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Impact of Selected Cultural Practices on Seedling Growth of Osage Orange (*Maclura pomifera*)

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ABSTRACT

Osage orange (*Maclura pomifera* [Raf.] C.K. Schneid.) is a perennial tree species whose fruit shows potential as a biofuel energy source. However, limited data exists describing the best management practices for seedling production. Research objectives included determining the effects of varying shade percentages on Osage orange seedling growth in a controlled greenhouse environment and the effect from being intercropped with soybean (*Glycine max* L. Merr.) in a field situation. In two separate greenhouse trials, Osage orange seedlings were subjected to a no shade control treatment and shading cloth treatments of 30%, 50%, and 70%. In a field experiment, Osage orange seedlings were intercropped and surrounded by two, one, or no rows of soybeans. In both greenhouse trials, height, fresh and dry leaf weight, dry shoot weight, fresh and dry root weight, and leaf area were significant ($P<0.05$). Fresh shoot weight was also significant in the 120 day greenhouse trial. Generally, height, leaf and shoot weights, and leaf area increased under increasing shade treatments. Contrarily, fresh and dry root weights decreased significantly under increasing shade treatments. In the field trial, Osage orange grown independently or surrounded by one soybean row had significantly ($P<0.05$) higher biomass compared to seedlings intercropped with soybean rows on each side. Although contrary to greenhouse trial results, competition effects such as nutrient and water availability from intercropping in the field, not shading, were likely greater factors in Osage orange seedling biomass. Results show Osage orange can tolerate increased shade without detriment to overall biomass, therefore showing promise for intercropping systems. However, water and nutrient competition should be considered.

Key words: biofuel, *Glycine max*, intercropping, shading, soybean

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INTRODUCTION

The need for alternative energy sources has never been more pressing. According to the 2007 Annual Energy Review, energy consumption in the U.S. was 29.9 quadrillion Btu

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greater than domestic energy production that year. Additionally, the consumption and production of fossil fuels has long outweighed the consumption and production of renewable energy sources. In 2007, fossil fuel usage totaled 86.3 quadrillion Btu while renewable energy accounted for only 6.8 quadrillion Btu of total usage. Similarly, the U.S. produced 49.7 quadrillion Btu more fossil fuel energy than renewable energy (EIA, 2007).

Biofuels show potential to help increase our national energy production from renewable sources. Many biofuel crops, including herbaceous and woody plants, have the potential for production on marginal land not suitable for traditional agricultural crops (Lemus and Lal, 2005), possess the ability to reduce atmospheric carbon through carbon sequestration (Powlson et al., 2005), and can improve soil quality through reduction of erosion and the increase of soil organic carbon (Ma et al., 2000).

Woody tree crops possess all of the aforementioned advantages and preliminary studies show potential from a variety of species including mesquite (*Prosopis* spp. L.), honeylocust (*Gleditsia triacanthos* L.), and persimmon (*Diospyros* spp. L). Another tree not previously studied for biofuel usage is Osage orange (*Maclura pomifera* [Raf.] C.K. Schneid.). Osage orange is a deciduous, hardwood tree, cold hardy to USDA hardiness zones four through nine. Osage orange is a fast growing tree and on average it can grow 2.7 to 3.6 m every three to five years reaching 6 to 12 m in height, with a similar spread (Dirr, 1998). Specifically, the fruit of Osage orange is being investigated for biofuel production due to its high percentage of oil, fermentable sugars, and other carbohydrates (Siebert et al., 1986). Osage orange can begin fruiting at four to six years of age, although fruiting at ten years of age is more common (Dirr, 1998). Siebert et al. (1986) reported preliminary studies that the fruit produced from planting densities of 100 trees per ha could produce 1,073 liters of ethanol per ha. Osage orange is also a long-lived species and it is not uncommon for trees to live to 150 years of age (Smith and Perino, 1981). The fruit can also be harvested without damage to the tree itself. This provides long-term productivity and high fruit yields up to 450 kilograms per tree (Clopton and Roberts, 1949). Osage orange warrants further investigation as a biofuel feedstock due to its extensive distribution, adaptability to a variety of site conditions, disease resistance, high yield potential and numerous by-products (Dirr, 1998; Siebert et al., 1986; Smith and Perino, 1981; Clopton and Roberts, 1949).

Historically used in unmanaged conditions, limited knowledge exists regarding best management practices for Osage orange production in an intercropping system with a cash crop. Since Osage orange does not begin bearing fruit until four to six years of age (Dirr, 1998), there is a need to evaluate the seedling stage of development to determine intercropping suitability. Therefore, the effects of varying shade amounts in a controlled environment and intercropping with soybean in a field situation on Osage orange seedling growth were investigated.

MATERIALS AND METHODS

Experimental Design

The following study consists of two separate investigations. The first was conducted under greenhouse conditions at Illinois State University, Normal, IL (lat. 40° 30’ N). The second was conducted in a field situation at the Illinois State University Horticulture

Center, Normal, IL. Potting mix and soil samples used were tested for physical and chemical properties (Table 1).

Controlled Environment: Shading Trials

The first investigation was conducted using two separate greenhouse trials, beginning in January and July 2008, respectively. For each trial Osage orange seeds (Sheffield's Seed Co., Inc., Locke, NY) were stratified for 30 days at approximately 4°C. Following stratification, seeds were hand sown into four 72-cell plug trays and placed under a mist chamber. The media in which they were grown was BACCTO® Professional Planting Mix (Michigan Peat Co., Houston, TX). After emergence and once seedlings obtained at least two true leaves, they were transplanted into Deepots™ (Hummert Intl., Earth City, MO) tree growing containers. The Deepots™ were suspended in accompanying support trays, placed on greenhouse benches, and covered with shade cloth treatments including a no shade control (0%) and 30%, 50% and 70% shading. Seedlings were hand watered daily or more frequently if required. Daytime temperature was set at 24°C (± 2°C) and nighttime temperature was set at 18°C (± 2°C). Throughout each trial temperature (°C) and light (PAR light; $\mu mol \cdot m^{-2} \cdot s^{-1}$) were monitored. Sensors located next to each group of seedlings recorded temperature and light readings every 10 minutes for the duration of each trial.

Shading Trial 1

For the first trial, 40 Osage orange seedlings were used in each of the four shade treatments. Seedlings were placed in 0.26 liter Deepots™ containers in a completely randomized design with four replications on the greenhouse bench. The trial began in January 2008 and was conducted for 90 days with data collection occurring at 0, 30, 60 and 90 days after transplanting.

Shading Trial 2

For the second trial, 35 Osage orange seedlings were used in each treatment. Seedlings were placed in 0.66 liter Deepots™ containers in a completely randomized design with four replications on the greenhouse bench. The trial began in July 2008 and was conducted for 120 days with data collection occurring at 0, 30, 60, 90 and 120 days after transplanting.

Controlled Environment Data Collection

During each trial, five plants were randomly sampled from each shade treatment at each collection date and destructively harvested. Growth parameters measured included height, number of leaves, fresh and dry weights of the leaves, shoots and roots, and leaf area. Height from the soil level to the terminal stem apex was measured with a ruler, the number of leaves per shoot was counted, and the leaf area was measured using a laser leaf area meter (model CI-203) with conveyor attachment (model CI-203CA; CID, Inc., Camas, WA). Fresh weights were then measured, recorded, and each sample was placed in a drying oven at approximately 75°C for approximately 72 hours to achieve a constant weight. Dry weights of the leaves, shoots and roots were measured and recorded. In shading Trial 2, height of stems and number of leaves were observed and recorded on a weekly basis in addition to previously described data collection.

Field Environment: Intercropping Experiment

An investigation was conducted in the field at the Illinois State University Horticulture Center on a Saybrook silt loam soil (Table 1). A block design with six replications was utilized. The field plot measured approximately 17.5 m by 16.8 m, containing six 3.8 m by 6.1 m blocks, each surrounded by a 1.5 m perimeter (Figure 1). Each block consisted of three rows of ten Osage orange seedlings and three rows of soybean (*Glycine max* L. Merr.) spaced approximately 0.7 m apart (Figure 1). Within row spacing for Osage orange was 61 cm and within row spacing of soybean was 5 cm. This arrangement allowed for each row of Osage orange to be surrounded by two, one or no rows of soybean, respectively. Osage orange seeds were stratified and then hand sown into 128-cell plug trays. After emergence and once seedlings obtained at least two true leaves or reached approximately 6 cm in height, they were directly transplanted into the field plot on June 12, 2008. Soybean seed was also hand sown at this time. Seedlings received supplemental water at transplanting, and then received only natural rainfall throughout the experiment.

Field Environment Data Collection

Data on height and number of leaves were recorded every four weeks for four months. Five Osage orange seedlings were sampled from each row in each of the six blocks and destructively harvested. At experiment completion fresh leaf and shoot weight were recorded. Leaves and shoots were then placed in a drying oven at 75°C for 72 hours. Dry weights of the leaves and shoots were measured and recorded.

Data Analysis

Data were analyzed statistically using the PROC GLM procedure of SAS (Ver. 9.1; Cary, NC). Least squared means for height, number of leaves, fresh and dry leaf, shoot, and root weights, and leaf area were separated statistically. Means values were considered statistically different between treatments at $P \leq 0.05$.

RESULTS AND DISCUSSION

Controlled Environment: Shading Trials

Mean values of Osage orange seedling growth parameters from the greenhouse controlled environment Trials 1 and 2 are listed in Table 2 and Table 3, respectively.

Height was shown to be a significant factor ($P \leq 0.05$) between shading treatments in both shading trials. At completion of 90 days in Trial 1, all shaded Osage orange seedlings were significantly taller than seedlings exposed to less or no shade. For example, mean height for seedlings shaded at 70% was 239.8 mm per plant, compared to 144.5 mm per plant for seedlings exposed to no shade. Results were similar in shading Trial 2, as unshaded control seedlings were significantly shorter ($P \leq 0.05$) at 230.8 mm per plant compared to 281.8 mm, 348.0 mm, and 343.6 mm per plant for seedlings exposed to 30%, 50%, and 70% shade, respectively. Groninger et al. (1996) reported stem height for both Red maple (*Acer rubrum* L.) and Yellow poplar (*Liriodendron tulipifera* L.) increased when exposed to an 89% shade treatment compared to 79% shade or full sunlight. Similarly, when grown under 79% or 89% shade, Sessile oak (*Quercus petraea* (Mattuschka) Liebl.), English oak (*Quercus robur* L.), and Overcup oak (*Quercus lyrat*a Walter) seedlings showed greater total height (Cardillo and Bernal, 2006).

While mean number of leaves was a significant factor over time as seedlings grew in both trials, it was not shown to be significantly different among treatments. Results are supported by Cardillo and Bernal (2006), who found no significant difference in number of leaves between diminishing light treatments at 90 days, and only small increases between 90 and 120 days. This finding suggests that number of leaves per plant is not a growth parameter that is significantly affected by changes in light environment.

Both fresh leaf weight (FLW) and dry leaf weight (DLW) were shown to be significantly greater ($P \leq 0.05$) in seedlings exposed to increased shade in both trials (Tables 2 & 3). In Trial 1, mean FLW was 2.51 grams (g) per plant and mean DLW was 0.56 g per plant under 70% shade, while unshaded control seedlings weighed 1.69 g and 0.49 g per plant for mean FLW and DLW, respectively. Results were similar in Trial 2 as mean leaf weights increased significantly in seedlings treated with heavier shade.

Fresh shoot weight (FSW) was also significant among treatments in each shading trial. Mean FSW was significantly greater ($P \leq 0.05$) among seedlings exposed to greater percentages of shade. Mean FSW were 0.96 g per plant for 70% shade and 0.67 g per plant for 0% shade, as illustrated in trial 1, and 1.35 g per plant for 70% shade compared to 1.06 g per plant for 0% shade, as illustrated in Trial 2 (Tables 2 & 3).

While mean FSW were significant between treatments in both greenhouse trials, mean dry shoot weight (DSW) was only significant ($P \leq 0.05$) in the Trial 2 (Table 3). Results for mean DSW followed those of mean FSW in that more heavily shaded seedlings possessed greater weights. For example, unshaded seedlings had mean DSW of 0.48 g per plant, which was significantly less ($P \leq 0.05$) than 0.50 g, 0.61 g, and 0.59 g per plant when exposed to 30%, 50%, and 70% shading, respectively.

At completion of each shading trail, significant differences in seedling leaf area were also shown. Leaf area in Trial 1 was significantly higher ($P \leq 0.05$) at 166.2 cm^2 per plant under 70% shade, compared to 107.7 cm^2, 146.1 cm^2, 96.3 cm^2 per plant in 50%, 30%, and 0% shade, respectively. Trial 2 demonstrated equally strong results as there was significantly higher leaf area in seedlings exposed to 70% shade with 286.6 cm^2 per plant. Comparatively, leaf area was only 275.8 cm^2, 248.7 cm^2, and 178.1 cm^2 per plant, when treated with 50%, 30%, and 0% shade, respectively (Table 3). These results are supported by studies done by Cardillo and Bernal (2006), where seedlings grown under diminished light had significantly higher leaf areas, and Groninger et al. (1996), in which leaf area in open-grown seedlings was significantly lower than those grown in shade. Loach (1970) reported that high leaf area under low irradiances may allow seedlings to harvest light more effectively and explains how seedlings adapt to low light environments.

Above ground biomass increases are supported by previous studies. For example, King (2003) reported Striped maple (*Acer pennsylvanicum* L.) and American chestnut (*Castanea dentata* (Marsh.) Borkh.) had substantial differences in the allocation of above-ground and below-ground biomass when comparing shade-grown and sun-grown saplings. Specifically, above-ground biomass increased in shaded saplings, most of which was allocated to the leaves (King, 2003). This finding corresponds to mean leaf and shoot weights recorded during both shading trials, as leaf weights were generally higher than shoot weights under similar treatments. It can be inferred from these findings that Osage orange will tolerate increasing shade without detriment to above-ground seedling biomass.

Contrary to above-ground growth parameters discussed, fresh root weight (FRW) and dry root weight (DRW) were significantly greater in unshaded control seedlings. For example, in shading Trial 1, mean FRW was 4.48 g per plant in the unshaded control, which was significantly greater ($P \leq 0.05$) than 3.97 g and 2.67 g per plant when exposed to 50% and 70% shade, respectively (Table 2). In Trial 2, mean FRW was also significantly greater ($P \leq 0.05$) when seedlings were exposed to no shade (Table 2). Unshaded seedlings had mean FRW of 5.89 g per plant, which were significantly higher than seedlings exposed to 30%, 50%, and 70% shade, weighing 4.87 g, 4.57 g, and 4.56 g per plant, respectively (Table 3). Mean DRW exhibited similar results to FRW. These results coincide with studies by Callaway (1992) who reported Valley oak (*Quercus lobata* Née) and Blue oak (*Quercus douglasii* Hook. & Arn.) exhibited large decreases in root mass when exposed to greater shade. Decreased root mass in seedlings exposed to increased shade is a result of greater energy allocation to above-ground biomass. Neufeld (1983) reported that a plants root system is more responsive to lower light levels and shade adaptation is accomplished at the expense of the root system.

Generally, treating Osage orange seedlings with increased shade resulted in increased growth and above-ground biomass, while decreasing below-ground biomass. This corresponds with work done by Retana et al. (1999) who reported Holm oak (*Quercus ilex* L.) showed better growth and increased survival in more shaded seedlings, especially in cases of reduced water availability. According to Canham et al. (1990), the morphological and physiological adaptations that allow improved growth in poor light conditions offer competitive advantage.

Field Environment: Intercropping Experiment

Overall, intercropping Osage orange with soybean tended to decrease plant growth in Osage orange (Table 4). For example, mean FLW of Osage orange grown with soybean on each side was 7.6 g per plant, which was significantly less ($P \leq 0.05$) than 10.4 g per plant when grown next to only one row of soybean. Similarly, mean FSW was significantly less ($P \leq 0.05$) when Osage orange was grown with soybean on both sides compared to only one side or when grown independently. Mean FSW was 5.72 g per plant when heavily intercropped versus 9.33 g and 9.32 g per plant, respectively, when grown both with soybean on one side and independently. Likewise, mean dry weights of Osage orange were significantly less ($P \leq 0.05$) when heavily intercropped with soybean (Table 4). These results coincide with Ssekabembe (1985) who reported higher Leucaena (*Leucaena* spp. Benth.) yields when wider alley spacings were utilized.

Mean plant heights and number of leaves were significantly different among treatments (Table 5). Mean plant height of Osage orange differed significantly ($P \leq 0.05$) among row treatments, with heavily intercropped trees being significantly shorter at 21.6 mm compared to trees intercropped on one side and grown independently at 22.2 mm and 27.1 mm, respectively. Likewise, mean number of leaves per plant was also significantly different among the three treatments. When intercropped with soybean on both sides, number of leaves per Osage orange plant decreased significantly ($P \leq 0.05$) to 43.9 leaves per plant from 65.1 and 51.9 leaves per plant, respectively, when grown with soybean on one side or independently.

It is important to note in this field experiment that replications were shown to be significantly different ($P \leq 0.05$), as indicated in Table 4 and Table 5. Significant replications were likely caused by row edge effects within the experiment plot. Generally, experimental data showed less overall plant mass and lower heights for Osage orange seedlings grown in the third row, or northern facing edge, of blocks three and six (Figure 1). Similarly, the first Osage orange seedlings grown in each row of blocks one, two, and three, or the western facing edge, tended to have less overall plant mass and lower heights than Osage orange seedlings grown further within each row of these blocks (data not shown).

Although results from the field trial are somewhat contradictory to results obtained in the greenhouse trials, decreased biomass in Osage orange seedlings which were heavily intercropped is more likely a factor of competition for nutrients and water and not directly due to shading. Ssekabembe (1985) discussed trees that have large portions of their root systems in the surface soil, especially before the tap root system can be developed, are more likely to be in competition for nutrients and water, rather than above-ground competition for light. This finding applies to the field experiment as the Osage orange seedlings were not likely to have fully developed their root systems before experiment completion.

CONCLUSION

Based upon results obtained from both the greenhouse controlled environment shading trials and the field intercropping experiment, it can be reasoned that Osage orange seedlings will tolerate increased shade amounts without detriment to overall biomass. However, when intercropped heavily, Osage orange seedling biomass will likely decrease due to nutrient and water competition because of its immature root system. From these findings, producers using Osage orange for biofuel production within an intercropping system of crops such as soybean should account for competitive crop effects with adequate row spacings, in addition to shading, in order to maximize growth and biomass amounts.

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Figure 1. Arrangement of each experimental block in the field plot (A) and arrangement of soybean (*Glycine max*) and Osage orange (*Maclura pomifera*) in each of the six blocks (B) on a Saybrook silt loam at the Illinois State University Horticulture Center, Normal, IL.

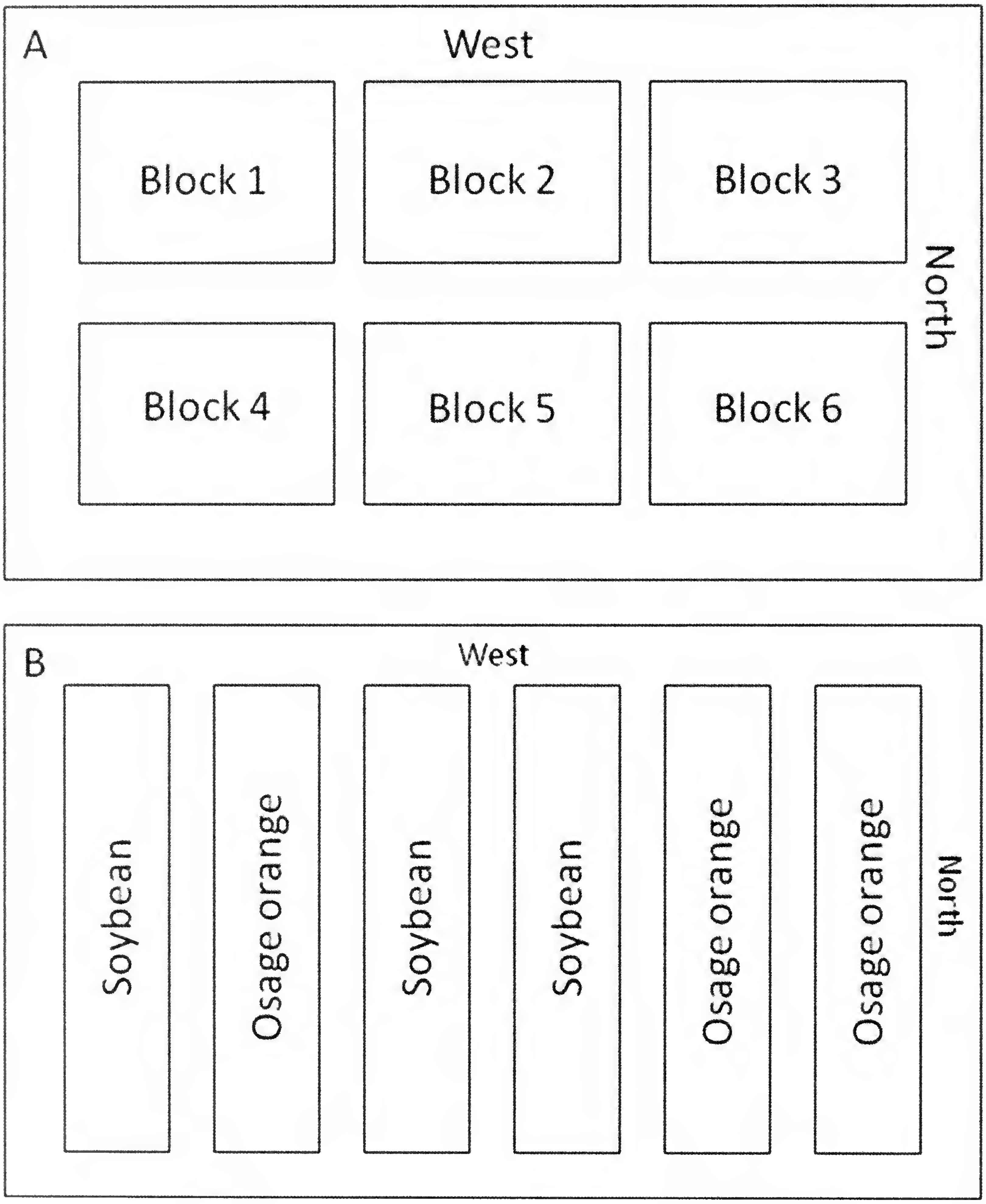

Table 1. Physical and chemical properties of potting mix and field soil used to determine the effects of shading and intercropping on Osage orange (*Maclura pomifera*) seedling development[z].

