt, however, that the results suggested a positive latitudinal trend — greater mean PS counts in the north, lesser in the south. The mean PS counts from both of our southwestern Illinois samples were lower than that reported by Hubert (1978, 1979) and by Lloyd (1998), respectively, for coyotes collected from more northern Illinois latitudes, lending support for his theory.

## SUMMARY

Based on our results, coyote harvests in southwestern Illinois during the late-1970s, appear to have been lower than expected given the increasing statewide harvest rates at the time. The increasing coyote numbers statewide during that time increased the percentage of juveniles within the population. This, in turn, resulted in somewhat lower female coyote reproductive measures. In the late-1990s, coyote harvests in southwestern Illinois, while lower than other parts of the state, were great enough to affect the population's reproductive rates. At this time, the coyote population in southwestern Illinois had apparently stabilized.

## ACKNOWLEDGMENTS

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Table 1. Sex ratios of Illinois coyotes.

| Study | Males | Females | Sex Ratio (M:F) |
|---|---|---|---|
| **Late-1970s sample[a]** | **47** | **53** | **0.89:1** |
| Adults | 14 | 17 | 0.82:1 |
| Juveniles | 33 | 36 | 0.92:1 |
| **Late-1990s sample[a]** | **93** | **107** | **0.87:1** |
| Adults | 54 | 55 | 0.98:1 |
| Juveniles | 39 | 52 | 0.75:1 |
| **Hubert (1978, 1979)** | **231** | **186** | **1.25:1[c]** |
| **Nelson and Lloyd (2005)** | **520** | **457** | **1.13:1[c]** |
| Adults[b] | 247 | 196 | 1.27:1[c] |
| Juveniles | 273 | 261 | 1.04:1 |

[a] present study

[b] >1 year of age; see text for explanation

[c] $x^2$ test, significantly different from 1:1, $P \leq 0.05$

## BOOK REVIEW 2007 - #4

Kennett, Douglas J. and Bruce Winterhalder (Editors). Behavioral Ecology and the Transition to Agriculture. 2006. xiv + 394 pages; figures; tables; black and white photographs; references; index. University of California Press, Berkeley, California. ISBN 0-520-24647-0. Hard Cover. Price: $60.00. Available from: University of California Press, 2120 Berkeley Way, Berkeley, CA 94704

Human behavioral ecology (HBE) is comprised of a set of inter-related models that aim at fine-grain analyses of human economic decision-making. In Behavioral Ecology and the Transition to Agriculture, the contributing authors set forth the basic premises of HBE, describe the principal models and illustrate their applications with case studies drawn from ethnographic and archaeological investigations. The volume begins and ends with theoretical discussions that position HBE in evolutionary theory. In addition, the authors address the data requirements and the appropriate scales of analyses for the successful applications of HBE models.

Behavioral ecology developed out of studies of animal population dynamics, habitat selection, and niche construction. In anthropology and archaeology, HBE has touchstones in the energy-capture models of Leslie White (White, 1949) and the cultural ecology of Julian Steward (Steward, 1955). In contrast to generalizing broad scale theories like those of White and Steward, HBE aims at elucidating subsistence options and choices at the levels of individuals and small groups over intra-generational time-scales. A central tenet is that subsistence choices have implications for the evolutionary fitness of individuals and their close kin. This application of evolutionary theory gives HBE models a robustness that more generalizing models often lack.

The editors of this volume, Douglas Kennett and Bruce Winterhalder, are among the pioneer scholars who have defined and refined HBE over the past three decades. Their introductory chapter sets out the overall aims and methods of HBE and directs the reader's attention to issues surrounding the origins of agriculture, the focal interest of the volume. As noted above, HBE encompasses a suite of models that can be applied to questions of human subsistence and behavior. The choice among them depends on the quality of the available data (especially in archaeological cases) and the nature of the research question at hand. The different models comprising HBE are in no way mutually exclusive, and they can be applied independently to the same data set as a way to check for consistency of results or to illuminate apparent departures from expectations. To reiterate, HBE and its constituent models make no claim to the status of generalizing (nomothetic; hypothetico-deductive) theory. Their utility is rather in generating hypotheses that can be tested using ethno-historical and archaeological data.