	Texture Class Percentage								Pounds per acre				Percent saturation				CEC[y]
	Sand	Silt	Clay	Peat	Perlite	Water pH	Buffer pH	OM%	P	K	Ca	Mg	Ca	Mg	K	H	meq/100g
BACCTO® potting mix	–	–	–	80-90	20-10	5.8	6.3	5	170	1238	1970	2336	22.9	46.1	7.2	23.9	21.5
Saybrook Silt Loam	17.1	52.7	30.2	–	–	6.2	6.7	4	54	394	4250	878	60.4	20.6	2.8	15.3	17.6

[z] Values are averages of three samples.

[y] CEC=Cation exchange capacity.

Table 2. Mean values[z] of Osage orange (*Maclura pomifera*) seedling growth parameters after 90 days in greenhouse Trial 1.

	0% Shade				30% Shade				50% Shade				70% Shade					P > F		
Time[y]	0	30	60	90	0	30	60	90	0	30	60	90	0	30	60	90	SEM[u]	Time	Trt	Time*Trt
Height[x]	89.8	138.2	99.8	144.5	93.4	97.5	147.3	237.3	64.6	131.0	121.4	172.5	86.0	138.0	150.0	239.8	13.325	<.0001	0.0020	0.0019
Number of Leaves	6.4	13.0	10.6	16.4	6.0	9.0	12.0	18.0	4.6	11.8	8.6	16.4	5.2	11.2	11.2	19.3	1.170	<.0001	0.3653	0.2510
FLW[w]	0.38	1.11	0.89	1.69	0.40	0.74	1.42	2.30	0.20	0.86	0.83	1.85	0.32	0.99	1.17	2.51	0.179	<.0001	0.0477	0.1441
DLW[w]	0.14	0.30	0.30	0.49	0.14	0.22	0.43	0.40	0.09	0.24	0.25	0.47	0.10	0.20	0.29	0.56	0.049	<.0001	0.0639	0.3823
FSW[w]	0.18	0.48	0.21	0.67	0.16	0.25	0.43	0.88	0.12	0.29	0.28	0.62	0.10	0.32	0.48	0.96	0.085	<.0001	0.1405	0.1168
DSW[w]	0.07	0.10	0.08	0.25	0.07	0.40	0.15	0.32	0.05	0.08	0.10	0.19	0.05	0.08	0.15	0.21	0.063	0.0009	0.0271	0.3170
FRW[w]	0.62	1.79	1.71	4.48	0.78	1.62	2.89	4.60	0.54	1.48	1.68	3.97	0.66	1.49	1.43	2.67	0.363	<.0001	0.0089	0.1358
DRW[w]	0.13	0.37	0.43	1.29	0.17	0.35	0.73	1.34	0.14	0.25	0.40	1.03	0.15	0.29	0.40	0.65	0.098	<.0001	0.0017	0.0193
CDW[w]	0.34	0.78	0.70	2.03	0.38	1.09	1.30	2.29	0.28	0.57	0.76	1.68	0.30	0.57	0.84	1.31	2.013	0.2201	0.1288	0.2394
Leaf Area[v]	24.8	66.5	50.1	96.3	28.3	46.97	70.6	146.1	18.4	58.3	48.2	107.7	17.9	66.3	67.9	166.2	9.820	<.0001	0.0084	0.0093

[z] Values are means of 5 plants.

[y] Days from transplanting.

[x] Height measured in millimeters (mm) from soil level to shoot apex.

[w] Weights measured in grams (g). Abbreviations FLW=fresh leaf weight; DLW=dry leaf weight; FSW=fresh shoot weight; DSW=dry shoot weight; FRW=fresh root weight; DRW=dry root weight; CDW=cumulative dry weight.

[v] Leaf area measured in squared centimeters (cm^2).

[u] SEM=Standard error of the mean.

Table 3. Mean values[z] of Osage orange (*Maclura pomifera*) seedling growth parameters after 120 days in greenhouse Trial 2.

	0% Shade					30% Shade					50% Shade					70% Shade						P > F		
Time[y]	0	30	60	90	120	0	30	60	90	120	0	30	60	90	120	0	30	60	90	120	SEM[u]	Time	Trt	Time*Trt
Height[x]	158.2	210.8	195.2	213.2	230.8	145.6	236.4	245.6	256.8	281.8	167.8	252.4	280.0	303.0	348.0	162.2	234.2	269.4	291.2	343.6	14.01	<.0001	<.0001	0.0132
Number of Leaves	12.0	20.0	19.2	19.6	24.4	10.0	18.4	23.0	23.8	25.6	11.4	19.0	26.8	28.8	28.0	12.4	17.4	23.6	21.2	28.0	2.479	<.0001	0.1168	0.6762
FLW[w]	0.93	2.39	1.92	2.29	3.40	0.63	2.01	2.63	2.74	4.36	1.09	2.62	3.59	3.97	4.39	1.01	1.87	2.51	3.13	4.14	0.318	<.0001	0.0003	0.2686
DLW[w]	0.24	0.66	0.56	0.65	1.06	0.17	0.56	0.72	0.75	1.26	0.27	0.62	0.85	1.03	1.26	0.26	0.44	0.75	0.78	1.14	0.086	<.0001	0.0134	0.3073
FSW[w]	0.25	0.77	0.58	0.92	1.06	0.280	0.71	0.95	1.09	1.18	0.36	0.61	0.94	1.29	1.37	0.36	0.64	0.91	1.01	1.35	0.097	<.0001	0.0173	0.1935
DSW[w]	0.09	0.27	0.22	0.36	0.48	0.07	0.25	0.36	0.42	0.50	0.11	0.26	0.38	0.48	0.61	0.11	0.20	0.31	0.39	0.59	0.035	<.0001	0.0048	0.1371
FRW[w]	1.83	2.62	3.66	5.25	5.89	1.09	2.61	3.78	4.58	4.87	2.15	2.90	3.25	4.41	4.57	1.91	2.18	3.01	3.13	4.56	0.413	<.0001	0.0119	0.1928
DRW[w]	0.30	0.71	0.93	1.28	2.04	0.18	0.69	0.97	1.36	1.49	0.33	0.69	0.97	1.26	1.50	0.26	0.46	0.67	0.80	1.40	0.118	<.0001	0.0003	0.1038
CDW[w]	0.63	1.64	1.71	2.29	3.58	0.41	1.49	2.06	2.53	3.25	0.71	1.49	2.10	2.77	3.37	0.63	1.10	1.73	1.97	3.13	0.199	<.0001	0.0274	0.5489
Leaf Area[v]	53.9	114.2	149.0	151.3	178.1	40.4	98.6	214.3	146.0	248.7	58.8	169.8	274.2	251.4	275.8	56.9	108.9	289.3	218.4	286.6	21.73	<.0001	<.0001	0.0331

[z] Values are means of 5 plants.

[y] Days from transplanting.

[x] Height measured in millimeters (mm) from soil level to shoot apex.

[w] Weights measured in grams (g). Abbreviations FLW=fresh leaf weight; DLW=dry leaf weight; FSW=fresh shoot weight; DSW=dry shoot weight; FRW=fresh root weight; DRW=dry root weight; CDW=cumulative dry weight.

[v] Leaf area measured in squared centimeters (cm^2).

[u] SEM=Standard error of the mean.

Table 4. Mean values[z] of Osage orange (*Maclura pomifera*) seedling growth parameters when intercropped with three treatments of soybean (*Glycine max*) grown on a Saybrook silt loam soil under field conditions.

	Osage Orange Row[y]				P > F	
	Row 1[x]	Row 2[w]	Row 3[v]	SEM[u]	Trt	Rep
FLW[t]	7.60	10.36	9.72	0.786	0.0386	0.0390
DLW	4.03	6.56	6.43	0.600	0.0066	0.0227
FSW	5.72	9.33	9.32	0.988	0.0147	0.0007
DSW	4.54	7.22	7.05	0.751	0.0224	0.0121

[z] Values are means of 5 plants.
[y] Weights are measured in grams (g).
[x] Osage orange seedlings surrounded by soybean on each side.
[w] Osage orange seedlings surrounded by soybean on one side.
[v] Osage orange seedlings surrounded by no soybean.
[u] SEM=Standard error of the mean.
[t] Abbreviations FLW=fresh leaf weight; DLW=dry leaf weight; FSW=fresh shoot weight; DSW=dry shoot weight.

Table 5. Mean values[z] of Osage orange (*Maclura pomifera*) seedling height and number of leaves when intercropped with three treatments of soybean (*Glycine max*) grown on a Saybrook silt loam soil under field conditions.

	Row 1[w]					Row 2[v]					Row 3[u]						P > F			
Time[y]	0	30	60	90	120	0	30	60	90	120	0	30	60	90	120	SEM[t]	Time	Trt	Rep	Time*Trt
Height[x]	2.6	8.4	14.4	19.3	21.6	2.6	8.8	15.2	19.9	22.2	2.6	10.9	18.1	23.9	27.1	0.906	< .0001	< .0001	< .0001	0.1023
Number of Leaves	3.1	15.4	26.8	36.6	43.9	3.2	18.5	32.2	43.2	51.9	3.2	25.0	41.2	54.1	65.1	2.587	< .0001	< .0001	< .0001	0.0093

[z] Values are means of 5 plants.
[y] Days from transplanting.
[x] Height measured in millimeters (mm) from soil level to shoot apex.
[w] Osage orange seedlings surrounded by soybean on each side.
[v] Osage orange seedlings surrounded by soybean on one side.
[u] Osage orange seedlings surrounded by no soybean.
[t] SEM=Standard error of the mean.

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A Two-Year Study of the Reproductive Phenology of *Baptisia alba* (Fabaceae)

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ABSTRACT

Baptisia alba L. (Vent.)(Fabaceae), is a native of tallgrass prairie that exhibits asynchronous flowering. The two-year study of *B. alba* was conducted during 2007 and 2008 in a re-created prairie in northeastern Illinois with the objective of identifying factors related to the flowering phenology of *B. alba*. Prescribed burning was conducted during early spring of both years, except a portion of the site was not burned in 2008. The flowering period of *B. alba* began and ended about 10 days later in 2008 than 2007, with the reproductive activity of the pre-dispersal seed predator *Apion rostrum* Say (Apionidae) following suit. Reproductive yield varied across years, including two years prior to the study. In 2008, *B. alba* from the burned area flowered for a longer duration, produced more racemes, flowers, and mature seeds than those in the unburned area. However, it was not known if these differences were attributed to burning. Common trends over the two-year study included the timing of first flowering being negatively related to flowering duration, flowering synchrony, raceme number/plant, and inflorescence size. Likewise, flowering duration showed positive relationships to plant size and inflorescence size. The count of seeds matured/plant was negatively correlated to flowering synchrony although the correlation was only significant in 2007. The count of seeds matured/plant was positively correlated to the count of racemes/plant in 2008, and to inflorescence size for both years. Larger plants tended to flower earlier and for a longer duration. Higher flowering synchrony among these plants suggests an advantage to this flowering phenology, although the benefit in seeds matured/plant was not clearly demonstrated in this study. A longer term study is required to test if sporadic, but ongoing reproductive successes among plants of various sizes can explain the variable flowering phenology of *B. alba*.

INTRODUCTION

The timing and duration of flowering are under multiple abiotic and biotic controls that vary within and across seasons. Patterns of precipitation and temperature provide abiotic controls (Bustamante and Burquez 2008, Evans et al. 1989), while biotic controls include the presence of pollinators and absence of seed predators and grazers (Evans et al. 1989, Mahoro 2002, Mendez and Diaz 2001, Pettersson 1994, Pilson 2000). Evolutionary theory predicts that the flowering phenology of a plant affects fitness. A perennial species may show a varied flowering pattern influenced by growth conditions, competition, and consumer pressures across seasons (Inouye et al. 2002).

Plant size is often a determining factor in the timing of flowering. Within a species, larger plant size has been associated with greater flower production, earlier flowering, and extended flowering period presumably because largeness confers a greater nutritional capacity to support reproduction (Bolmgren and Cowan 2008, Bustamante and Burquez 2008, McIntosh 2002, Pettersson 1994). However, greater seed yield of larger plants may not be assured by factors such as aberrant weather which can cause premature fruit abortion and the attraction of consumers such as seed predators (Mduma et al. 2007).

We examined flowering phenology of the legume, *Baptisia alba* (L.) Vent (=*B. leucantha* Torrey & Grey), within a re-created tallgrass prairie in northeastern Illinois. This perennial has been found to show asynchronous flowering where most flowering occurs during a two week period beginning in May and proceeding into June (Petersen et al. 2008). However, a few individuals, which tend to be smaller in size and possibly younger, bloom later for a shorter period of time.

The yearly growth cycle of *B. alba* begins with the emergence of a new shoot after the ground thaws during spring (Petersen and Sleboda 1994). By early May flowering has begun with *Bombus* species being the major pollinators. The plants produce a main stem with a racemous inflorescence, and often secondary racemes which number 2 to over 10. Plant height at the tip of the central raceme commonly exceeds one meter. Pods inflate from the pollinated flowers shortly after flowers fade. The pods, which may contain over 30 ovules, mature by August. Seeds are dispersed as pods detach or dehisce by fall. Frequently many, or all, initially inflated pods abort prior to ripening. Abortion appears selective, favoring those pods having fewer seeds (Petersen and Sleboda 1994). Factors linked to pod abortion include pre-dispersal predation by *Apion rostrum* Say (Apionidae) and weather conditions. *B. alba* dies back to the ground with the approach of winter.

This study was conducted over a two year period to investigate factors related to flowering phenology of *B. alba* within evolutionary and ecological contexts. These factors were plant size, inflorescence size, reproductive yield, pre-dispersal seed predation by *A. rostrum*, and fire. As a measure of reproductive yield, seeds matured/plant provided a means to investigate the advantages of certain parameters of flowering phenology, including the time of first flowering, flowering duration, and flowering synchrony.

METHODS

The study site was the Russell Kirt Tallgrass Prairie located on the main campus of College of DuPage, in DuPage County, Illinois. The 7.1 hectare plot encloses two marshes and a retention pond, each about a half hectare in area (Figure 1). Re-construction of the mesic prairie began in 1984. The common grasses are big bluestem (*Andropogon gerardii* Vitman), prairie dropseed (*Sporobolus heterolepis* Gray), and Indian grass (*Sorghastrum nutans* (L.) Nash). *B. alba*, one of more than a hundred species of forbs (Kirt 1996), selected for this study were located around the north marsh. Historically, the prairie has been burned annually during early spring. The entire study site was burned during 2007, but only the south side of the north marsh was burned during 2008.

Methodology was the same for both years except that the area under study was expanded in 2008 to increase the sample size of *B. alba*. Sampling began with the first individual *B. alba* that flowered. This plant, along with the succession of others that followed, was tagged for continued observation through the maturation of pods and seeds. Recorded from each plant were first and last flowering dates, and counts of racemes, flowers, inflated pods, ripened pods, seeds matured per plant, and *A. rostrum*/ripened pod. Counts of seeds matured and weevils were taken from five ripened pods sampled from each raceme of a plant. The most basal and most distal pods were sampled along with three pods located between. If a raceme had fewer than five pods, all pods were sampled. Seeds matured/plant were estimated using the product of the mean count of seeds matured/pod and the count of ripened pods. The count of racemes/plant was used as a measure of plant size, the count of seeds matured/plant was used as measure of reproductive yield, and the count of weevils/pod provided a measure of infestation.

The first appearance and final disappearance of overwintered adult *A. rostrum* was monitored on *B. alba* through visual observations. The visual observations of plants were during the morning, afternoon, or evening to take into account varied activity over the course of a day.

Flowering synchrony (X) was measured following the procedure of Augspurger (1983) using the equation:

$$X_i=(1/(n-1))(1/f_i)\sum_{j=1}^{n} ej\neq i$$

where $\sum$ $ej\neq i$ is the number of days in which individuals i and j overlap in flowering, f_i is the number of days individual i flowered, and n is the number of individual plants in the sample. A synchrony of 1 indicates a plant is fully in synchrony with flowering of all other individuals while a value of 0 indicates no synchrony in flowering.

All statistical summarization was done using Statistica (StatSoft 2001). Nonparametric tests were used due to non-normal distribution of data even with transformations. Mann-Whitney U tests were used to determine statistical differences between years, and for 2008, between areas burned and not burned. The Chi-square goodness of fitness test was used to test for differences in the number of plants with ripened pods between years in burned areas, and between the burned and unburned areas in 2008. Relationships among flowering and reproductive yield components were explored using Spearman rank correlation. Significance was determined at $P \leq 0.05$.

RESULTS

Flowering by *B. alba* began and ceased later in 2008 than in 2007 (Table 1). The reproductive activity of *A. rostrum* partly followed the development of *B. alba* with early activity of the weevil being directed to the congener, *B. bracteata* Muhl. ex. Ell. that also grows in the prairie. Table 2 provides a summary of flowering phenology and growth parameters of *B. alba* according to year, and for 2008, to burn treatment. Flowering duration was significantly longer in 2008 than 2007, and for year 2008 in the burned area than in the area not burned (Tables 3 and 4). In all comparisons, flower synchrony did not vary significantly.

Initial reproductive yield/plant in burned areas was greater in 2008 than in 2007, although this did not lead to greater numbers of pods ripened and seeds matured (Tables 2 and 3). The difference in the relative numbers of plants bearing ripened pods between years was also non-significant ($\chi^2 = 0.29$, $P = 0.593$). Median count of *A. rostrum*/pod was not high enough to be significant and explain the losses in "mature" yield. *B. alba* in the burned area for year 2008, showed a higher reproductive output than individuals in the area unburned in all categories, though counts of *A. rostrum*/pod were not higher in the unburned area (Table 4). Where the prairie was burned in 2008, plants flowered longer and produced more racemes, flowers, inflated pods, and mature seeds. In addition, the counts of pods ripened/plant and seeds matured/plant were significantly higher, and proportionately more plants were able to produce ripened pods ($\chi^2 = 15.76$, $P < 0.001$).

The timing of first flowering was negatively correlated to flowering duration, flowering synchrony, count of racemes/plant, and count of flowers/plant, although not significantly in the burned area during 2008 (Table 5). Correlations to *A. rostrum*/pod were conflicting between years, with a negative correlation to first flowering in 2007, and a positive correlation in 2008. Flowering duration showed positive relationships to counts of racemes/plant and flowers/plant during 2008 with significance achieved except in the burned area. Negative correlations were found between seeds matured/plant and flowering synchrony, although the correlation was significant only during 2007. Across the study area, the count of seeds matured/plant was positively correlated to the count of racemes/plant in 2008 and to the count of flowers/plant in both years.

DISCUSSION

Larger *B. alba* may have the nutritional reserves to flower earlier and for a longer duration. Higher flowering synchrony may suggest an advantage to this flowering phenology. However, benefit in the form of seeds matured/plant was not clearly demonstrated in this study. The parameters of reproductive yield, particularly pods ripened/plant and seeds matured/plant, were inconsistent between years, between burn treatments in 2008, and compared to earlier years (Petersen et al. 2006, Petersen and Wang 2007). Pre-dispersal seed predation by *A. rostrum* may partially explain patterns. Counts (mean ± standard error (n)) of seeds matured/plant have ranged to a high of 386 ± 66.2 (36) in 2004 when the count of *A. rostrum*/pod was lowest at 1.47 ± 0.14 (36). However, the highest count of *A. rostrum* of 3.91 ± 0.16 (35) was recorded in 2006 when the count of seeds matured/plant was measured at 19.3 ± 4.3 (35). The variability in the timing of flowering and reproductive yield shown by *B. alba* suggests that factors including, but not limited to, pre-dispersal seed predation, are affecting the overall reproductive phenology of the plant. Weather has been linked to pod and seed loss, and to changes in the timing of flowering of legumes (Evans et al. 1989, Mduma et al. 2007, Siemens and Johnson 1995).