Foraging theory and its variants (e.g., optimal foraging and central place foraging) make optimizing assumptions about subsistence behavior. That is, they assume that people seek to maximize the net energy return from their subsistence labors, preferentially harvesting high-ranking foods (with respect to energy return) when they are available and closely monitoring search and processing time. However, the Mikea of southwestern Madagascar, as discussed ethnographically in the chapter by Bram Tucker, seem at first blush to violate the maximizing assumption. The Mikea are forest-dwelling foragers who also casually (i.e., without systematic weeding or other care) cultivate maize (*Zea mays*) and manioc (*Manihot esculenta*). They are kin to the Masikoro, who live in close proximity but are intensive farmers. There is evidence that the Mikea once farmed more intensively than they do now. Conventional models that view simple horticulture as a stepping stone between foraging and more intensive farming can offer nothing to explain this apparent retrogression. Tucker combines foraging theory with future discounting models drawn from economics. In essence, future discounting describes how people calculate the value of delayed rewards, such as crops that provide no energy return until they ripen and are harvested. Thus, the Mikea have a choice between the immediate rewards of foraging and the delayed rewards of farming, or any combination of the two.

In Tucker's analysis, the Mikea plant maize and manioc because of the potential energy return at harvest time. However, particularly in the case of maize, there are constant risks—too little rain, too much rain, garden pests, livestock, etc.—and these risks tend to increase as the crop matures. More or less constant labor input in the form of weeding, guarding the fields and so forth can to some extent mitigate the risks, but that takes labor away from the foraging that provides the bulk of food energy on a day-to-day basis. Thus, the Mikea are willing to invest labor in their crops until immediate concerns (hunger) lead them to resume foraging. But active foraging means less labor invested in crop care, with the result that the anticipated return at harvest is discounted even more heavily. Therefore, while the Mikea are aware that they could intensify their farming, the imperative to meet immediate needs results in a cycling back and forth between foraging and horticulture. This insight sheds important light on the question of agricultural origins, since it provides an explanation for why the arrival of cultigens (i.e., domesticated plants) in many parts of the world did not immediately give rise to farming.

The next ten chapters illustrate the applications of HBE to archaeology, with case studies ranging from the origins of farming in the neotropics to the spread of cultigens in Oceania (the islands of the central and south Pacific). Two selected examples will serve to convey the rich variety of approaches subsumed under HBE.

As several authors point out, the origins of farming no longer appear to be 'revolutionary' either in timing or in social impact. Rather, cultigens seem to have played marginal roles in subsistence for hundreds or thousands of years before they became the mainstays of human economies. Such a lag time is evident on the Cumberland Plateau in eastern Kentucky, where foragers began exploiting seed crops between 4000 and 3000 radiocarbon years ago. By at least 1200 BC, seeds of chenopod (*Chenopodium berlandieri*), sumpweed (*Iva annua*), gourds (*Cucurbita* spp. & *Lagenaria* spp.), maygrass (*Phalaris caroliniana*), and knotweeds (*Polygonum* spp.) were being stored in dry rock shelters in the slopes above the floodplain of the Red River. Contributor Kristen Gremillion construes these storage sites as central places to investigate possible garden locations. Central place foraging theory recognizes several key variables as conditioning human decision-making. Four among them are: the distance of 'patches' of resources from the central place; the density of resources within such 'patches'; harvesting and in-field processing time; and the maximum loads that people can transport on a regular basis. Gremillion observes that while foraging theory would predict that gardens be located close to the central place (in this case, storage facilities), other considerations, such as the density and dependability of wild resources in potential garden sites, might shift the calculation in favor of gardens some distance away. Gremillion concludes that people on the Cumberland Plateau probably employed a flexible land-use strategy. That is, they based their decisions about how to use floodplain and hillside gardens—whether to plant cultigens or leave them to wild foods—on the plants' relative productivity at specific moments in time, as well as on the total energy costs of travel, harvesting, and transport. Hence, the choice to abandon a mixed foraging-cultivating strategy in favor of farming may have been spurred by increasing population or by changing environmental conditions that reduced the natural productivity of wild plants compared to domesticated crops. It is just this sort of hypothesis-generating utility that distinguishes HBE and its methods and models from generalizing theories that are insensitive to specific places and times.

Human behavioral ecology is robust in part because it explicitly links subsistence behavior to Darwinian evolutionary fitness. In most cases, the net rate of energy return from food serves as a proxy for fitness on the thesis that those who maximize their net energy gain relative to their neighbors are likely to have a greater range of mating choices. Energy capture, however, is only one way among many of enhancing reproductive success, hence fitness. Contributor Mark Aldenderfer invokes costly signaling theory and the sexual division of labor in combination with diet breadth models to investigate the domestication of guanaco (*Lama guanicoe*) at the sites of Asana and El Panteon in the Andean highlands. 'Costly signaling' refers to displays or behaviors that communicate trustworthy information about the qualities—health, competitiveness, intelligence, etc.—of the signaler. One way that the trustworthiness of such signals is evaluated by signal recipients is that the signals are costly to the signaler in terms of energy expended or opportunities deferred. Noteworthy recipients of costly signals are potential mates, competitors, and allies. Put simply, whereas the payoff for foraging optimally is energy, the payoff for costly signaling is status.

Importantly, Aldenderfer notes that men and women "have different subsistence strategies that may or may not converge." Women's fitness increases with increased parental investment, notably including provisioning their offspring. Men's fitness is increased by expanding opportunities for mating, as well as by cowing competitors and enlisting allies. Aldenderfer weaves together a diet breadth model (when high energy-ranked food resources are abundant, people will forego collecting low-ranked ones; when highly ranked resources are scarce, people will add a broader spectrum of low-ranked foods to their diets) with costly signaling and the sexual division of labor to construct a model of guanaco domestication that considers changing social factors (residential site choice; the sexual division of labor) as well as ecological factors (the locations of water, forage, crops, etc.).

In Aldenderfer's view, herding may have begun in the Andean highlands under conditions of growing human population and declining game populations. As some people moved elsewhere in search of more abundant resources, the remaining hunters would have had to decide whether to take game upon encounter or to conserve it by lowering the rate at which future gains were discounted. However, decisions to begin herding animals (i.e., conserve resources) would have been based not only on the discounted rate of energy return, but also on the increased status that accrued to men who were able successfully to begin controlling groups of animals.

This new form of costly signaling had significant consequences for the subsistence strategies and status of women. Archaeological and paleobotanical data suggest that women traditionally collected wild chenopods (*Chenopodium* spp.) as they foraged in a radius around their home sites. This continued even as the men began to move their herds to locations where water was available during the dry season. Eventually, a confluence of factors including lower yields from wild stands of chenopods and dense stands growing up where guanaco were pastured led women to shift their own foraging strategy to one that drew them closer to the herded animals, where they also contributed labor to the maintenance of the herd. This shift was accompanied by a change in women's status, since women were no longer the primary sources of household food. (While hunted game animals are generally considered a public resource, domesticated animals tend to become private goods.) Thus, Aldenderfer provides a fascinating example of the ways in which HBE can illuminate changing social relationships in the context of changing subsistence strategies.

The final two chapters of the book consider the epistemological status of HBE, broadly construed, and the cases in which its application is or is not warranted. The authors, Bruce Smith and Robert Bettinger, respectively, remind their readers that HBE comprises a set of hypothesis-generating models and is not an overarching or generalizing theory. This is an important caution because of the temptation to over-generalize or to interpret a successful test of an HBE-generated hypothesis as confirming some underlying theory. A second reason to be cautious when applying HBE, especially in archaeological cases, is the requirement for appropriate data. As the case studies in this volume illustrate, the best results are obtained when archaeological data (faunal and plant remains and artifacts related to the food quest, etc.) are combined with contemporary ecological and ethnobotanical data. Since HBE models focus on individual decision-making at intra-generational time scales, the data should provide resolution at that level, a condition that is seldom met in practice. Still, when researchers exercise due caution and choose models suitable for the available data, HBE has the potential to reveal much more about the processes underlying domestication than any other approach currently in use.

Behavioral Ecology and the Transition to Agriculture is sure to be of interest to anthropologists, archaeologists, human ecologists, and all those with an interest in the origins of agriculture. The volume is an appropriate text for upper division undergraduate and graduate courses in those and related disciplines. Furthermore, this book is an essential reference for college and university libraries.

Reviewer: Richard G. Milo, Professor and Dean, Honors College, Chicago State University, Chicago IL 60628

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# Announcements

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APRIL 4 & 5, 2008

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