We have just begun to examine the effects of fire on the legume. Besides being important to the maintenance of tallgrass prairie by removing competing woody vegetation, fire affects flowering, species richness, and ecological succession (Copeland et al. 2002, Howe 1995). Burning removes over-shading senescent growth and darkens the earth, thereby increasing exposure to sunlight and warming the soil faster in spring (Hulbert 1988). These effects could promote earlier above-ground growth and the sequestering of nutrient reserves needed for *B. alba* to flower for a longer period of time, resulting in larger plants, more flowers, and higher seed yield/plant. However, the greater reproductive productivity of *B. alba* in the burned area could also be indicative of a unique genetic collection of plants, larger plants, older plants, and/or local growth conditions within the prairie. Continued study is required to scrutinize the effects of burning.

In their multi-year study, Haddock and Chaplin (1982) reported that despite *B. alba* initiating a relatively large number of seeds, nearly all were destroyed prior to dispersal except during one year when a large seed crop was observed. The authors explained this large seed crop as resulting from a lower than average population of pre-dispersal seed predators. It may be that sporadic, but ongoing reproductive successes are strong enough to select for variable flowering phenology of this perennial. A longer-term study is needed to test this hypothesis.

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Table 1. Dates of flowering initiation, flowering termination, and appearance of *Apion rostrum* on *Baptisia alba* according to year.

Event	2007	2008
Date first individual began to flower	May 20th	June 1st
Date last individual began to flower	July 2nd	July 10th
Date last individual ceased to flower	July 14th	July 26th
First appearance of *Apion rostrum*	May 2nd	May 22nd
Last appearance of *Apion rostrum*	June 26th	July 28th

Table 2. Summary (mean ± standard error) of growth parameters of *Baptisia alba* and infestation of pods by *Apion rostrum* during the years of 2007 and 2008. The entire study site was burned in 2007. Data are partitioned according to burn treatment for the year 2008. Date of flower initiation is based on days after when the first plant flowered for a particular year.

Growth Parameter	Year 2007	Year 2008		
		All plants	In burned area	In area not burned
Sample size	63	80	21	59
Number of plants with ripened pods	39 (61.9%)	23 (31.9%)	15 (71.4%)	8 (13.6%)
Flower initiation	10.3 ± 1.2	12.7 ± 1.2	7.0 ± 0.7	14.7 ± 1.5
Flowering duration/plant	17.7 ± 0.7	18.5 ± 0.8	25.1 ± 1.1	16.2 ± 0.8
Synchrony of flowering	0.544 ± 0.030	0.520 ± 0.019	0.587 ± 0.015	0.501 ± 0.025
Racemes/plant	3.85 ± 0.32	3.74 ± 0.26	5.48 ± 0.41	0.61 ± 0.32
Flowers/plant	71.2 ± 7.6	71.9 ± 6.0	116.7 ± 11.4	55.9 ± 5.9
Inflated pods/plant	44.4 ± 6.4	33.4 ± 3.3	54.4 ± 7.2	25.9 ± 3.2
Ripened pods/plant	9.30 ± 3.42	1.78 ± 0.52	5.05 ± 1.67	0.61 ± 0.32
Seeds matured/plant	30.8 ± 13.5	5.1 ± 2.0	11.9 ± 4.8	2.7 ±2.1
Apion rostrum/pod	2.87 ± 0.25[a]	3.39 ± 0.29[b]	3.43 ± 0.35[c]	3.33 ± 0.55[d]

[a] denotes n = 39, [b] denotes n = 24, [c] denotes n = 15, and [d] denotes n = 9.

Table 3. Mann-Whitney rank comparison of plant growth parameters and infestation of pods by Apion rostrum between years 2007 and 2008 in burned areas. n = 63 for 2007 and n= 21 for 2008, except for the count of Apion rostrum/pod/plant where n = 39 for 2007 and n = 15 for 2008.

Growth parameter	U	P
Flowering duration	229.3	<0.001
Synchrony of flowering	576	0.377
Count of racemes/plant	365.5	0.002
Count of flowers/plant	308	<0.001
Count of inflated pods/plant	463.5	0.041
Count of ripened pods/plant	611.5	0.606
Count of seeds matured/plant	595	0.492
Count of Apion rostrum/pod	225.5	0.196

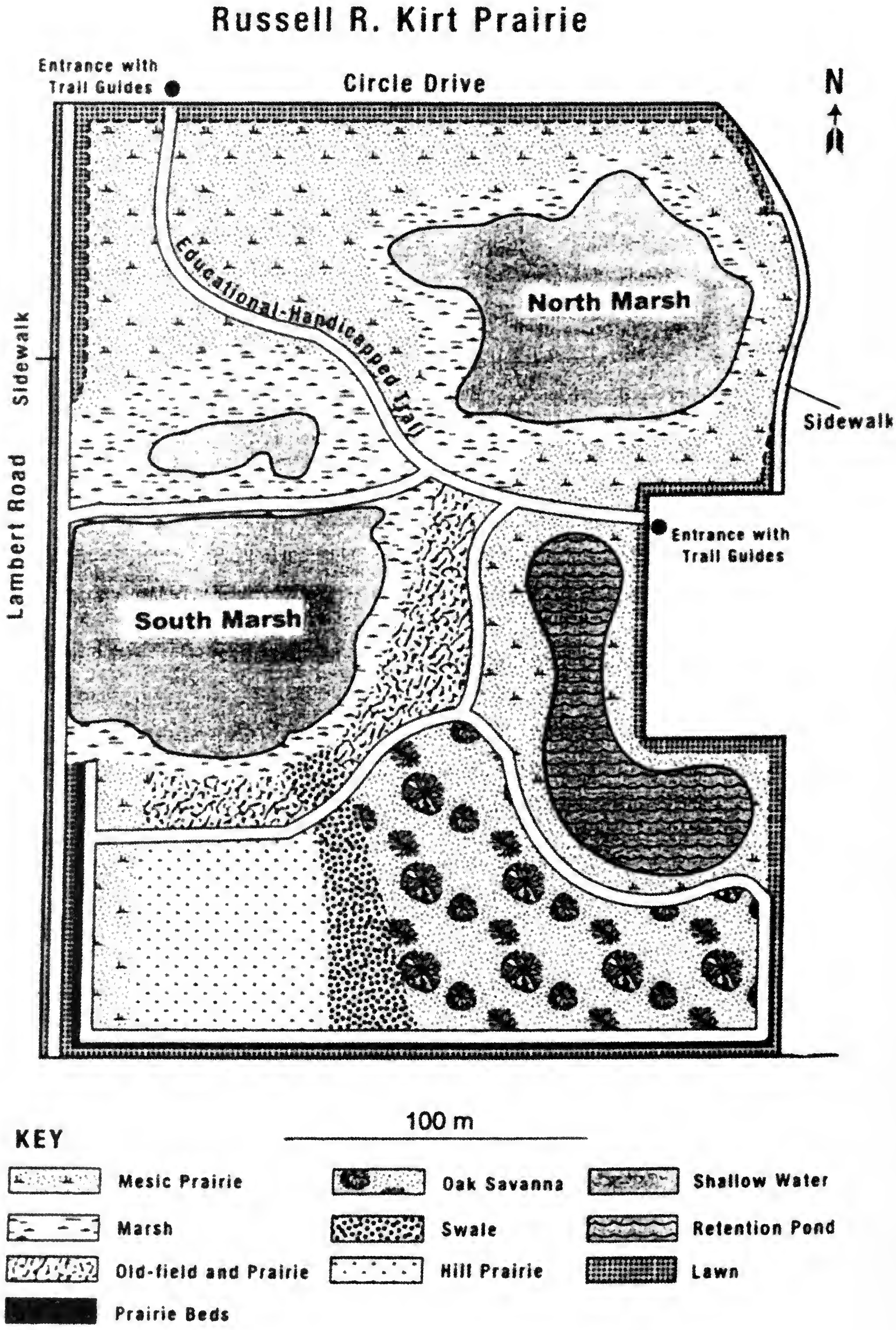
Table 4. Mann-Whitney (U) rank comparison of plant growth parameters and infestation of pods by *Apion rostrum* between burned and unburned areas during 2008. n = 21 for the burned area and n = 59 for the unburned area, except for the count of *Apion rostrum*/pod/plant where n = 15 for the burned area and n = 9 for the unburned area.

Growth parameter	U	P
Flowering duration	164.5	<0.001
Synchrony of flowering	596	0.797
Count of racemes/plant	274	<0.001
Count of flowers/plant	221	<0.001
Count of pods inflated/plant	286	<0.001
Count of pods matured/plant	246	<0.001
Count of seeds matured/plant	328	<0.002
Count of *Apion rostrum*/pod	53.5	0.400

Table 5. Spearman rank correlation showing relationships between flower phenology and growth characteristics of *Baptisia alba*. Date of flower initiation is based on days after when the first plant flowered for a particular year. *Significant (P ≤ 0.05).

Growth parameter	Timing of first flowering	Flowering duration	Flowering synchrony	Count of seeds matured/plant
2007 – [a]denotes n = 39, otherwise n = 63				
Flower duration	*-0.518			
Flowering synchrony	*-0.297	*-0.371		
Count of seeds matured/plant	0.129	0.235	*-0.289	
Count of racemes/plant	*-0.543	*0.669	-0.011	0.226
Count of flowers/plant	*-0.532	*0.756	-0.095	*0.271
Count of *Apion rostrum*/pod	*-0.319[a]	0.152[a]	0.274[a]	-0.080[a]
2008 - [a]denotes n = 24, otherwise n = 80				
Flower duration	*-0.643			
Flowering synchrony	*-0.363	-0.031		
Count of seeds matured/plant	-0.098	*0.434	-0.124	
Count of racemes/plant	*-0.520	*0.696	0.050	*0.315
Count of flowers/plant	*-0.448	*0.661	-0.020	*0.384
Count of *Apion rostrum*/pod	*0.407[a]	-0.013[a]	0.161[a]	*-0.478[a]
2008 – burned area, [a]denotes n = 15, otherwise n = 21				
Flower duration	-0.343			
Flowering synchrony	-0.344	*0.968		
Count of seeds matured/plant	-0.105	0.222	-0.311	
Count of racemes/plant	*-0.445	0.431	-0.420	0
Count of flowers/plant	-0.369	0.361	-0.351	0.070
Count of *Apion rostrum*/pod	*0.636[a]	-0.091[a]	0.128[a]	-0.364[a]
2008 – are not burned - [a]denotes n = 9, otherwise n = 59				
Flower duration	*-0.712			
Flowering synchrony	*-0.494	0.181		
Count of seeds matured/plant	0.051	0.251	-0.113	
Count of racemes/plant	*-0.479	*0.641	0.164	0.199
Count of flowers/plant	*-0.389	*0.567	0.031	0.251
Count of *Apion rostrum*/pod	0.120[a]	-0.111[a]	0.451	*-0.730

Figure 1. Map of the study site. *Baptisia alba* selected for study were located around the North Marsh, distributed in mesic prairie to the south up to the Educational-Handicapped Trail, north, and west of this marsh.



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Soil Quality, Forests, and Water Resources of Stripmines

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ABSTRACT

Surface mining for coal excavates deep pits that are refilled at the bottom with large rocks and in the root zone with a loose mixture of soil and shattered mineral-rich shales, sandstones, and/or limestones from above the coal. If not overlaid with massive fragic or claypan subsoils compacted by excessive grading the mineral fragments near the surface rapidly weather to become nuggets of nutrients and moisture for plant growth on well-aerated soils. Creatively-reclaimed soils have historically grown outstanding trees on productive forested lands. Regulations mandated by the Illinois Department of Natural Resources for unrealized agricultural land uses have resulted in extensive deforestation with other values of stripmined lands reduced especially in southeastern Illinois. The replaced fine-textured layered soil materials excessively graded and compacted at great cost limit soil water entry and penetration and have commonly been abandoned to grasses and invasives. Mineral riches above the coal are buried and wasted. A vital loss is the potential for abundant clean water that once was stored in mine pits underground and in deep lakes that are now required to be largely filled. Southeastern Illinois needs a long-term scientific reclamation agenda based on its environmental, economic, and cultural potential. Misdirected provisions of federal and state stripmine laws and counter-productive regulations urgently need to be reviewed and remedied.

Key words: environmental services, plant nutrients, Public Law 95-87, reclamation, reforestation, surface coal mining, sustainability, tree growth

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INTRODUCTION

The focus of this paper is the coal lands east of the geological Du Quoin monocline in Jackson, Saline and Williamson counties of southeastern Illinois. Pre-mining soils are largely order Alfisols and Subgroup Typic Fragiudalfs (Miles and Weiss, 1978) including infertile fragipan and claypan soils. Farmlands commonly have little remaining agricultural topsoil with some physical and chemical properties of the unmined subsoils inherently limiting when replaced for crop production. Both before mining and more so when replaced and commonly compacted the subsoils are glue-like when wet, brick-like when dry, and limit water entry, aeration, rooting, and plant growth.

During the first four decades of surface mining in Illinois most mined lands were left relatively unaltered. Tree seedlings commonly planted after mining grew well, with exceptions, and early forested lands have now been logged. With later moderate grading of mine banks pasture and livestock became important. Other land uses included crops, lakes, orchards, parks, housing, landfills, wildlife, roads, fairgrounds, airports, and shopping malls. Federal and state agencies and universities in cooperation with coal industry associations developed high-quality reclamation practices for sustainable soil, plant, and water resources. Ways were found to speed up the natural revegetation of infrequent "moonscapes" and remedy acid stream drainage that resulted from early lack of knowledge or understanding of geochemistry, and from carelessness in placing sulfide-rich minerals at or near the surface (Ashby et al., 1979). Tree species successful on initially barren stripmines are valuable for reclaiming other barren areas and may be adapted for reclaiming brownfields, parkways, or other adverse urban sites.

After earlier state laws Public Law 97-87 (U.S. Congress, 1977) with nine subdivisions or Titles placed stripmine reclamation operations under federal government control. Other agencies conducting reclamation research and demonstration were later eliminated or reclamation research reduced. States were given authority to administer P.L. 95-87, in Illinois the now Department of Natural Resources (IDNR). Both federal and state agencies published numerous detailed reclamation regulations.

PRE-REGULATION SOIL QUALITY AND WATER RESOURCES

Surface mining for coal created productive soils and abundant water resources, with exceptions discussed later. The deep plowing in stripmining broke up the pans of unproductive soils and replaced them with loose mixtures of soil particles and rock fragments called geological topsoil or spoil (Committee on Soil as a Resource in Relation to Surface Mining for Coal, 1981). The rock fragments or nuggets of sedimentary shales, sandstones, and limestones from deeper in the coal overburden when exposed at the surface to oxidation, wetting and drying, microbial and root penetration, and animal activities release nutrients. Commonly renewed are essential potassium and from shales phosphorus (Underwood and Smeck, 2002; Brantley, 2008). Vigorous alfalfa (*Medicago sativa*) growth on a nugget-enriched rooting medium versus poor growth on adjacent replaced soil was attributed by visiting Polish scientists to available boron. Rock fragments also become nuggets for soil moisture (Limstrom, 1960; Hansen and Blevins, 1979; Schafer et al., 1979) and greatly increase essential soil aeration. Black walnut (*Juglans nigra*) rooted much more deeply and widely on spoil than on replaced soils (Josiah, 1986). Soil loosening and the mineral riches of rock nuggets as slow-release fertilizer pellets could be of greater long-term value than the coal mined (Ashby et al., 1984; Ashby, 1996).

"Water is a product of the land" (Colman, 1953). Pre-regulation minelands with loose spoil had high rates of water infiltration and of percolation to deep storage. Low places in contact with stored pit water became wetlands, ponds, or streams. With little post-mining human disturbance native plants and animals moved into the forested habitats as natural areas.

Water from rainfall/snow melt impounded underground deep within mine pits had neither siltation nor evaporative losses and typically extended to a deep, long, and narrow lake at the end of the pit with no further coal overburden excavated to fill it. Aerial photos of 347 ha (858 ac) in Saline County mined and leveled by dragline pullback of spoil banks in the 1950s had 28 ha of lakes fed by much more water stored underground. A later mining permit application for the same mine proposed having at no cost to society seven lakes on 156 ha. Stripmine lakes and ponds with clear water have been used extensively by hunters, fishermen, and boaters, for recreation and education, and for consumptive domestic and agricultural needs. The original Pyramid State Park mined pre-law in Perry County is a recreational mecca with untold megaliters of clear water underground and in numerous lakes. Mined land with lakes is commonly the highest-price real estate in an area (Christy et al., 1979).

PRE-REGULATION VEGETATION RESOURCES

For decades before government control of the coal industry experienced reclamation specialists voluntarily planted numerous tree species on mine soils with some early failures and increasing later success (Limstrom, 1960; Ashby, 1996). Plantings in Saline County of 47-year-old tuliptree (*Liriodendron tulipifera*) and sweetgum (*Liquidambar styraciflua*) each averaged 28 m tall with diameters breast height (DBH) of 36 and 30 cm. Thriving white (*Quercus alba*) and red/Shumard oaks (*Q. rubra*/*Q. shumardii*) 55 years old averaged 26 and 33 m tall with 23 and 35 cm DBH. Planted forest stands on fertile, well-drained post-mining soils soon developed volunteer mesic tree and ground cover occasionally with ladies'-tresses (*Spiranthes spp.*) and other orchids related to the availability of propagules (Ashby et al., 1981; Ashby, 2009). Ants, earthworms, root nodules, and mycorrhizae are typically found on forested mined lands. Pioneer settlers valued land by kind of trees. Today forests are valued for clean water and air, flood protection, soil building, carbon sequestration, timber and other forest products, habitats for native plants and animals, recreation, and education.

POST-REGULATION SOIL, WATER, AND VEGETATION

IDNR reclamation regulations required mining permits and bonding for site preparation and revegetation to meet performance standards in 5 or more years. Formerly integrated reclamation operations were increasingly contracted out with loss of coal company/industry control and downsized numbers of reclamation specialists.

Under TITLE IV - "Abandoned Mine Reclamation" poorly-vegetated pre-law mined lands with off-site environmental damage became a management priority regardless of ownership. Reclamation with massive grading and pasture-type reclamation practices resulted in negligible survival of typically-planted tree seedlings and staggering over-all costs. Many more Abandoned Mine Land (AML) sites could be vegetated by working with nature, preserving flora already established, and supporting research for site-adapted trees, shrubs, and herbs to increase plant cover and soil organic matter that ameliorates toxic and drought conditions. The ecological amplitude and value of plants is commonly not recognized or utilized. Acid-tolerant river birch (*Betula nigra*), pin oak (*Q. palustris*), and sweetgum that establish naturally get bulldozed. Many smaller AML sites with scant off-site damage need little grading or "reclamation" and have significant long-term value for research and environmental education, historical relevance, innovative forestry, recreation, natural areas, and fossil collecting.

TITLE V - "Control of the Environmental Impacts of Surface Coal Mining" eliminated later "moonscapes" by mandating identification and deep burial or flooding of potentially harmful spoil materials during mining. Post-mining lands are intensively graded to Approximate Original Contour and commonly compacted hindering water entry, aeration, rooting, and revegetation and negating reclamation goals. IDNR rather than reclaiming typically replaces to 1.2 m depth soil types described in county soil reports and classified for engineering and biological uses by the USDA Natural Resources Conservation Service. Productivity indexes otherwise developed for pre-mining southern Illinois soils are among the lowest in the state for crop and less so for timber yield (Fehrenbacher et al., 1978). IDNR disregards biological properties of the root zone, an important federal reclamation criterion, and uniquely and perversely replaces poorly-productive soils with deleterious fragic materials that reform as pans and elsewhere are deeply buried. Federal provisions for soil quality have not prevailed. Similar adverse effects of government control of reclamation under P.L. 95-87 have been reported for Appalachia (Palmer et al., 2010).

Crop production with at least two years of acceptable corn (*Zea mays*) yields became an Illinois reclamation requirement for performance bond release. Unacceptably low yields soon made necessary further unsustainable deep soil ripping, exceptionally high levels of fertilization, and specially bred corn varieties. After a performance bond is released coal companies in southeastern Illinois commonly have left idle the replaced fragipan lands.

Water resources have been greatly limited by IDNR with minimal recharge and percolation to deep storage of the massive replaced surface soils. Water storage capacity of stripmine lakes has further greatly been reduced by faulty federal and state requirements for partial refilling, reportedly related to unique mining problems in Appalachia. Both the inner and outer highwalls at the open end of a mine pit must be graded to gentle slopes with both the mined and unmined adjacent land shoved into the future lake basin. Thousands of kiloliters of lake water storage capacity are needlessly lost (Chugh and Grandt, 1981). Such a shallow lake cannot be replenished by water stored in voids between the large rocks replaced deep in the pit. Filling-in water bodies violates the spirit if not the requirements of the National Environmental Policy Act and the Clean Water Act and denies future generations vital water resources that are increasingly needed.

TITLE VII Section 711 “Experimental Practices” authorizes, with environmental safeguards, innovative research studies. A cooperative grading study by a reclamation-conscious coal company and my research group was spurned with no reason by IDNR. A second experimental practices proposal was rejected with “You can’t grow corn on spoil” despite numerous examples of corn grown on spoil in northern and central Illinois and in other states (Grandt, 1978; Nielsen and Miller, 1980). Before IDNR banned forestry and required costly uncertain corn production for bond release there had been no reason for coal companies with forestry equipment and expertise to become farmers. We cooperated with local agronomists and for four years experimentally grew corn on graded spoil mined in 1971 formerly a 20-ha hayland in Saline County. Variability in yields was traced to soil patches with re-sprouting alfalfa, nitrogen and moisture limitations related to uneven soil compaction in grading, and especially potassium fixation by shrinking clays as the soil dried. We made mistakes, had lots of visitors and professional advice and encouragement, and no visitors came from IDNR. Letters from a local agricultural supplier and farmers gave support. Farm operations on nugget-enriched friable soils with large rocks deeply buried can readily be carried out with modern equipment. In 1980, the first and a severe drought summer with no later comparisons our corn yield exceeded that of an unmined reference field planted by a local farmer. In numerous soil pits corn rooted much less deeply than alfalfa. Unlike soil and water benefits with reclaimed forests, corn fields are relatively barren for most of the year and tend to decrease rather than build organic matter and natural soil fertility and not to conserve water or enhance ecosystem values.

DISCUSSION

Potential benefits from productive, sustainable stripmine reclamation relate directly to national and world needs. Leadership of the Soil and Water Conservation Society has emphasized the increasing importance of improving the quality of soil resources (Towery, 2009). Deforestation is widely and recently was strongly condemned at the international Copenhagen conference (Kintisch, 2009). Regulatory authorities in Appalachia encourage building soils and safeguarding water supplies under a new forestry reclamation approach (Burger et al., 2009) that could readily be fulfilled in Illinois. The USDA Forest Service (2009) considers clean water the most vital of the ecosystem services provided by our forests. Reforestation of stripmines interspersed with farming areas would allocate land uses in an efficient way (Fischer et al., 2008).

Fields of soil study are genesis, classification, and as a medium for plant growth. Important findings from numerous studies of soil genesis/development after natural disturbances (Jenny, 1980) and on stripmines (Thomas and Jansen, 1985; Sencindiver and Ammons, 2000) seem to be ignored by IDNR. USDA soil scientists found deep prime soils in 1979 under thriving forest stands planted in 1938 (Personal communication). Productive soils if needed for other purposes are available after timber harvests. “Collapse - how societies choose to succeed or fail” (Diamond, 2005) has worldwide examples from earlier centuries of use of rocks and reforestation to renew/build soils and sustain societies. Blackbourn (2006) documents pitfalls in management of natural resources from unwise government control.

Land uses with replaced fragipan and other degraded soils mandated by government in mining permits commonly are not sustained after release of performance bonds. Reclamation expenditures of eight to ten million dollars in the 1980s, now likely much higher, for a typical 120-ha mining reclamation operation have been a flush of wealth for local businesses and governments with scant long-term benefits. Soils replaced for presumed and unfulfilled crop production have failed to support adequate growth or even survival of many tree species (Ashby and Kolar, 1998). More sustainable environmental and economic reclamation practices both short- and long-term are needed for crop and pasture production, forest habitats and products, improved soil, air, and water quality, and new kinds of biomass production for energy independence instead of growing costly corn for ethanol production with no energy gain. Coal companies are willing to contribute use of land, personnel, and other resources for reclamation research while our regulatory authority has seemingly been hostile to environmental quality.

Public Law 95-87 requires restoring capability at least equivalent to pre-mining. Noncompliant Illinois regulations state that forested land is to be reclaimed as woody or herbaceous cover including weeds on replaced soils. Such changes in land use are masked as simply changes in vegetation to accommodate IDNR's failed soil reclamation practices. Southern Illinois was formerly about 40% forested and I have not found data on how many thousands of hectares have been deforested. Extensive "reclaimed" lands between Harrisburg and Marion north of Illinois route 13 previously forested now have broomsedge (*Andropogon virginicus*), other grasses, autumn olive (*Elaeagnus umbellata*), and other invasives. Near-by pre-law lands south of Illinois route 13 have forests with the best or near-best growth of white and red oak, tuliptree, and black walnut in upland areas of the region (Ashby, 1996).

Water readily available from lands suitably reclaimed after surface mining for coal is an important option overlooked for future water needs of numerous upland Illinois localities with scant natural surface or usable ground water (Hood, 1981). Community water systems built by earlier generations typically rely on "borrowed" stream water from distant areas impounded in shallow man-made lakes that fill with sediment at about 1% a year. What replacement water supplies will be politically or economically available when today's lakes become unusable is not known. Few sites for new impoundments are likely to be available. In recent years irrigation to offset declining crop yields has increased greatly in the Midwest.

A public outraged by increased costs for electricity generated using coal ignores significant coal industry costs of federal tonnage fees and of compliance with numerous cosmetic and often fruitless mandates for segregating, replacing, grading, and ripping degraded soils that are commonly later abandoned. Untold thousands of gallons of fossil fuels with consequent CO_2 emissions would not be needed with more environmentally responsible reclamation requirements. The costly soil replacement agenda of the politically-dominant central Illinois agricultural community implemented by IDNR has too often brought about the end rather than the beginning of productive sustainable post-mining land uses in southeastern Illinois. Texas implements P.L. 95-87 with diverse and effective stripmine reclamation regulations for multiple uses. Illinois should do no less. Direct and effective federal control may be the answer.

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A Survey of the Robber Flies (Diptera: Asilidae) of Ira and Reatha T. Post Wildlife Sanctuary, McDonough County, Illinois USA

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ABSTRACT

Robber flies (Diptera: Asilidae) represent a diverse family of predatory insects of potential importance to conservation biology. Diversity and vertical distribution of forest robber flies were studied at Western Illinois University's Ira and Reatha T. Post Wildlife Sanctuary from May to October 2008. Canopy traps were used to collect robber flies in the lower and upper understory. *Leptogaster flavipes* Loew was the most abundant robber fly collected, comprising 43.5% of total captures. Overall, robber flies were significantly more abundant in the lower traps, but diversity and species composition/relative abundance were similar in lower and upper traps. Robber flies were most abundant in June, due primarily to the abundance of *L. flavipes* during that month. These results indicate that *L. flavipes* is a substantial component of the robber fly fauna at Post Wildlife Sanctuary. Robber flies are present and active in the upper understory, but the upper understory does not harbor a robber fly fauna distinct from the lower understory.

INTRODUCTION

Robber flies (Diptera: Asilidae) represent a large family of predatory insects with roughly 1,000 North American species and over 7,000 species worldwide (Borror et al., 1989; Ghahari et al., 2007). They are found throughout most of the world on all continents except Antarctica (Wood, 1981). Robber flies are aerial predators that usually capture insects in flight. Strong raptorial legs are used in capturing prey, which is stabbed with a piercing proboscis. The robber fly then injects paralyzing saliva and proteolytic enzymes into its victim, and the liquefied contents of the prey are sucked out (Kahan, 1964). Some robber flies can successfully prey on well defended insects such as bees and wasps (Wood, 1981). Greatest robber fly species richness is found in dry, open environments; relatively few species inhabit forests (Ghahari et al., 2007). Forest robber flies are relatively poorly studied compared to those of more open, arid environments.

Robber flies are top insect predators, and many species have specialized habitat associations which can make them vulnerable to habitat destruction but also valuable bioindicators (van Veen and Zeegers, 1998; Barnes et al., 2007). Microclimatic conditions appear to have a strong effect on activity patterns of some robber fly species as well (O'Neill et al., 1990; O'Neill and Kemp, 1992). Their distinctive appearance and relatively large size make robber flies one of the few dipteran groups with potential for targeting by nonspecialist collectors, making it possible to obtain adequate sample sizes over large geographic areas. Robber flies thus have potential importance as subjects of conservation research (Larsen and Meier, 2004).

The Ira and Reatha T. Post Wildlife Sanctuary is a 57 ha property acquired by Western Illinois University in 2003. The Sanctuary is primarily upland oak-hickory forest that surrounds the former site of a small resort town known as Vishnu Springs that existed in the late 1800s-early 1900s (Taylor, 2008). The site has remained relatively undisturbed for several decades, and now represents a large tract of forest habitat surrounded by agricultural lands. The site represents an excellent opportunity to document the insect diversity of a relatively undisturbed west-central Illinois forest. The objectives of this study were to: 1) assess the diversity of forest robber flies at Post Wildlife Sanctuary, 2) compare abundance and diversity of robber flies between the lower and upper forest understory, and 3) examine seasonal patterns of robber fly abundance and diversity.

MATERIALS AND METHODS

This study was conducted from May to October 2008 at the Ira and Reatha T. Post Wildlife Sanctuary (N 40° 25' 59", W 90° 53' 49"), which is located ca. 6.5 km northwest of the town of Tennessee, in McDonough Co., Illinois USA. The sanctuary is primarily upland oak-hickory forest with common overstory species including shagbark hickory (*Carya ovata* (Miller) K. Koch.), black walnut (*Juglans nigra* L.), black oak (*Quercus velutina* Lam.), white oak (*Quercus alba* L.), and northern red oak (*Quercus rubra* L.). Elm (*Ulmus* sp. L.), wild black cherry (*Prunus serotina* Ehrh.), and ironwood (*Ostrya* sp. Scop.) are common understory species. Plant nomenclature follows that of Gleason and Cronquist (1991).

Canopy traps were used to collect robber flies. These are a form of malaise trap (Malaise, 1937), which is a flight interception trap with a mesh barrier that allows insects to fly into the barrier, move upward due to phototactic behavior, and become trapped in a collection container. They are effective in capturing active flying insects including Diptera (Ozanne, 2005). Each trap had an effective trapping surface on each side of 1.45 m high and 1.30 m wide, with an open bottom and a collection bottle located at the top of the trap. Six of these traps were set, with three located in the lower understory near the forest floor (lower edge of the traps 0.5 m from the ground) and three located in the upper understory (lower edge of the traps 3.5 m from the ground). Traps were arranged in pairs, with lower and upper traps within 25 m of each other. Pairs were arranged in a transect, with the midpoint of trap pairs 75 m apart. Collection bottles were filled with 75% EtOH. These bottles were collected weekly and replaced with a bottle containing fresh EtOH. Robber flies were collected from the samples, pinned, labeled, and identified. Traps were operated continuously from 26 May to 20 October 2008.

Robber fly species richness was determined for each understory level. Because species richness is associated with sample size, rarefaction was used to evaluate species richness of the two levels. Rarefaction provides an estimate of the expected number of species for a given sample size (Krebs, 1999). The University of Alberta Department of Biology online rarefaction calculator (http://www.biology.ualberta.ca/jbrzusto/rarefact.php #Calculator, last accessed 10 August 2009) was used to obtain rarefaction estimates and 95% confidence intervals. The binomial test was used to compare numbers of robber flies collected in the lower vs. upper traps. For all species combined, expected values were based on a 50/50 distribution of captures in lower vs. upper traps. Binomial tests were also used to compare numbers of the two most common species of robber flies captured in lower vs. upper traps. This was done 1) using expected values based on a 50/50 distribution of captures in lower vs. upper traps, and 2) using expected values based on the overall distribution of robber flies captured in lower vs. upper traps (70.2% vs. 29.8%). Fisher's exact test was used to examine potential associations between sex and understory level.

Simpson's diversity index (Simpson, 1949) was used to measure robber fly diversity at each understory level. Simpson's index considers the number of species (species richness) as well as the evenness in the proportion of the total that occurs for each species. It represents the probability that two randomly selected individuals will belong to different species, and can range from 0 to 1. Simpson's indices of lower and upper traps were compared using a t-test, with variances for each sample approximated based on the proportions of the total number of individuals occurring in each species. The test statistic is compared to 1.96, the critical value of Student's t, for infinity degrees of freedom at alpha = 0.05. The above method is described in Keefe and Bergersen (1977) and Brower et al. (1998).

The multi-response permutation procedure (MRPP) was used to compare robber fly species composition/relative abundance between the two understory levels and to examine heterogeneity of robber fly species composition/relative abundance within each level. MRPP is a nonparametric statistical technique for testing the hypothesis of no difference in two or more groups, such as species composition/relative abundance between two or more habitats (McCune and Grace, 2002). MRPP provides a measure of within-group homogeneity (A), which increases as the communities in different groups deviate, to a maximum of 1. An A value greater than 0.3 suggests substantial differences between groups (McCune and Grace, 2002). MRPP also provides a "distance measure" of within-group heterogeneity. This distance measure ranges from 0 to 1, with higher values reflecting greater heterogeneity of species composition/relative abundance among traps at a particular level.

RESULTS

A total of 131 robber flies, representing fourteen species and ten genera, were collected during the study (Table 1). All 14 species were collected in lower traps, whereas 10 species were collected in upper traps. Observed species richness was within 95% confidence intervals of expected richness based on rarefaction for each trap level (Table 1). Simpson's diversity index was 0.769 for the lower traps and 0.807 for the upper traps. There was no significant difference in diversity indices between lower and upper traps (t = 0.5770, df = ∞, $P > 0.5$).

Across the entire season, mean numbers of robber flies collected per trap (± SE) were 30.7 ± 10.1 for the lower traps (min = 16, max = 50) and 13.0 ± 2.5 for the upper traps (min = 8, max = 16). Overall, there was a significantly greater number of robber flies collected in the lower traps (92) than in the upper traps (39) ($P = 0.000004$, binomial test). *Leptogaster flavipes* Loew and *Ommatius gemma* Brimley were the most abundant species, representing 56.5 % of total captures. Species identifications of *Leptogaster* are generally done by examining male genitalia; females are difficult to identify to species level. Since all 28 male *Leptogaster* were identified as *L. flavipes*, we assumed that female *Leptogaster* were *L. flavipes* as well. Both *L. flavipes* and *O. gemma* were significantly more abundant in lower than upper traps ($P = 0.0013$ and $P = 0.013$, respectively, binomial test), however in neither case was the relative frequency between trap levels different from that of all robber flies ($P = 0.8851$ and $P = 0.4267$, respectively, binomial test). The proportion of males vs. females collected did not vary significantly between trap levels for all species ($P = 0.4327$, Fisher's exact test) nor for *L. flavipes* ($P = 0.3786$, Fisher's exact test). There was a small but significant difference in species composition/relative abundance between trap levels based on results of MRPP ($A = 0.0796$, $P = 0.0295$). Distance measures for lower and upper traps were 0.5739 and 0.4311, respectively.

The earliest robber flies, *Laphria index* McAtee, *Machimus* sp. Loew, and *Neoitamus flavofemoratus* (Hine), were collected on 9 June, and the latest, *Neomochtherus auricomus* (Hine) on 29 September. June was the most active month for robber fly captures with 52, and the peak collection occurred on 23 June (Fig. 1). In general, lower traps collected substantially more robber flies than upper traps throughout the season, but greater numbers were captured in upper than lower traps in mid-July collections (Fig. 1). With regard to the two most common robber fly species, captures of *L. flavipes* occurred from the 16 June to 4 August collection dates, peaking on the 23 June collection date. Captures of *O. gemma* occurred from the 21 July to 15 September collection dates (Fig. 2).

DISCUSSION

Our results revealed no significant differences in species diversity or richness (based on rarefaction) in relation to trap height, but robber fly abundance was greater in the lower understory traps, with 70.2% of captures occurring there. The more dense vegetation near ground level probably provides more perching locations for robber flies, and many robber fly species also use stones, logs, or the ground itself as perching surfaces (Wood, 1981). However, our results also show that robber flies are not uncommon in the upper understory. Little research has been done comparing insect abundance and diversity at different understory levels. Hill and Cermak (1997) found nearly 30-fold greater abundance of Diptera at ground level vs. 5 m above ground level in a northern Queensland, Australia rain forest, using flight interception traps, versus our 2.4-fold difference. Their study did not include species-level identifications, and included all dipterans (except nematoceran flies), meaning that many small, weakly flying species were included. Many of these species are probably unlikely to fly very far above ground level, unlike robber flies which are generally strong fliers. There was little difference in species composition/relative species abundance between upper and lower traps in our study, based on MRPP. This suggests that individual robber fly species have vertical distributions that encompass at least the height differential of our traps.

The two most common species of robber flies found at Post Wildlife Sanctuary were *L. flavipes* and *O. gemma* (Table 1). *Leptogaster flavipes* is a member of the subfamily Leptogastrinae, commonly known as "grass flies." Leptogastrines possess several morphological and behavioral characteristics that differ from other asilids. Leptogastrines capture primarily stationary prey, whereas other asilids generally capture moving prey (Martin, 1968). In a study using malaise traps and aerial nets, Scarbrough and Sipes (1973) found *L. flavipes* to be common in a hardwood forest in Baltimore Co., Maryland, and suggested that these flies tend to be associated with humid areas with dense undergrowth. Post Wildlife Sanctuary has received little or no management for control of understory vegetation and consequently has a relatively dense understory which appears to provide favorable habitat for *L. flavipes*. Scarbrough and Sipes (1973) observed that *L. flavipes* generally fly at "a height of 1 to 2 feet below and between branches of low plants covering the forest floor," but their study evidently did not include collection attempts higher in the understory. Our results show that *L. flavipes*, while most abundant in the lower understory, can be found higher in the understory as well.

McAtee and Banks (1920) reported *L. flavipes* to be active in the Washington, D.C. area from late May to early September, and Scarbrough and Sipes (1973) found this species to be most abundant in July in Maryland, with lower numbers in June and August. Our results agreed most closely with those of Scarbrough and Sipes (1973), although we found *L. flavipes* to be most abundant in late June (Fig. 2). Overall abundance of robber flies in June in our study was driven primarily by the abundance of *L. flavipes* (Figs. 1 and 2). Along with much of the Midwestern USA, west-central Illinois received large amounts of rainfall that resulted in substantial flooding during June 2008. In light of the apparent association of *L. flavipes* with high humidity environments (Scarbrough and Sipes, 1973), it is possible that wet conditions during June were favorable for increased *L. flavipes* abundance and activity. We collected *O. gemma* from mid-July to early September (Fig. 2), which is consistent with previous collections of this species in west-central Illinois (McCravy et al., in press).

Species composition of robber flies collected at Post Wildlife Sanctuary differed somewhat from that of previous collections in west-central Illinois. Two species collected in the present study, *N. flavofemoratus* and *N. auricomus*, were not found in malaise trap collections of over 300 robber flies in oak-hickory forests at Alice L. Kibbe Life Science Station in Hancock Co., approximately 65 km east of Post Wildlife Sanctuary (K. W. McCravy and K. A. Baxa, unpublished data). Conversely, the leptogastrine *Psilonyx annulatus* was relatively abundant at Kibbe Life Science Station, but uncommon in the present study. Unlike Post Wildlife Sanctuary, Kibbe Life Science Station consists of a mosaic of forest and prairie habitats that are intensively managed with prescribed fire (McCravy et al., 2009), which may produce environmental conditions conducive to a somewhat different robber fly species composition. More research on the habitat requirements of robber flies and effects of habitat disturbance on robber flies is needed.

In summary, *L. flavipes* was by far the most abundant robber fly species found at Post Wildlife Sanctuary, with *O. gemma* also being relatively abundant. Robber flies were most abundant in the lower understory, but robber fly diversity and species composition/relative abundance were similar in lower and upper traps. These results suggest that robber flies are most abundant at lower levels, but still may be present at substantial distances above ground level. However, the upper understory does not appear to harbor a distinct robber fly fauna. Robber flies are probably ecologically important components of the upper understory environment, but our results suggest that information obtained from robber fly studies in the lower understory for ecological monitoring purposes would be representative of the upper understory as well in the hardwood forests of the Midwest.

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Table 1. Numbers, species richness, rarefaction estimates of species richness (with 95% confidence intervals) and species diversity of robber flies captured in lower and upper understory canopy traps in a west-central Illinois upland oak-hickory forest. Traps were operated continuously from 26 May to 20 October 2008 in McDonough Co., Illinois USA. Percentages do not sum to 100.0 due to rounding error.

Species	Lower Traps	Upper Traps	Total	% of Total
Diogmites neoternatus (Bromley)	2	0	2	1.5
Heteropogon macerinus (Walker)	5	2	7	5.3
Laphria divisor (Banks)	1	0	1	0.8
Laphria index McAtee	6	2	8	6.1
Laphria thoracica Fabricius	1	0	1	0.8
Leptogaster flavipes Loew	41	16	57	43.5
Machimus antimachus (Walker)	3	3	6	4.6
Machimus sp. Loew	5	1	6	4.6
Neoitamus flavofemoratus (Hine)	5	3	8	6.1
Neomochtherus auricomus (Hine)	4	4	8	6.1
Nerax aestuans (L.)	1	0	1	0.8
Ommatius gemma Brimley	14	3	17	13.0
Ommatius ouachitensis Bullington & Lavigne	2	4	6	4.6
Psilonyx annulatus (Say)	2	1	3	2.3
Total Captured	92	39	131	100.1
Species Richness	14	10	14	
Rarefaction Estimate	12.99 ± 0.845 (11.32 – 14.66)	10.47 ± 1.1974 (8.12 – 12.82)		
Simpson's Diversity	0.7688	0.8070		

Figure 1. Weekly collections of robber flies captured in lower and upper understory canopy traps in a west-central Illinois upland oak-hickory forest. Traps were operated continuously from 26 May to 20 October 2008 at Ira and Reatha T. Post Wildlife Sanctuary in McDonough Co., Illinois USA.

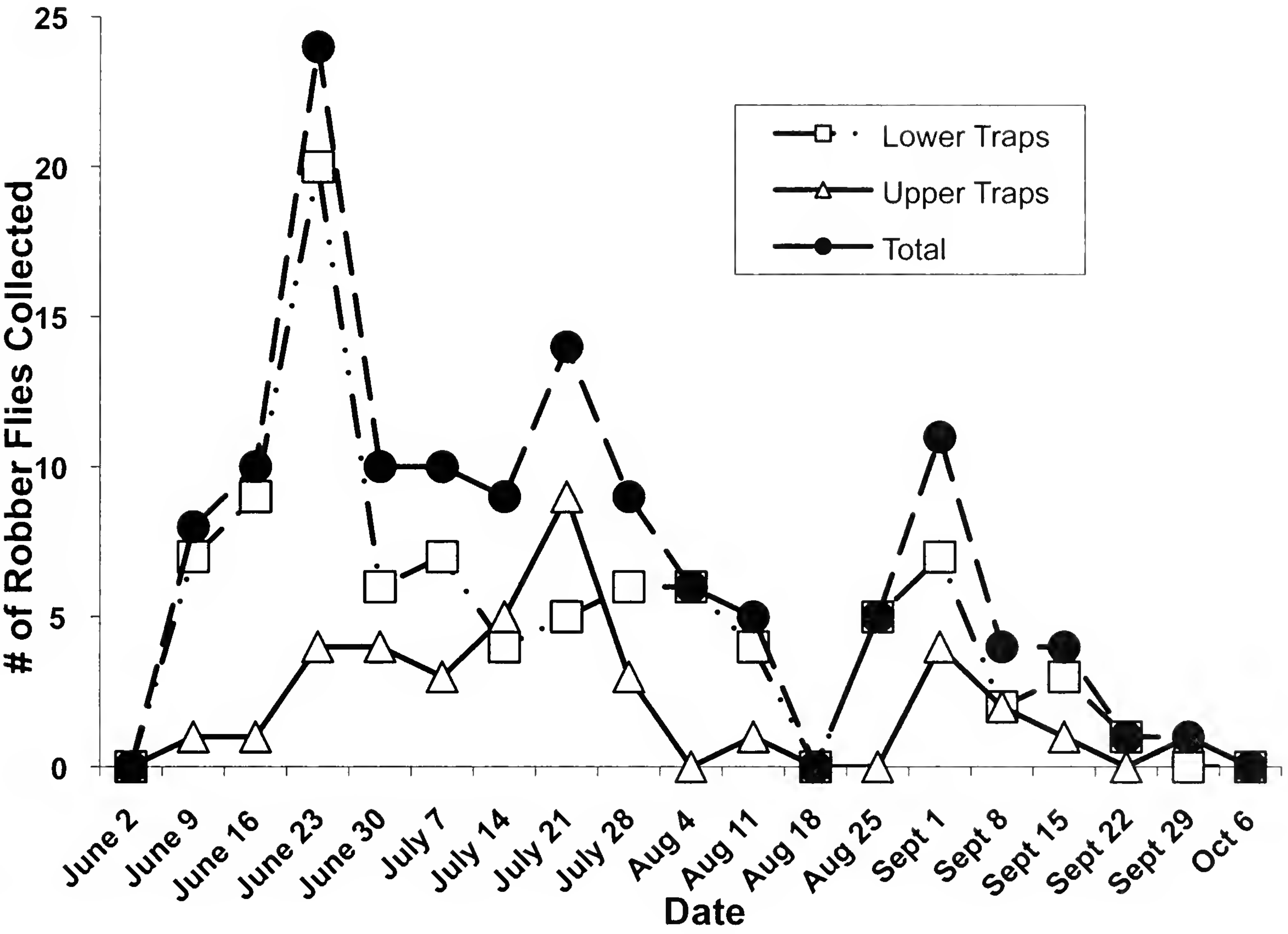
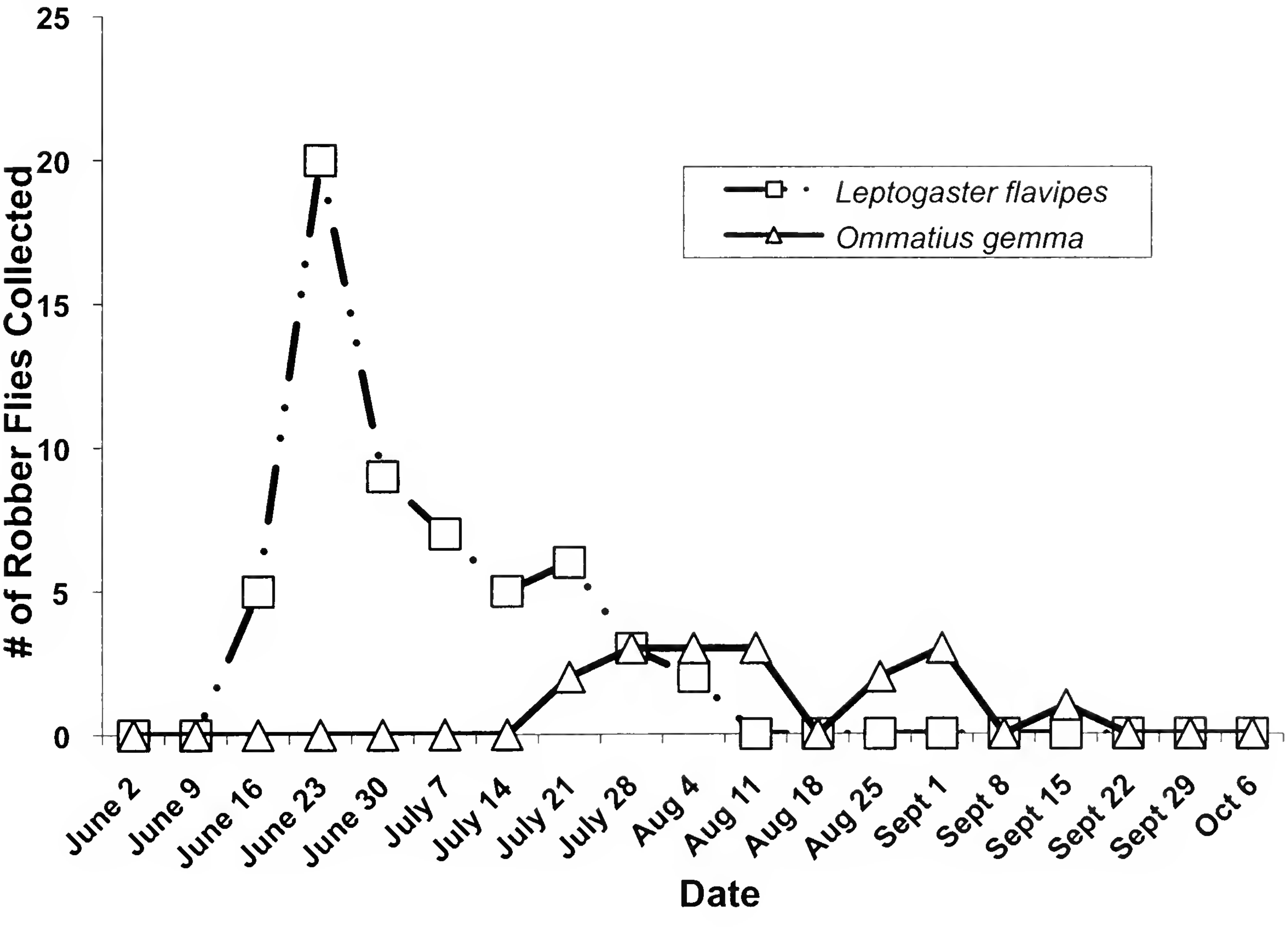


Figure 2. Weekly collections of two species of robber flies captured in canopy traps in a west-central Illinois upland oak-hickory forest. Traps were operated continuously from 26 May to 20 October 2008 at Ira and Reatha T. Post Wildlife Sanctuary in McDonough Co., Illinois USA.



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A Survey Of Bluff Forest Avifauna In Southwestern Illinois

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ABSTRACT

The forested bluffs of southwestern Illinois attract large numbers of migrating songbirds due to their prime location near the confluence of the Mississippi, Missouri, and Illinois Rivers. Our objective was to assess avian populations in several forest patches in order to characterize existing habitat as well as to inform future land use decisions. Fixed-distance point-count surveys (25 m radius) were conducted from May-July, 2008 at 129 randomized plots in three forest patches in Madison County, Illinois. Density estimates, species richness, species diversity, and indicator species analysis were used to assess the avifauna. We identified a total of 90 species, including species of conservation concern. Of the three forest patches surveyed, Bohm Woods Nature Preserve exhibited the highest numbers of forest interior species. Efforts should be made to acquire or convert additional habitat to buffer sensitive species against the negative effects of forest fragmentation.

INTRODUCTION

The forested bluffs of southwestern Illinois attract large numbers of migrating songbirds due to their prime location near the confluence of the Mississippi, Missouri, and Illinois Rivers. These once extensive oak-hickory forests are now highly fragmented, initially due to agriculture and more recently due to increasing urbanization. As the St. Louis metropolitan area continues its rapid expansion eastward, protection and management of remaining forests is crucial. The campus of Southern Illinois University Edwardsville (SIUE) and adjacent Bohm Woods Nature Preserve include some of the largest remaining forest tracts in Madison County, Illinois.

Population declines have been noted for many neotropical migrants in Illinois (Robinson et al., 1995), and are hypothesized to be influenced by fragmentation of forests on breeding grounds (Gates and Evans, 1998; Robinson and Robinson, 2001), brood parasitism by Brown-headed Cowbirds (Robinson et al, 1995), deforestation in the tropics (Bollinger and Linder, 1994), invasion of exotic plants and increasing populations of browsers (Elphick et al., 2001) and predators (Heske et al., 2001). Our objective was to assess avian populations in several forest patches in southwestern Illinois in order to characterize existing habitat as well as to inform future land use decisions in this rapidly developing area.

The three forest patches included in the survey occur on or adjacent to the SIUE campus in Madison County, Illinois (Fig. 1). All occur on loess bluffs at the edge of the Mississippi River floodplain known as the American Bottoms. Sweet William Woods is the largest forest patch covering 59.7 ha. The majority of this mesic/dry-mesic upland forest was formerly agricultural land that has experienced recent regrowth (<50 years). Portions of the forest that are along ravines have had trees present for over 100 years. Sweet William Woods includes an extensive network of trails and experiences the greatest amount of foot traffic. Bluebell Woods is a smaller mesic/dry-mesic upland forest that covers 30.3 ha and has a similar history of disturbance. However, it lacks trails and experiences little foot traffic. Bohm Woods Nature Preserve is largely mesic/dry-mesic upland forest, but also includes portions of wet bottomland forest. It covers 25.6 ha and has a more uniform distribution of mature trees than the other two forest patches. In addition, it has had little logging disturbance and receives intermediate levels of human traffic. All three forests have abundant deer populations due to adjoining agricultural land coupled with minimal hunting pressure.

MATERIALS AND METHODS

Fixed-distance point-count surveys (25 m radius) were conducted from May-July, 2008 at 129 randomized plots on the SIUE campus and adjacent Bohm Woods Nature Preserve (Bluebell, n = 34; Bohm, n = 29; Sweet William, n = 66). Surveys were conducted daily from 0600-1000 hours except when raining, foggy, or excessively windy. Each survey included a 1 minute warm-up period, followed by a 5 minute sampling period. Before the warm-up period a laser rangefinder (Bushnell Yardage Pro 500) was used to mark distance in the 4 cardinal directions (unless prevented by vegetation). All birds seen or heard during the sampling period were recorded, but only species within the 25 m radius were used in population density estimates (Bibby et al., 2000). During the sampling period a digital voice recorder (Olympus DS-40) was used to record songs and calls for subsequent identification in the lab. Sites were chosen each day to maximize distance between sampling locations, and the most direct routes to those sites were traveled in order to minimize disturbance (Bibby et al., 2000). Plots were visited 3 times each for a total sampling effort of 32.25 hours.

Density estimates for each bird species assumed there was one female for each singing male recorded. Densities were then calculated within plots and scaled up to one hectare. Overall densities for each forest patch were summed across all plots and average densities were estimated. In addition, species richness (S; total number of species), Shannon's diversity index ($H'\log_e$; measure of diversity incorporating richness and evenness), and Hill's diversity index (N1; exponential of $H'\log_e$) were calculated for each forest patch using Primer 6 (Clarke and Gorley, 2008). Indicator species analysis (ISA) was used to identify bird species that best characterized each forest patch (Dufrene and Legendre, 1997). We used a liberal P-value of 0.2 for ISA since we intended it as an exploratory analysis rather than as an explicit test of hypotheses.

RESULTS

Species richness was highest for the largest forest patch, Sweet William Woods (S = 63), with Bluebell and Bohm Woods exhibiting identical richness (S = 45; Table 1). Species diversity, as measured by Shannon's diversity index, was similar between Sweet William ($H'(\log_e) = 3.39$) and Bohm Woods ($H'(\log_e) = 3.38$), despite a large difference in area. Bluebell Woods (30.3 ha) had the lowest species diversity ($H'(\log_e) = 3.16$; Table 1).

Tables 2-5 list the densities for each species within each forest patch. Overall, warbler population densities were relatively low throughout the three forest patches (<1 individual/ha; Table 2). Exceptions, included Northern Parula, which was abundant (>2 /ha) at all three sites, and Magnolia, Yellow, and Black-throated Green Warblers, which were moderately abundant in Bohm Woods (1-2 individuals/ha). Among other migratory passerines, densities exceeded 1 individual/ha at all three sites for Eastern Wood-Pewee, Acadian Flycatcher, Wood Thrush, Great Crested Flycatcher, Indigo Bunting, Blue-gray Gnatcatcher, and Red-eyed Vireo (Table 3). In addition, Swainson's Thrush and White-throated Sparrow were abundant in Bohm Woods. Among resident passerines, Tufted Titmouse, Northern Cardinal, American Goldfinch, Brown-headed Cowbird, Eastern Towhee, Carolina Chickadee, White-breasted Nuthatch, Carolina Wren, and American Robin were abundant at all three sites. The Blue Jay was abundant at Bluebell and Sweet William Woods. (Table 4). Among nonpasserines, Red-bellied and Downy Woodpeckers were abundant at all three sites; whereas, Ruby-throated Hummingbird, Chimney Swift, Northern Flicker, and Hairy Woodpecker were abundant at Bohm Woods (Table 5).

Table 6 describes the results of the indicator species analysis (ISA). Seven species were identified whose relatively high indicator values acted to differentiate Bluebell Woods from the remaining forest patches. These included Northern Cardinal, American Goldfinch, Tufted Titmouse, Eastern Towhee, Blue-gray Gnatcatcher, Common Grackle, and Black-capped Chickadee. Three species differentiated Sweet William from the other forests: Carolina Chickadee, Carolina Wren, and Kentucky Warbler. Lastly, 12 species served as indicators for Bohm Woods: Acadian Flycatcher, American Robin, Ruby-throated Hummingbird, Downy woodpecker, Wood Thrush, Hairy Woodpecker, Chimney Swift, Northern Flicker, Yellow Warbler, White-throated Sparrow, Black-throated Green Warbler, and Swainson's Thrush.

Table 7 lists additional species encountered during the sampling period outside of 25 m plots and not included in species richness or density estimates. Table 8 lists additional species encountered outside of the sampling period and not included in species richness or density.

DISCUSSION

We identified 90 species among three forest patches on and adjacent to the Southern Illinois University Edwardsville campus, including species of conservation concern such as the state threatened Black-billed Cuckoo (proposed) and the state endangered Northern Harrier. Bohm Woods appears to be particularly valuable from a conservation perspective. It is the only patch to feature migratory transients as indicator species, including Black-throated Green Warbler and Swainson's Thrush (Table 6). This suggests an important role as a migratory stopover site, despite its small size. Nevertheless, Bohm Woods is also comprised of relatively undisturbed mature forest which may make it more attractive than larger forest patches with greater levels of disturbance. In addition, Bohm Woods is also distinguished by supporting higher numbers of forest interior species, including two Neotropical migrants sensitive to fragmentation, Acadian Flycatcher and Wood Thrush (Roth et al., 1996; Whitehead and Taylor, 2002; Table 6).

The Acadian Flycatcher breeds near water in deciduous forests of the Midwest (Whitehead and Taylor, 2002). They have been found to exhibit low reproductive success within 600 m of a forest edge in southern Illinois due to cowbird parasitism and predation resulting from fragmentation (Hoover et al., 2006). None of the forest patches surveyed in the present study include habitat greater than 600 m from an edge. This would seem to make the entire area a population sink for Acadian Flycatchers. However, another study in Illinois determined that Acadian Flycatchers may be less sensitive to fragmentation than other forest passerines in Illinois and may exhibit reproductive success in narrow riparian corridors (Chapa-Vargas and Robinson, 2007). The extensive network of ravines, transitioning to wet, bottomland forest in Bohm Woods may provide ideal conditions for Acadian Flycatchers, as evidenced by the high density estimates (6.79/ha; Table 6). The degree of reproductive success should be monitored to determine which of these two scenarios characterizes this population.

Wood Thrushes in Illinois also exhibit low nesting productivity due to the effects of forest fragmentation. Forest patches as large as 2200 ha have been found to be population sinks (Trine, 1998). Given the small size of the forest patches in the present study, local populations are likely to exhibit low recruitment. Nevertheless, Bohm Woods attracts relatively large numbers of Wood Thrush due to its mature trees. Despite its likely status as a population sink, it undoubtedly has value as a migratory stopover site.

Bohm Woods exhibited the lowest Brown-headed Cowbird density of the three forest patches (Table 4). Brown-headed Cowbirds are brood parasites that lay their eggs in the nests of many avian host species, providing no additional parental investment. The hosts may then incubate and rear cowbird offspring to the detriment of their own fitness (Brittingham and Temple, 1983). Cowbirds forage in agricultural areas and are typically more abundant at forest edge rather than forest interior (Lowther, 1993). Despite its small size and close proximity to agriculture, Bohm Woods may be less attractive to cowbirds than larger surrounding patches due to its mature trees and circular shape, which maximizes the amount of interior forest habitat.

Sweet William and Bluebell Woods are comprised of large areas of regrowth and are characterized by higher numbers of bird species associated with this habitat type (Table 6). However, they maintain core areas of mature trees, concentrated around ravines. These areas are important for forest interior bird species and should be protected from future disturbance. As the surrounding forest continues to mature, the value for interior species will increase.

Efforts should be made to acquire additional land and convert adjacent non-forested land to forest in order to benefit forest interior species. Although, young forest would be of little direct value to these species in terms of suitable foraging or nesting habitat, it would serve an important indirect role by providing a buffer to cowbirds and predators. This is critical for Bohm Woods which has higher numbers of sensitive species.

Bluff forest avifauna should continue to be observed over the long term in order to monitor population trends. This is especially important due to current and predicted changes in vegetation. Long-term monitoring may allow elucidation of the effects of rapid expansion of bush honeysuckle (*Lonicera maackii*), as well as the predicted loss of ash (*Fraxinus* sp.) from these forests. The plots used in this study are permanently marked and georeferenced and we intend to resample them regularly in the future to monitor changes in the vegetation and bird communities.

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Table 1. Species richness (S), Shannon (H' $\log_e$) and Hill (N1) diversity indices for 3 forest patches in Madison County, Illinois.

Forest	S	H'($\log_e$)	N1
Bluebell	45	3.16	23.6
Bohm	45	3.38	29.5
Sweet William	63	3.39	29.6

Table 2. Estimated population densities (individuals/ha) for warblers in 3 forest patches in Madison County, IL

Species	Common Name	Bluebell	Bohm	Sweet William
Dendroica coronata	Yellow-rumped Warbler	0.60	0.34	0.15
Dendroica dominica	Yellow-throated Warbler	0.00	0.34	0.15
Dendroica fusca	Blackburnian Warbler	0.30	0.00	0.15
Dendroica magnolia	Magnolia Warbler	0.30	1.02	0.23
Dendroica pensylvanica	Chestnut-sided Warbler	0.00	0.85	0.62
Dendroica petechia	Yellow Warbler	0.00	1.53	0.31
Dendroica striata	Blackpoll Warbler	0.00	0.00	0.46
Dendroica virens	Black-throated Green Warbler	0.00	1.02	0.15
Geothlypis trichas	Common Yellowthroat	0.60	0.00	0.15
Mniotilta varia	Black-and-white Warbler	0.00	0.00	0.15
Oporornis formosus	Kentucky Warbler	0.00	0.00	0.39
Oporornis philadelphia	Mourning Warbler	0.00	0.17	0.00
Parula americana	Northern Parula	4.19	2.55	3.70
Seiurus aurocapilla	Ovenbird	0.00	0.34	0.31
Seiurus motacilla	Louisiana Waterthrush	0.00	0.00	0.46
Setophaga ruticilla	American Redstart	0.30	0.51	0.39
Vermivora peregrina	Tennessee Warbler	0.30	0.34	0.31
Vermivora ruficapilla	Nashville Warbler	0.00	0.00	0.15
Wilsonia citrina	Hooded Warbler	0.00	0.34	0.00

Table 3. Estimated population densities (individuals/ha) for other (non-warbler) migratory passerines in 3 forest patches in Madison County, IL.

Species	Common Name	Bluebell	Bohm	Sweet William
Catharus fuscescens	Veery	0.00	0.00	0.15
Catharus ustulatus	Swainson's Thrush	0.60	1.53	0.08
Contopus virens	Eastern Wood-Pewee	2.10	1.36	2.39
Dumetella carolinensis	Gray Catbird	0.00	0.00	0.23
Empidonax alnorum	Alder Flycatcher	0.00	0.00	0.15
Empidonax flaviventris	Yellow-bellied Flycatcher	0.30	0.00	0.46
Empidonax virescens	Acadian Flycatcher	2.10	6.79	2.16
Hylocichla mustelina	Wood Thrush	1.95	4.07	2.08
Icterus galbula	Baltimore Oriole	0.00	0.34	0.08
Myiarchus crinitus	Great Crested Flycatcher	2.40	1.19	3.47
Passerina cyanea	Indigo Bunting	5.69	8.49	4.01
Pheucticus ludovicianus	Rose-breasted Grosbeak	0.15	0.34	0.00
Piranga olivacea	Scarlet Tanager	0.00	0.00	0.46
Piranga rubra	Summer Tanager	0.00	0.34	0.08
Polioptila caerulea	Blue-gray Gnatcatcher	4.04	1.19	2.47
Sayornis phoebe	Eastern Phoebe	0.00	0.00	0.08
Spizella passerine	Chipping Sparrow	0.30	0.00	0.15
Toxostoma rufum	Brown Thrasher	0.30	0.00	0.15
Troglodytes aedon	House Wren	0.30	0.00	0.85
Tyrannus tyrannus	Eastern Kingbird	0.30	0.00	0.08
Vireo flavifrons	Yellow-throated Vireo	0.00	0.34	0.15
Vireo gilvus	Warbling Vireo	0.00	0.00	0.15
Vireo griseus	White-eyed Vireo	0.30	0.00	0.31
Vireo olivaceus	Red-eyed Vireo	6.89	5.09	5.63
Vireo philadelphicus	Philadelphia Vireo	0.00	0.34	0.31
Zonotrichia albicollis	White-throated Sparrow	0.15	1.02	0.00

Table 4. Estimated population densities (individuals/ha) for resident passerines in 3 forest patches in Madison County, IL.

Species	Common Name	Bluebell	Bohm	Sweet William
Agelaius phoeniceus	Red-winged Blackbird	0.60	0.34	0.00
Baeolophus bicolor	Tufted Titmouse	7.79	5.77	5.09
Cardinalis cardinalis	Northern Cardinal	12.58	6.45	9.80
Carduelis tristis	American Goldfinch	11.38	4.24	4.48
Corvus brachyrhynchos	American Crow	0.75	0.00	0.77
Cyanocitta cristata	Blue Jay	1.50	0.68	1.62
Mimus polyglottos	Northern Mockingbird	0.00	0.00	0.31
Molothrus ater	Brown-headed Cowbird	5.09	2.89	4.63
Pipilo erythrophthalmus	Eastern Towhee	5.54	1.53	3.63
Poecile atricapilla	Black-capped Chickadee	1.05	0.00	0.00
Poecile carolinensis	Carolina Chickadee	5.69	2.89	7.18
Quiscalus quiscula	Common Grackle	1.80	0.00	0.62
Sialia sialis	Eastern Bluebird	0.00	0.00	0.15
Sitta carolinensis	White-breasted Nuthatch	0.75	2.21	2.24
Sturnus vulgaris	European Starling	0.30	0.00	0.00
Thryothorus ludovicianus	Carolina Wren	1.20	1.70	2.86
Turdus migratorius	American Robin	2.40	4.92	1.77

Table 5. Estimated population densities (individuals/ha) for nonpasserines in 3 forest patches in Madison County, IL.

Species	Common Name	Bluebell	Bohm	Sweet William
Archilochus colubris	Ruby-throated Hummingbird	0.60	2.55	0.39
Chaetura pelagica	Chimney Swift	0.00	1.70	0.00
Coccyzus americanus	Yellow-billed Cuckoo	0.90	0.68	0.46
Colaptes auratus	Northern Flicker	0.45	1.36	0.15
Dryocopus pileatus	Pileated Woodpecker	0.30	0.85	0.46
Melanerpes carolinus	Red-bellied Woodpecker	1.35	2.55	2.16
Meleagris gallopavo	Wild Turkey	0.00	0.00	0.15
Picoides pubescens	Downy Woodpecker	3.15	3.90	2.08
Picoides villosus	Hairy Woodpecker	0.75	2.21	0.85

Table 6. Indicator species analysis for 3 forest patches in Madison County, IL. Tabulated indicator values are the product of fidelity and constancy. P values are based on 10,000 random permutations of group membership. Species with $P < 0.2$ are shown. A liberal P-value of 0.2 since was used since this was an exploratory analysis rather than an explicit test of hypotheses. Bold values indicate the group for which the species is a significant indicator.

Species	Common Name	Bluebell	Bohm	Sweet William	P
Baeolophus bicolor	Tufted Titmouse	**26**	14	12	0.1401
Cardinalis cardinalis	Northern Cardinal	**35**	16	28	0.1058
Carduelis tristis	American Goldfinch	**32**	8	8	0.0055
Pipilo erythrophthalmus	Eastern Towhee	**20**	3	12	0.1258
Poecile atricapillus	Black-capped Chickadee	**6**	0	0	0.1181
Polioptila caerulea	Blue-gray Gnatcatcher	**19**	3	9	0.1053
Quiscalus quiscula	Common Grackle	**11**	0	2	0.0385
Archilochus colubris	Ruby-throated Hummingbird	1	**17**	0	0.0051
Catharus ustulatus	Swainson's Thrush	1	**9**	0	0.037
Chaetura pelagica	Chimney Swift	0	**13**	0	0.0027
Colaptes auratus	Northern Flicker	1	**12**	0	0.0213
Dendroica petechia	Yellow Warbler	0	**11**	1	0.0149
Dendroica virens	Black-throated Green Warbler	0	**9**	0	0.0313
Empidonax virescens	Acadian Flycatcher	3	**41**	4	0.0001
Hylocichla mustelina	Wood Thrush	4	**15**	5	0.124
Picoides pubescens	Downy Woodpecker	10	**17**	4	0.125
Picoides villosus	Hairy Woodpecker	2	**14**	2	0.0559
Turdus migratorius	American Robin	6	**20**	4	0.0409
Zonotrichia albicollis	White-throated Sparrow	0	**9**	0	0.0155
Oporornis formosus	Kentucky Warbler	0	0	**6**	0.1546
Poecile carolinensis	Carolina Chickadee	18	7	**25**	0.1737
Thryothorus ludovicianus	Carolina Wren	2	7	**17**	0.1497

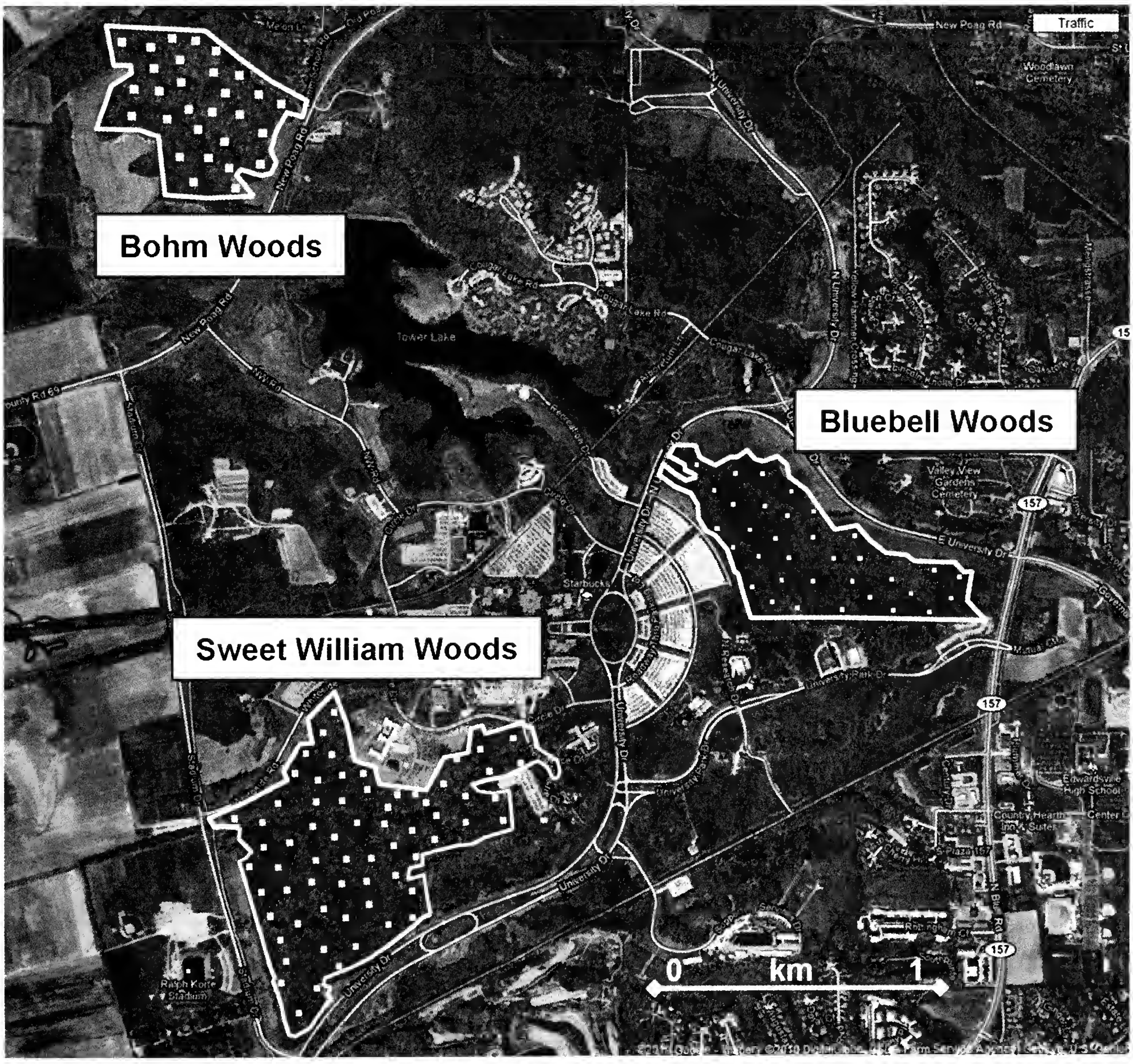
Table 7. Observations of additional species encountered during sampling period outside of 25 m plots and not included in species richness or density estimates.

Species	Common Name	Bluebell	Bohm	Sweet William
Branta canadensis	Canada Goose	11	4	7
Buteo jamaicensis	Red-tailed Hawk	-	2	-
Cathartes aura	Turkey Vulture	2	1	-
Catharus guttatus	Hermit Thrush	-	1	3
Charadrius vociferous	Killdeer	1	-	-
Coccyzus erythropthalmus	Black-billed Cuckoo	1	-	1
Colinus virginianus	Northern Bobwhite	3	3	5
Dendroica tigrina	Cape May Warbler	1	-	-
Helmitheros vermivorum	Worm-eating Warbler	-	-	2
Passerina caerulea	Blue Grosbeak	-	-	-
Spizella pusilla	Field Sparrow	11	3	8
Sturnella magna	Eastern Meadowlark	1	-	-
Vermivora pinus	Blue-winged Warbler	1	-	-
Zenaida macroura	Mourning Dove	3	1	2

Table 8. Observations of additional species encountered outside of sampling period and not included in species richness or density estimates.

Species	Common Name	Bluebell	Bohm	Sweet William
Circus cyaneus	Northern Harrier	-	1	-
Megaceryle alcyon	Belted Kingfisher	-	1	-
Strix varia	Barred Owl	-	1	-
Vermivora chrysoptera	Golden-winged Warbler	-	1	-
Vireo bellii	Bell's Vireo	-	-	1

Figure 1. Aerial photo of 3 forest patches in Madison County, IL where avian point count surveys were conducted. White lines indicate boundaries of sampled areas and dots indicate locations of sampling plots (N=129).



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The First Record of American Tadpole Shrimp (*Triops longicaudatus*) in Illinois

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ABSTRACT

The American tadpole shrimp is widely distributed throughout the Western United States and has recently been found in rice fields in the bootheel of Missouri. We document the first record of this species in Illinois.

INTRODUCTION

American tadpole shrimp was traditionally considered to be a species of the Western U.S. but seems to have been on an eastward range expansion for several years (Taylor et al. 1987, Tindall et al 2009). Tindall et al. (2009) described the all documented specimens in Missouri. First reported in 1979 and 1983, specimens were collected near Jackass Bend on the Missouri River in Jackson County near the Kansas line. Single specimens were found in east central Missouri in St. Charles County on the Missouri River and in the bootheel in Pemiscot County on a rice field near the Mississippi River in 2007. Rice fields in the counties of Stoddard and New Madrid were reported to be infested with the species in 2008. In 2009, rice field infestations were reported in the bootheel counties of Dunklin and Mississippi. This species is considered to be a pest of rice throughout its range.

COLLECTION

On May 26, 2009, we captured three specimens by hand in an ephemeral pool near the Mississippi River on the inside of Potato Bend at an unpaved boat ramp parking lot in Jackson County, two miles south of Cora IL (UTM NAD 1983 zone16 4186057N 265856E). The silt bottom pool was estimated to be 2 meters by 4 meters with a maximum depth of 20 cm. Specimens were captured by hand. All three specimens captured were preserved and will be deposited in the Illinois Natural History Survey Crustacean Collection.

The species is known to disperse via floodwater (Taylor et al. 1987). It was likely brought down the Mississippi River from the Missouri River during spring floods. Because this species is also known to disperse via birds and wind, it will likely be on the batture (inland) side of the levee soon if it is not already (Green and Figuerola 2005; Caceres and Soluk 2002; Nathan et al 2005; Graham and Wirth 2008). Although considered a pest by rice farmers, it is considered as a possible human ally against West Nile virus and a biological control agent for certain weeds (Fry et al.1994; Takahashi 1977).

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Status of the Snuffbox Mussel *Epioblasma triquetra* (Rafinesque) in Illinois: a Functionally Extirpated Species

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ABSTRACT

Within Illinois, the state-endangered snuffbox mussel *Epioblasma triquetra* (Rafinesque) is currently found only in a small stretch of the Embarras River in Douglas and Coles counties and is considered one of the rarest freshwater mussels in the state. To assess the current population status of *E. triquetra* in Illinois, I estimated density, length frequency, and sex ratio of the Embarras River population. I also examined the status of the snuffbox mussel's host fish, the logperch *Percina caprodes* (Rafinesque), to determine if the fish was present in this area. Seven sites in the Embarras River were sampled for freshwater mussels and fishes during the summers of 2007 and 2008 using common sampling protocols. Only five adult (>55 mm) *E. triquetra* males were collected from two sites, suggesting this species is functionally extirpated in Illinois. Although *P. caprodes* was collected at five sites including the two that housed *E. triquetra*, it occurred at low densities. It seems unlikely that *E. triquetra* can recover naturally in Illinois, and carefully planned translocation or augmentation methods might be required to restore the species.

INTRODUCTION

Freshwater mussels (Bivalvia) are the most imperiled group of organisms in North America (Williams et al., 1993). Of the approximate 300 species native to North America, nearly two-thirds are extinct, federally-listed as endangered or threatened, or are in need of conservation. This reduction also is evident in Illinois. Of the 80 historical species known to inhabit the state, 19 are extirpated from Illinois, 16 are state-endangered, eight are state-threatened, and only 22 are considered to have relatively stable populations within Illinois (DeWalt et al., 2009). Factors responsible for the decline in freshwater mussels include habitat destruction, environmental contamination, and invasion of exotic species (Williams et al., 1993).

One of the rarest species in Illinois is the snuffbox mussel *Epioblasma triquetra* (Rafinesque), which is listed as state-endangered (IESPB, 2005). Historically, *E. triquetra* was found in 14 drainages in the state but currently is found only in a small stretch (<40 km) of the Embarras River (Tiemann et al., 2007; DeWalt et al., 2009). The logperch *Percina caprodes* (Rafinesque) is the predominant host fish for *E. triquetra* (Zanatta and Murphy, 2008 and references therein), and the mussel has evolved a unique strategy of capturing the fish to infest it with glochidia (Barnhart et al., 2008). Both the unionid and its host fish inhabit medium to large streams in clear, sand/gravel riffles (Smith, 1979; Cummings and Mayer, 1992). Concurrent with the disappearance of *E. triquetra*, the logperch might be declining in portions of its range in Illinois (Smith, 1979). The objectives of this study were to estimate the population demographics (e.g., density, length frequency, and sex ratio) of *E. triquetra* in Illinois to note its current status in the state, and examine the occupancy of *P. caprodes* in the portion of the Embarras River where *E. triquetra* is extant to determine if the host fish is present in this area.

STUDY AREA

The Embarras River basin drains approximately 6,200 km^2 of east-central Illinois (Page and Smith, 1970; Page et al., 1992). The river originates in Champaign, Champaign County, and meanders nearly 290 km south-southeast before empting into the Wabash River near Billett, Lawrence County. The Embarras River basin historically supported 47 species of freshwater mussels (Tiemann et al., 2007) and at least 14 species of darters (Page and Smith, 1970). Even though the Embarras River has experienced anthropogenic disturbances (e.g., industrial and agricultural pollution, channelization, and impoundments), the middle section of the Embarras River, which is in Coles and Douglas counties, has been described as one of the outstanding streams in Illinois based on a wide variety of habitats and rich species diversity (Smith, 1968; Smith, 1971; Page et al., 1992). The dominant stream substrates in this area include sand and gravel bars, rubble riffles, and silt bottomed pools (Page and Smith, 1970; Page and Smith, 1971).

METHODOLOGY

Seven sites were established in a 40 km^2 portion of the Embarras River basin in Douglas and Coles counties, Illinois (Table 1). Sites included the most recent known locations of *E. triquetra* in the state, along with those sites where valves had been found during previous surveys (data taken from INHS Mollusk Collection, Champaign). The aforementioned surveys utilized timed-searches, which is a quick, cost effective method used for obtaining information on species richness (Strayer and Smith, 2003; Tiemann et al., 2009 and references therein); however, none of the previous surveys used quadrats. Area searches (e.g., quadrats) are better suited than timed-searches for determining densities and length frequencies of freshwater mussels (Strayer and Smith, 2003; Tiemann et al., 2009 and references therein), thus 1-m^2 quadrats were used in this study. At each site, at least five transects were uniformly spaced 5-m apart, perpendicular to the river channel along a sandy-gravel riffle / run, and up to five points were evenly established 0.5-m apart along the length of each transect. At each point, a quadrat was placed on the streambed and the substrate within the quadrat was examined for live unionids by searching tactilely and excavating the substrate. A total of 30 points were sampled at each site. Upon completion of a site, individuals were identified to species, counted, measured to the nearest millimeter, and then returned to the stream. Fishes were collected bimonthly from May-September 2007 and May-September 2008 by kick-seining, which is a quantitative method used to collect benthic fishes including darters (Tiemann, 2008). A transect-point method similar to that used for unionids also was implemented for fishes. However, instead of using quadrats, fishes were collected from a 4.5 m^2 area at each point by kicking the substrate 3-m upstream from a stationary 1.5-m wide, 3-mm mesh seine and proceeding downstream to the seine in a back and forth path covering the width of the seine. To minimize disturbance, transects were sampled from downstream to upstream and points were sampled near shore to far shore. A total of 30 points were sampled at each site. Fishes were identified to species, counted, and then returned to the stream. Funding and landowner permission prevented additional sites from being sampled.

RESULTS / DISCUSSION

Snuffbox mussel densities varied from 0 – 0.13 indiv/m^2 per site (mean = 0.02 ± 0.05 indiv/m^2). Five *E. triquetra* males were collected from two sites during the course of the study (Table 1). Length frequency data (58, 59, 63, 68, and 71 mm) suggests that these individuals were all adults. The lack of smaller size classes indicates that *E. triquetra* is not reproducing in Illinois as no small and presumably young individuals were collected. These findings suggest that *E. triquetra* might be functionally extirpated in Illinois.

Logperch were captured at five of the seven sites, including the two sites where *E. triquetra* was collected (Table 1). The site with the greatest number of *E. triquetra* also had the greatest number of *P. caprodes*. Although the host fish was present, relatively few individuals were collected. Monthly site *P. caprodes* densities varied from 0 – 0.052 indiv/m^2 (mean = 0.006 ± 0.010 indiv/m^2). It is unknown what density of logperch is required to support a viable population of *E. triquetra*. My data only show that *P. caprodes* is present in the area. Because *P. caprodes* might be declining in portions of its range (Smith, 1979), it cannot be ruled out that the host fish's abundance is a limiting factor in *E. triquetra* recruitment.

The snuffbox mussel has been collected only at two sites in Illinois since 1985 (data taken from INHS Mollusk Collection, Champaign). Site 4 was sampled using timed-search techniques ten times between 1986 and 2008, whereas Site 5 was sampled three times during this same time period. The number of live *E. triquetra* collected at Site 4 during those surveys is as follows: 1986 (2), 1992 (2), 2001 (1), 2002 (2), and 2005 (1); no live individuals were collected in 1988, 1990, 1991, 1994, or 2008. Seven live individuals were found at Site 5 in 1986, but none were located in 1992 or 2005. The amount of effort during these surveys varied from one to four person-hours. Notes from some of the surveys indicated that only adults were collected, strengthening the argument that *E. triquetra* is not reproducing in the state.

The physical habitat (e.g., sand/gravel riffles) in this area of the Embarras River appeared suitable for *E. triquetra*. Chemical measurements were not taken, but water quality in this portion of the river in the 1960s was reported to be high and pollution minimal (Page and Smith, 1970). However, the Wabash River drainage has experienced significant physical and biological changes as a result of anthropogenic disturbances during the past century (Simon, 2006), and the Embarras River basin is no exception (Smith, 1968; Smith, 1971). Human induced modifications include draining of wetlands, dredging of streams, pollution from agriculture and industrial sources, removal of riparian areas, development of floodplains, and impounding of streams. My study was not designed to determine if anthropogenic disturbances are responsible for the reduction of *E. triquetra* in Illinois, but these factors have been shown to cause alterations in both freshwater mussel and fish assemblages (Smith, 1971; Cummings, 1991).

MANAGEMENT CONSIDERATIONS

Although a small, isolated reproducing population could exist in unsampled areas, the data from this survey and prior surveys suggest that *E. triquetra* may be functionally extirpated in Illinois. Because many populations have been greatly reduced or have disappeared completely, the species is currently under status review for potential listing under the United States Endangered Species Act (Zanatta and Murphy, 2008). For over two decades, qualitative and quantitative surveys within the last refuge for snuffbox in Illinois have consistently recorded very low numbers of individuals and no sign of recent recruitment (data taken from INHS Mollusk Collection, Champaign). It seems unlikely that *E. triquetra* can recover naturally in Illinois given that it might be isolated from adjacent populations due to impoundments and habitat alterations (Zanatta and Murphy, 2008), and darters (e.g., host fish) tend to have limited dispersal capabilities (McLain and Ross, 2005; Roberts et al., 2008). To recover *E. triquetra*, natural resource agencies should determine why the species is not reproducing (e.g., whether host fish densities or physicochemical issues are limiting *E. triquetra*). Once the problem is rectified, agencies could implement recovery efforts in Illinois by either translocation to existing snuffbox mussel habitats or propagation to establish new populations in other basins with suitable host fishes, substrate, and physicochemical parameters.

If natural resource agencies implement a recovery plan, stocking rates should be modeled after streams that have viable, reproducing populations and genetic diversity should be maintained (Crabtree and Smith, 2009). If the population from a particular region has been extirpated or is too small to propagate then brood stock should be taken from the nearest viable population based on riverine distance and known genetic profile (Zanatta and Murphy, 2008). Reproducing populations of snuffbox mussel are still found within the Wabash River drainage in Indiana (Fisher, 2006); therefore, *E. triquetra* brood stock could come from within the Wabash River drainage to help preserve the genetic integrity of the species. Additional funding needs to be secured to allow natural resource agencies to work with landowners on sampling additional areas / establishing recovery sites and on propagating / translocating individuals. In the meantime, the snuffbox mussel should remain listed as state-endangered, and all efforts should be taken to protect the last population of *E. triquetra* in Illinois.

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Table 1. Sampling locations and total number of snuffbox mussel and logperch collected during the 2007-2008 survey in the Embarras River basin, Illinois; stream includes Embarras River (ER) and North Fork Embarras River (NFER).

Site	Stream	County	Common location	# *E. triquetra*	# *P. caprodes*
1	ER	Douglas	0.5 mi SE Hugo, CR 1725E	0	0
2	ER	Douglas	2 mi SE Hugo, CR 1900E	0	0
3	ER	Douglas	3 mi NW Oakland, CR 2200E	0	3
4	ER	Douglas	2 mi W Oakland, IL Rte 133	4	15
5	ER	Coles	3 mi SW Oakland, ford	1	3
6	ER	Coles	6 mi SSW Oakland, ford	0	6
7	NFER	Coles	4 mi S Oakland, CR 1500N	0	6

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BOOK REVIEW 2010 - #1

Shennan, Stephen (Editor). Pattern and Process in Cultural Evolution. 2009. viii + 341 pages; figures; tables; chapter references; index. University of California Press, Berkeley, California. ISBN 978-0-520-25599-9. Hard Cover. Price: $60.00. Available from: University of California Press, 2120 Berkeley Way, Berkeley, CA 94704

The contributors to Pattern and Process in Cultural Evolution endeavor to make the case that cultural change and biological evolution are sufficiently similar that theoretical and analytical concepts from evolutionary biology can productively be applied to cultural "evolution." Their position justifies an evolutionary anthropology that can embrace a variety of approaches to the archaeological and ethnographic records. Some of the more theoretical pronouncements are problematic (see below), and some of the applications are a bit strange (e.g., the phylogenetic branching of European knives and forks). Collectively, however, the volume's chapters clearly demonstrate the middle-range potential of evolutionary approaches for generating and testing hypotheses about the mechanisms underlying cultural change.

Shennan's introductory chapter makes clear that practitioners of evolutionary anthropology and archaeology are a diverse group and may sometimes disagree with each other about theory and method. For example, human behavioral ecology (HBE) is advanced by its advocates as the quintessential evolutionary approach to archaeology and ethnology (e.g. Kennett and Winterhalder, 2006) but is regarded by others (e.g. Fitzhugh and Trusler, chapter 14) as insensitive to creativity and social and technological innovation. These authors favor cultural transmission theory (CT) which focuses on how skills, attitudes and artifacts are passed between generations (vertical transmission) and across social boundaries (horizontal transmission).

Following Shennan's introduction, the volume is divided into three sections: Understanding Cultural Transmission (chapters 2 through 9), Testing Evolutionary Hypotheses (chapters 10 through 14), and Social Evolution (chapters 15 through 21). The chapters in each section are loosely organized around the section theme, although some could be shuffled among the themes without loss of coherence. Understanding Cultural Transmission is the most theoretically and philosophically dense section, although not necessarily the most illuminating. Mesoudi and O'Brien (chapter 2) argue for incorporating an analog of virtually every concept from evolutionary biology—from selection to phylogenesis (in biology, the appearance of new taxa)—into evolutionary anthropology. They also introduce the reader to dual inheritance theory (i.e. genetic and cultural inheritance) and its offspring, cultural transmission theory (CT). Briefly, CT attempts to specify all of the ways that cultural knowledge can be can be passed from individual to individual and group to group, along with predictions about the degree of variation associated with each transmission pathway.

Strong advocates of mathematical modeling and simulations, Mesoudi and O'Brien argue that, "only by using quantitative methods such as gene culture coevolution models or phylogenetic analyses, together with controlled experimental simulations, can we begin to unravel [the] complexity" of multiple variables influencing the trajectories of cultural change (p. 28). In their insistence on experimentation and simulation, Mesoudi and

O'Brien recall the New Archaeology of the 1970s and 80s (e.g. Binford, 1977), whose practitioners argued that archaeological interpretation must be based on models derived from experiment and ethnographic observation.

Robert Aunger (chapter 3) expands on cultural transmission theory, arguing that human beings use communication to construct individual and social niches: "communication can be defined as *an instance of niche construction using signs, signals, or artifacts that is targeted at changing the behavior of conspecifics*" (original emphasis). Unfortunately, in promoting his own view Aunger distorts or misrepresents the work of other theorists. A good example is his treatment of the epidemiological model for the transmission of cultural information developed most fully by Dan Sperber (e.g. Sperber, 1996). The model proposes that "ideas" spread in a way analogous to the spread of an infectious agent. In Aunger's account, the epidemiological model takes little account of mutation or variation. In fact, Sperber (1996, pp. 25-27) noted that mutation of ideas is likely much more common than mutation of organisms: it is the rule in the former, the exception in the latter. Moreover, Sperber suggested that communication begins when an individual forms a mental representation of an idea in her head. It is the mental representation, not the idea itself, that is transmitted via a public representation. Yet Aunger cannot grasp how an idea could exist in a mind independently of its representation. He claims that, "it is rarely assumed that ideas duplicate themselves within one mind prior to being ejected into the external environment...: people would have to sneeze away the only copy of the idea they have" (p. 36). This, too, is a misrepresentation, and a rather silly one at that.

The remainder of the chapters in the book focus on illustrative case studies, each accompanied by an explanation of the theoretical orientation and methods employed. The contributors investigate a fascinating variety of topics, from the technological "evolution" of bicycle design (Lake and Venti, chapter 10) to a persuasive if ultimately speculative proposal for the evolutionary origins of social prestige and prestige goods (Plourde, chapter 18). In general, the case studies prove more interesting and potentially useful the farther away they get from grand theorizing.

An excellent example is chapter 12 by Smith, Hughes and Mithen, which illustrates the potential of Darwinian concepts for testing and generating hypotheses about cultural transmission and change. Their focus is on the Lower and early-Middle Paleolithic, ca. 1.8 to 0.5 million years ago, and the analysis attempts to clarify and explain the so-called Movius Line, named for archeologist Hallam Movius. Movius observed that the Acheulean stone tool tradition, which appeared in East Africa some 1.6 million years ago, seems never to have arrived in east Asia. Instead, an older pebble tool tradition similar to the African Oldowan seems to have persisted for hundreds of thousands of years. The Movius Line, which runs roughly southeast from the Black Sea to the Bay of Bengal, marks the eastern boundary of the Acheulean. The authors employ a mathematical simulation to investigate several proposed explanations: hominids dispersing to Asia left Africa before the Acheulean appeared; geographic or ecological barriers impeded cultural transmission; Asia lacked appropriate stone or offered an abundance of alternative tool materials (e.g. bamboo); or hominids simply forgot the techniques for making Acheulean tools.

Multiple runs of the simulation, with changes in environmental and cultural variables, provide persuasive support for the hypothesis that geographic and/or ecological barriers impeded the transmission of Acheulean technology from Africa to Asia and, to a somewhat lesser degree, from Africa into Europe. The simulations also predict that in India a pebble tool tradition should precede the late-arriving Acheulean, an eminently testable hypothesis. Thus, this kind of modeling is highly useful for both testing and generating hypotheses about the diffusion of hominid populations and technology across the Old World.

While the contributions to Pattern and Process in Cultural Evolution are interesting and sometimes provocative, the question remains: In what sense is cultural change "evolution?" Mesoudi and O'Brien (p. 21) assert that culture change arises from the same "underlying Darwinian processes" as biological evolution: "variation, differential selection, and the inheritance of selected variants." In biology, however, variants are selected on the basis of the fitness advantage (differential reproductive success) they confer on the individuals that possess them. While it may be possible to represent changing fashions in European knives and forks by a phylogenetic tree, it is not clear that either the implements or their inventors enjoyed any fitness advantage.

Furthermore, cultural evolution can be viewed as Lamarckian at least as much as Darwinian. That is, variants produced during the lifetime of an individual or an artifact (i.e. acquired characteristics) can be inherited. Indeed, guided or directed variation is crucial to any notion of human innovation or creativity. In making this point, Fitzhugh & Trusler (chapter 14, p. 205) complain that some evolutionary anthropologists "assume that the generation of novelty is undirected or effectively random—like genetic mutation," which would be a requirement under a strict Darwinian model.

Finally, not even the contributors to this volume agree on how literally to apply biological analogs to things cultural. One indicator is some authors' tendency to hedge their bets. Tehrani and Collard do so when they state that "these studies have sought to evaluate how well cultural patterns fit a branching, treelike model of evolution in which ancestral traditions split into new ones" (chapter 7, p. 99). Cochrane makes a similar point: "This framework [for archaeological studies] is based on generalizing evolutionary theory beyond its original biological purview, so that artifactual variation is *conceptually* similar to phenotypic variation and is a product of cultural transmission, distinct from biological transmission" (chapter 8, p. 113, original emphasis).

These caveats in no way diminish the usefulness of Pattern and Process in Cultural Evolution. The differing theoretical and methodological approaches showcased in the volume make it especially appropriate for undergraduate and graduate-level classes in anthropology, archaeology, human ecology and a variety of related disciplines. Outside of the classroom, the book will be of interest to anyone interested in human prehistory and the broader issues of social and technological change.

Reviewer: Richard G. Milo, Professor and Dean, The Honors College, Chicago State
University 60628

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Kennett, Douglas J., and Bruce Winterhalder (eds). 2006. Behavioral Ecology and the Transition to Agriculture. Berkeley, CA: University of California Press.

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BOOK REVIEW 2010 - #2

Gibson, David J. Grasses and Grassland Ecology. 2009. viii + 305 pages; tables; figures; colored photographic plates; references; plant index; animal index; subject index. Oxford University Press Inc., New York, New York. ISBN13: 978-019-852918-7 (hard cover) and ISBN13: 978-019-852919-4 (soft cover). Price: $140.00 and $70.00, respectively. Available from Oxford University Press, Inc., 198 Madison Avenue, New York, NY 10016.

This marvelous book is a comprehensive account of evolutionary biology of grasses, particularly in relation to modern systematics, and grassland ecology encompassing a global perspective with an emphasis on North American prairies. The chapters are expanded versions of lectures from a course the author developed and teaches at Southern Illinois University at Carbondale. Eloquently written in concise and clear language and style, a result of extensive personal knowledge and experience with the subject matter, Gibson offers the reader a remarkable balance between details of essential topics while limiting citations often to a single reference for each referenced material. Nevertheless, 44 pages of bibliography attest to the comprehensiveness of the review of applicable literature.

The introduction (Chp.1) provides an excellent review for any biologist working with, or interested in, grasslands including insightful information on a broad range of topics that are covered more thoroughly in subsequent chapters. Of particular interest is a short discussion of two prominent early ecologists, J. W. Bews of South Africa and J. E. Weaver. I had the privilege 30 years ago of taking grassland ecology from Gibson's predecessor, the late John Voigt, a student of J. E. Weaver. This book, with its historical perspective combined with modern synthesis of population, community, and ecosystem ecology and systematics, could not have been written as effectively three decades ago. Grasses and Grassland Ecology provides a timely and fitting treatment of grasslands with unparalleled detail, in a single volume, on the biology of grasses and grassland habitats.

The author takes a broad view of grasslands in an introductory summary of critically endangered ecoregions, including shrublands and savannas and such varied habitats as the *Protea* and *Erica*-dominated fynbos of the Cape Floristic Region of South Africa characterized not by grasses but by the related Restionaceae. Also included are Mediterranean woodlands and scrublands where grassy patches are characteristic. Ignoring these areas underestimates total world grassland area, while including them amplifies estimates. However, this broad perspective of grasslands was not always followed. For example, reported remaining grassland in Illinois included only estimates for high-quality prairie (0.01% of the extent present at the time of Euro-American settlement) without the inclusion of remaining savanna habitats.

In the chapter on Systematics and Evolution (Chp. 2), botanists who learned the former supra-generic tribal classifications of grasses based on morphological attributes will be interested in reading the revised approach, based on phylogenetic order, that recognizes 12 subfamilies. The subfamilies are described briefly and proposed phylogenetic relations of the 12 subfamilies and their precursor groups are graphically illustrated.

Chapter three presents an ecological perspective on grass morphology and anatomy beginning with growth and development. The detailed description of leaf, culm, and spikelet morphology provides insights helpful in understanding and interpreting ontogenetic development. Grass spikelets also are addressed with a phylogenetic view that puts into perspective structural specialization and reduction. The closing section of chapter two describes many of the distinctive anatomical features of grasses and provides helpful background information towards understanding grass physiology discussed in the following chapter.

Chapter four begins with a detailed introduction to C3 and C4 photosynthetic pathways and further characterizes the physiological ecology of the three types of C4 photosynthesis found among warm-season grasses. These basic physiological differences among grasses are put into a very useful ecological context providing a framework for understanding distribution patterns among genera and species. In addition, the author includes an outline of the trade-offs likely to occur in abiotic and biotic interactions, and clearly notes how predictions of responses for pools of grassland species to global climate change are a very complex challenge. A map (Fig. 4.3) illustrates projected changes in C4 grass abundance in South America, that correspond to a doubling of atmospheric CO_2 concentrations according to three general atmospheric circulation models. Unfortunately, the map is difficult to interpret because it relies on four fairly indistinct shades of grey.

The chapter on grass population ecology (Chp. 5) is highly recommended reading for biologists working in grasslands for its insightful discussion of pollen incompatibility and other issues related to breeding systems of grasses. The treatment of cleistogamous and combined cleistogomous and chasmogamous breeding systems among some grass species is particularly interesting. A mixed cleistogomous and chasmogamous breeding system is found with *Triplasis purpurea* (Purple Sandgrass), a species of limited distribution in Illinois to inland deep sand deposits. Knowledge of this mixed breeding system provides a renewed appreciation for selected reproductive strategies, particularly in the unpredictable and often harsh sand prairie environment. Perhaps other species in Illinois habitats demonstrate this type of ecological bet hedging, as described by the author, of producing some seeds in secured locations within the sheath for later dispersal upon senescence. Some grasses demonstrate an extreme form of cleistogamy with production of underground spikelets, a strategy that may allow for greater seed survival in fire-prone landscapes. The chapter section on seed bank ecology is particularly relevant to grassland restoration efforts, providing insights for planting designs and implementations based on relevant ecological principles.

The role of fungal pathogens in controlling community organization in grasslands is noted to be significant (Chp. 5), something I had not considered despite the well-known diseases of turf grasses. How these pathogens interact with fire effects in the community assemblage is an area of needed research. Chapter five concludes with an extended section characterizing aspects of the genetic structure of grasslands put into an ecological context. Recent investigations have found greater genetic diversity within populations of *Andropogon gerardii* (Big Bluestem), compared to diversity among different populations, bringing particular importance to protecting prairie remnants. In addition, high levels of ecotypic variation have been reported for grassland species. As noted in a memorable quote from McMillan (1959), "Through natural selection, each stand of true prairie may be fundamentally different from any other stand", placing due importance on the protection and conservation of each individual remnant. Furthermore, a summary of recent findings documenting the spatial patterns of genetic diversity, by noting the occurrence of high levels of local genetic variation, also provides key insights to the design of prairie plantings.

Chapters six through ten address grasslands primarily at the community and ecosystem levels of organization. Chapter six addresses the central principles of community ecology, including plant-environmental relations, succession, the array of species interactions including competition, allelopathy, parasitism, facilitation, and mutualisms; and these topics are presented with useful, relevant examples. The debates concerning the chief models of community assembly and structure (e.g., Clements' community-unit hypothesis and the continuum ideas that emerged from Gleason, and the subsequent mechanistic models presented by Tilman's resource ratio model and Grime's CSR model) receive fair and balanced treatment highlighting the insights and limitations of the competing theories. Chapter six concludes with a review of Hanski's core-satellite species hypothesis developed as an explanation of meta-population and meta-community patterns and Hubbell's unified neutral theory of biodiversity and biogeography. This chapter is essential reading, especially for graduate students in the plant sciences, because it provides an introduction to the central theories developed to explain biotic and abiotic interactions in natural communities.

Ecosystem-level processes related to grasslands are characterized in chapter seven. Here Gibson examines components of the major factors of productivity, nutrient cycling, and decomposition, including historic perspective as to the development and testing of ideas and the role of simulation modeling in gaining insights. The first third of chapter seven concisely summarizes the ample literature on interactions between productivity and resource gradients, and how these interact at the community level across a range of environmental conditions, grazing history, and fire frequency. The key questions of how species diversity is related to stability of grassland ecosystems is discussed under the heading: 'Productivity relationships with diversity, invasibility, and stability'.

The transfer and fluxes of nutrients among soil, plant, and animal components are characterized in a section of chapter seven on nutrient cycling leading to a concluding section on grassland soils. The key role of nitrogen among soil nutrients is made particularly clear. Fertilization experiments involving nitrogen additions consistently result in changes in grassland community structure and declines in species diversity. The alarming link between industrial sources of nitrogen in soils (exceeding inputs by natural sources of biological nitrogen fixation) and associated patterns of species losses in European grasslands begs for similar studies in Illinois grasslands.

The types of grasslands found worldwide are described in chapter eight. First with a general summary of vegetation classification systems at various spatial scales, from those with a local focus on species associations to ecoregional-scale classifications based more on physiognomy. Climate is a major factor in grassland development, and grasslands of the world are characterized based on six global climatic regions (for example, Moist subtropical mid-latitude climates [Pampas], Moist continental mid-latitude climates [incl. true prairie], and Highland climates [montane grasslands]). Regional classification systems are described including examples from the US National Classification System (Grossman et al., 1998). Examples of how grasslands are classified in Europe and China also are included. Plates 5-14 present colorful images of some of the types of grasslands found worldwide.

Disturbances have such a major role contributing to the persistence of grasslands and in patterns of composition and diversity that an entire chapter is devoted to the topic (Chp. 9). Many grasslands persist as a consequence of particular disturbances, and alterations to these disturbance regimes can lead to dramatic changes in grasslands, including conversion to other vegetation types (e.g., savanna, woodland). Gibson first meticulously characterizes the fundamentals of disturbance noting the conundrum when considering the case of grassland fires, because fires can be viewed both as a disturbance when present or absent (i.e., extended absence of fire can lead to equally dramatic changes compared with changes brought by occurrences of fire). There is an extensive literature on fire in grasslands and its effects on vegetation, particularly in tallgrass prairie, and the core portion of chapter nine is a thorough synthesis of this work, noting the dependence on fire for persistence and spread of grasslands worldwide. The conclusion that fire leads to a reduction in species diversity immediately following fire, found in studies in Kansas and elsewhere in the Great Plains, is presented as a general pattern. However, Gibson notes that for all reported fire effects on vegetation, there are counter examples. In Illinois, for instance, diversity has been shown to be greatest in frequently burned sand prairies compared to infrequently burned sites (Bowles et al., 2003). Furthermore, in a dry prairie-like woodland opening, species diversity spiked dramatically following fires but gradually declined between burns in years afterwards (Taft, 2003). Detailed assessments of long-term fire effects on diversity in species-rich mesic tallgrass prairie, however, are lacking in Illinois.

The influences of herbivory and drought on grasslands also receive ample consideration. The significant role of small mammals on community structure and dynamics is particularly interesting since the impacts are largely out of sight when compared to the effects of larger herbivores such as *Bison bison* (American bison) in portions of the original North American prairie. Speaking of hidden effects, the reduction by invertebrate herbivores of 5-15% of above-ground and 6-40% below-ground annual net primary production are particularly startling statistics showing the important role of these species in grassland ecosystems.

The book content on communities, ecosystems, and disturbance (Chp. 6, 7, and 9) is nicely integrated into a concluding chapter (Chp. 10) on grassland management and restoration practices where research and theories are put to the "acid test". Principles of range management applicable to both commercial and subsistence pastoralists are considered in the introductory section of the chapter followed by methods for assessing rangeland habitat condition. Grassland restoration is described for a wide range of methods from restoring degraded remnants, to the complete reconstruction of grassland communities on former grassland sites. The importance of using local ecotypes is stressed to improve successful grassland plantings.

The contrast in grassland management methods employed between those efforts coordinated by local land managers and citizen volunteers and approaches informed by the scientific method is nicely portrayed. Coincidentally, a similar topic is discussed by Anderson (2009) in a recent publication on the history of restoration ecology that focuses on tallgrass prairie. Anderson and Gibson use the Curtis Prairie at the University of Wisconsin at Madison as a vital case history given its notoriety as the oldest grassland restoration in the world begun in 1934 by Aldo Leopold and others.

One of the great values of the book is the many ways it serves students of grasses and grassland ecology by providing detailed accounts of the biology of grasses and grasslands. In addition, it should stimulate hypotheses for a myriad of ecological interactions at the population, species, and community levels of organization. I could not be more enthusiastic about this book and its valuable contents. It is well conceived with the organization following a logical transition from historical accounts, to taxonomic, systematic, anatomical, and genetic levels, followed by broader perspectives of communities and ecosystems. All materials are presented from a deeply insightful ecological perspective. It is a unique combination of relevant content, honed from years of lecturing on the topic and research experience. It is a vital, consolidated resource for the research ecologist, graduate students in plant biology, as well as the field biologist working particularly with natural grassland ecosystems and is a highly recommended text that should serve as a guide to grasses and grassland ecology for many years to come. Convenient indices for plant and animal species referenced in the text follow the bibliography.

Reviewer: John B. Taft, Illinois Natural History Survey, 1816 S. Oak Street, Champaign, IL 61820.

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2010 Annual Meeting Student Awards

AGRICULTURE DIVISION

1st Place Poster

Ramya Vittal
University of Illinois – Urbana-Champaign
Detection of mRNA by reverse transcription-PCR as an indicator of
specificity and viability in *Phakopsora pachyrhizi*

BOTANY DIVISION

1st Place Poster

Melissa Hall
Southern Illinois University – Edwardsville
Comparing edge and interior population contributions
to the seed rain of invasive bush honeysuckle
(*Lonicera maackii*, Caprifoliaceae)

2nd Place Poster (tie)

Tara Stapay
Southern Illinois University – Edwardsville
Examination of hybridization relationships between
Schoenoplectus hallii and *S. saximontanus* (Cyperaceae)
using ISSR markers

Gerald A. Pantoja
Millikin University
Comparison of control of two spotted spider mites,
Tetranychus urticae Koch (Arachnida: Acari: Tetranychidae),
in greenhouse grown *Glycine max* (soybeans) using
neem oil and predatory mites, *Phytoseiulus persimilis*

1st Place Presentation

Danielle M. Ruffatto
University of Illinois – Champaign-Urbana
Gender differences in the reproductive ecology of
Lobelia spicata L.(Campanulaceae), a gynodioecious prairie species

2nd Place Presentation

Jaclyn M. Smith
Illinois College
Floral fragrance composition of the ghost orchid,
Dendrophylax lindenii (Lindley) Bentham ex Rolfe (Orchidaceae)

CELL, MOLECULAR, AND DEVELOPMENTAL BIOLOGY DIVISION

1st Place Undergraduate Poster

Ishtiaq Habib
Benedictine University
Taurine supplemented diet confers life span extension in adult
Drosophilamelanogaster (Drosophilidae) and arrests development in eggs

1st Place Graduate Poster

Kate Springer
Southern Illinois University – Edwardsville
Three amino acid positions cooperatively determine
Schizophyllum commune(Aphyllophorales)
pheromones' specificity for Bα receptors

1st Place Undergraduate Presentation (tie)

Emily Settlemoir
Southern Illinois University – Edwardsville
Response to constitutive pheromone receptor activity
is observable following site-directed mutagenesis in
Schizophyllum commune (Aphyllophorales)

Beth Boudreau
Bradley University
Construction of a *tpsA* knockout strain of
Fusarium verticillioides (Hypocreales)

1st Place Graduate Presentation

Paul Orlando
University of Illinois – Chicago
Relating Dr. Jekyll and Mr. Hyde transmogrification and intraguild
predation to *Tetrahymena* (Tetrahymenidae)

CHEMISTRY DIVISION

1st Place Undergraduate Poster (tie)

Tiffany Boyle
Southern Illinois University – Edwardsville
Conformational states and kinetics of the
calcium binding domain of NADPH oxidase 5

Sarah Elkins
Southern Illinois University – Edwardsville
Characterizing sodium chloride crystallized in the presence
of sodium ferrocyanide with powder x-ray diffraction
and scanning electron microscopy

CHEMISTRY DIVISION – CONT'D

1st Place Graduate Poster

Seth Lamb
Western Illinois University
Development of a Disposable Pipette Extraction (DPX) Method
for the Trace Analysis of Common Propellant Powder Stabilizers
in Gunshot Residue

1st Place Undergraduate Presentation (tie)

Clayton Parks
Millikin University
Synthesis of 1,1-dimethoxybutan-2-one by ether extraction and a
Grignard reaction with dimethoxyacetaldehyde

Lauren Hollandsworth
Bradley University
Influence of aromatic substituents on the antibiotic activity of
5-aryl-4,4-dimethyl-3-oxo-delta-lactones against *Bacillus subtilis*

1st Place Graduate Presentation

Josiah Miller
Bradley University
Catalysis by metal colloids synthesized
within silane-containing polymers

ENGINEERING & TECHNOLOGY DIVISION

1st Place Presentation

Jesse James
Illinois College
Electronic speckle pattern interferometry:
image acquisition and data analysis

ENVIRONMENTAL SCIENCE DIVISION

1st Place Poster

Angela M. Bertucci
Chicago State University
Phytoplankton assessment of the Calumet and Little Calumet Rivers
with an emphasis on seasonal changes and nutrient relationships

1st Place Presentation

Jie Hong
Southern Illinois University – Edwardsville
Selenium Phytoremediation Management:
Development of Selenium-Biofortified Mushrooms from Plant Waste

HEALTH SCIENCES DIVISION

1st Place Poster

Sam Schwarm
Southern Illinois University – Edwardsville
Small molecule analogues of schizozygane indoline alkaloid
as potential antimicrobial agents

1st Place Presentation

Daniel P. Cassidy
Eastern Illinois University
Effects of varying caffeine doses on heart rate in neonatal rats

MICROBIOLOGY DIVISION

1st Place Poster

Mohammed A.W. Kahn
Eastern Illinois University
Utilization of bioelements and carbohydrates in an
acidophilic consortium comprising of suspected nitrogen fixer

1st Place Presentation

Oliwia W. Zurek
Knox College
Echinacea purpurea's immunomodulatory properties:
assessment of morphological changes, CB2 and iNOS expression
in macrophages treated with *Echinacea* simulated digestion

PHYSICS, MATHEMATICS, AND ASTRONOMY DIVISION

1st Place Presentation

Andrew Schenk
Millikin University
Computer Simulations of Solar System Formation

ZOOLOGY DIVISION

1st Place Poster

Stephanie Miller
Southern Illinois University – Edwardsville
Effects of shell orientation on drag experienced by *Elimia pototsiensis*

1st Place Presentation

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Impacts of prescribed burning on soil and litter invertebrate diversity
in a northeastern IL oak woodland

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Assessment of Illinois Corn Yields in a Unique Wet and Cool Growing Season

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ABSTRACT

The 2009 growing season in Illinois had exceptionally low temperatures and heavy rainfall, serving as the record wettest and coldest growing season. The weather during the growing season produced exceptionally high corn yields that were well above expectations. Crop experts, farmers, and outputs from crop-weather models failed to detect and predict the magnitude of the 2009 yields. The inability to predict the above average yield in 2009 likely resulted from knowledge that past comparably cold-wet seasons had produced relatively low yields. The different outcome in 2009 reflects on-going improvements in plant genetics making them less sensitive to weather stress, and also on improved farm practices that collectively produced a different yield outcome than those in similar growing seasons 10 to 50 years ago.

INTRODUCTION

Illinois crop yields in 2009 were near record highs and occurred in a year with highly unusual growing season weather. Most months from March through November had above average precipitation and below average temperatures. During the cool and wet growing season, agricultural experts predicted below average crop yields (FarmWeek, June 8a, and August 3b). The wet and cold spring greatly delayed planting of corn, usually detrimental yields. Past research has shown that wet-cold springs acted to decreased yields (Thompson, 1969). The wet and cold fall in 2009 delayed harvesting, a situation also considered detrimental to high corn yields (FarmWeek, September 21c and 28). Persistent wetness in past falls delayed harvesting and reduced yields (Garcia et al., 1990).

Another recent year also had unusual weather conditions and high corn yields in Illinois. In 2004 Illinois had an abnormally large number of sunny days with average temperatures and above normal rainfall and the corn yield was 180 bu/acre (Changnon and Changnon, 2005). One explanation for the unexpected outcome in 2004 was that improved crop genetics had resulted in higher corn yields than in prior years with similar stressful conditions.

The goal of this study of 2009 was to describes why near record corn yields came with weather conditions previously thought to be crop limiting. Assessment was based on comparison of yields in prior years with weather conditions similar to those in 2009.

INVESTIGATION

Examination of the past growing seasons weather conditions, dating back to 1940, revealed very few years with wet and cool conditions during most of the growing season. No past year exactly matched the conditions of 2009. The monthly departures from average for precipitation and for temperatures in 2009 are shown in Table 1. The 2009 growing season had precipitation that was 14.6 inches above average and a temperature that was 1.2 degrees below average, and together these are the greatest seasonal departures on record dating back to 1940.

Table 1. Departures from average of monthly temperatures and precipitation in Illinois for March-November 2009

Month	Precipitation, inches	Temperature, degrees f
March	+1.0	+2.1
April	+2.4	-0.9
May	+1.6	-0.5
June	+1.2	+0.8
July	+1.1	-5.3
August	+1.4	-2.9
September	0.8	-0.4
October	+6.0	-4.8
November	-0.7	+4.2

Examination of past climate data for Illinois for 1941-2009 found that four past years had growing season conditions similar to those in 2009. These years included 1945, 1970, 1974, and 1990. Their monthly values of temperatures and precipitation, expressed as being above average, near average, or below average, are shown in Table 2 along with the values for 2009.

Table 2. Departures from average of monthly precipitation and temperatures in Illinois for 2009 and four similar years (1).

	Mar		Apr		May		June		July		Aug		Sept		Oct		Nov	
Year	P	T	P	T	P	T	P	T	P	T	P	T	P	T	P	T	P	T
1945	A	A	A	B	A	B	A	B	B	B	A	B	A	B	N	B	B	N
1970	B	N	A	B	A	A	A	A	B	B	A	B	A	A	A	B	B	A
1974	A	A	A	A	A	B	A	A	B	A	A	B	B	B	B	B	A	N
1990	A	A	B	B	A	B	A	N	A	B	A	B	B	A	A	B	A	A
2009	A	A	A	B	A	B	A	A	A	B	A	B	B	N	A	B	B	A

(1) P=precipitation, T=temperature, A=above average, B=below average, N=average.

Comparison of the 1945 values (departures from average) with those in 2009 revealed similar precipitation values + or _ 0.5 inch) in 6 months (not July, September, and October) and similar temperatures (+ or - 1.0 degree) in 6 months. Comparison of the 1970 precipitation values with those in 2009 also reveled agreement in six months, and temperature values were alike in 6 months. The 1974 precipitation values matched those in 2009 in 6 months and temperature values also in 6 months. The precipitation values in 1990 matched those in 2009 in 7 months and temperature values agreed in 7 months. Thus, 1990 was slightly more like 2009 than the other three prior.

Figure 1 presents the annual corn yields for 1941 through 2009 in Illinois, and the corn yields expected under average weather conditions appear as a dashed line. Annual values above the average curve represent high yields resulting from highly favorable weather conditions, and values below the curve reflect relatively low yields from unfavorable weather conditions that lowered yields.

The five yield values for 2009 and the four similar seasons were compared with the expected average yield values, and the results are shown in Table 3. This reveals that 2009 had a corn yield (174 bu/acre) that was 5 bushels above that expected with average weather, a significant difference (Fig. 1). However, the yields in the four similar weather seasons were all below average expectations.

Crop yield-weather models developed during the 1950-1990 period (Odell, 1959, Thompson, 1969, Garcia et al., 1990) were used to test the 2009 weather conditions. All models showed a decrease in corn yields such as those shown in Table 3 for 1945, 1970, 1974, and 1990. These modeling results help indicate why agricultural experts were predicting low yields during 2009. The yield differences were all statistically significant.

Furthermore, field experiments with corn in central Illinois conducted during 1988-1994 involved applications of various increases in the natural rainfall by +10, +25, and +40 percent. These tests showed that the increases of 25 and 40 percent in growing season rainfall led to corn yield decreases in naturally wet seasons (Changnon and Hollinger, 2003).

Table 3. Comparison of corn yields obtained in the five wet and cool growing seasons with yields expected under average weather conditions.

Year	Yield, bu/acre	Average weather yield	Difference, average minus actual
1945	46	55	-9
1970	80	96	-16
1974	98	104	-6
1990	127	131	-4
2009	174	169	+5

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SUMMARY

The wet and cool weather during 2009 growing season in Illinois produced exceptionally high corn yields that were well above expectations. Crop experts, farmers, and outputs from crop-weather models failed to correctly predict the magnitude of the state's final yield.

The inability to predict the above average yield in 2009 likely resulted from awareness that past similar cold and wet seasons had resulted in relatively low corn yields. The unique 2009 outcome likely reflects on-going changes in plant genetics making them less sensitive to weather stress, and farm practices that collectively produce different outcomes in recent years from those in similar growing seasons 10 to 60 years ago (Changnon and Hollinger, 2003).

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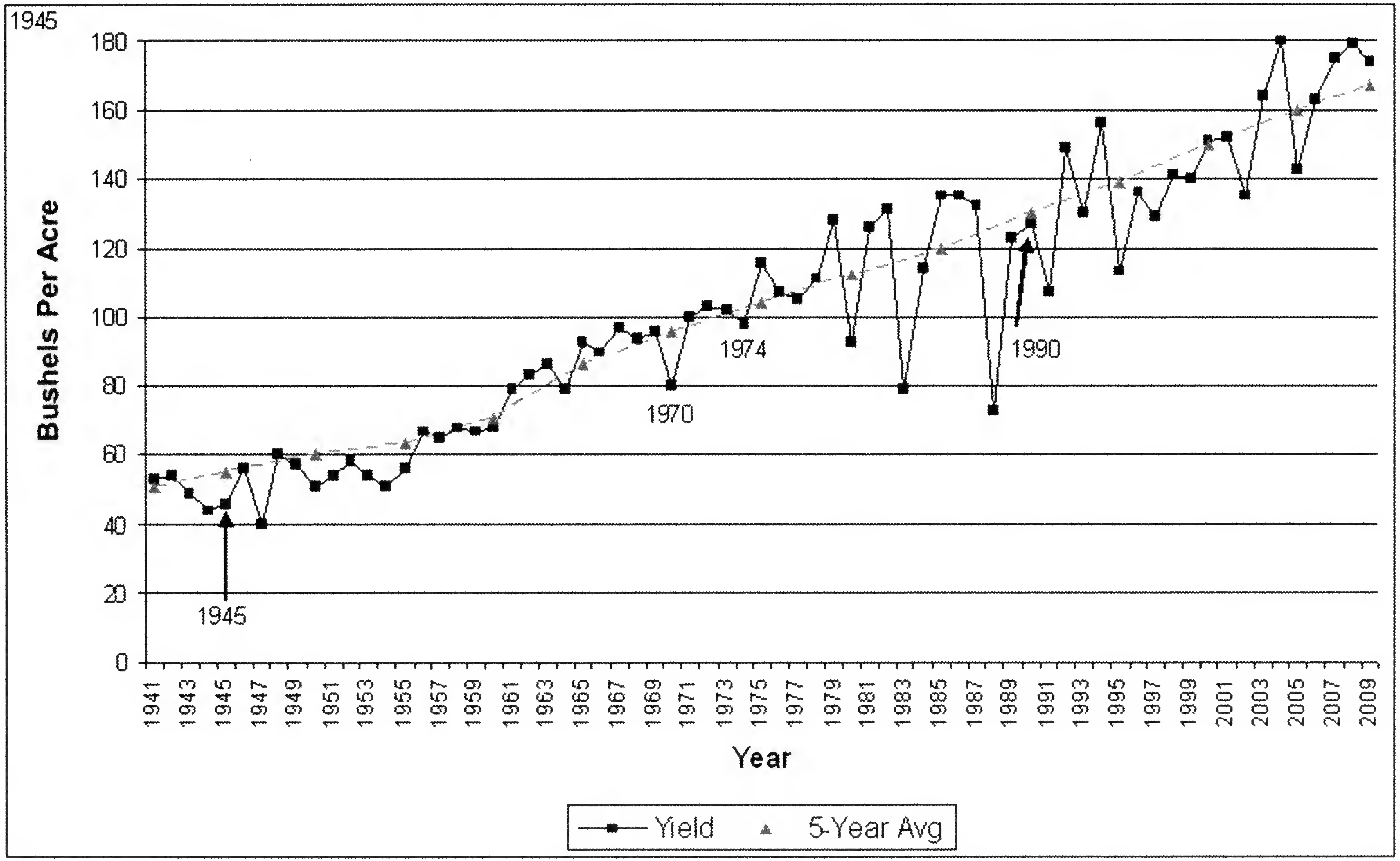
Figure 1. Annual corn yields in Illinois form 1941-2009, and average yields based on average growing season weather conditions.



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New and Noteworthy Sedge Records in Illinois

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ABSTRACT

Sedges (Cyperaceae) are a very diverse and significant group of plants in Illinois, as elsewhere, with approximately 250 species reported, approximately 150 of which are in the genus *Carex* (the most species-rich genus in Illinois). This study discusses 15 taxa in particular, three of which (*Carex cherokeensis*, *C. triangularis*, and *Lipocarpha aristulata*) are reported for the state of Illinois for the first time. Two additional taxa, *Carex aureolensis* and *C. oklahomensis*, were reported in 2002 for the first time in Illinois in the *Flora North America* based upon specimens cited here. The remaining sedges discussed here are examples of taxa whose nomenclature and ranges have been clarified recently (*C. corrugata*, *C. echinodes*, *C. opaca*, *C. stipata* var. *maxima*, *C. tonsa* var. *rugosperma*, and *C. tribuloides* var. *sangamonensis*) or that have new range extensions in the state (*Carex arkansana*, *C. socialis*, *C. texensis*, *Cyperus iria*). Each sedge is discussed in conjunction with significant collections. A summary of *Carex* species added to the Illinois flora since Mohlenbrock's 1986 *Guide to the vascular flora of Illinois* is presented.

Key words: sedges, *Carex*, *Lipocarpha*, additions to Illinois flora, new plant records

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INTRODUCTION

The sedge family, Cyperaceae, is well-known to be diverse in Illinois, particularly within the genus *Carex*. The number of known Illinois species has increased over the years as botanists have continued to study and sample the flora. Jones (1963) included 14 sedge genera [*Bulbostylis*, *Carex*, *Cladium*, *Cyperus*, *Dulichium*, *Eleocharis*, *Eriophorum*, *Fimbristylis*, *Fuirena*, *Hemicarpha*, *Lipocarpha*, *Rhynchospora*, *Scirpus*, *Scleria*] in the state with 196 species, 122 of which were in the genus *Carex* alone. Mohlenbrock (1986) included 13 sedge genera in the state (combining *Hemicarpha* with *Scirpus*) with 230 species, 141 of which were in *Carex*. His increase of 34 species included (among others) 3 additions in *Rhynchospora*, 4 in *Cyperus*, 7 in *Scirpus*, and 19 additions in *Carex* - mostly as a result of new finds, but also partly as a result of combinations and splits in some species by sedge experts. The most recent treatment of the Illinois flora by Mohlenbrock (2002) included an increase of sedge genera to 19 due to changes in nomenclature rather than to finds of new genera in the state. *Scirpus* was divided into six genera: *Bolboschoenus*, *Hemicarpha* [resurrected], *Isolepis*, *Schoenoplectus*, *Scirpus*, and *Trichophorum*, and *Cyperus* was divided into *Cyperus* and *Kyllinga*. This 2002 treatment of Illinois Cyperaceae included 251 species, 159 of which were in *Carex*. The increase in the number of reported *Carex* species can be explained by several nomenclatural changes as well as by new discoveries made since Mohlenbrock (1986). The new discoveries included, among others, *Carex arkansana* (L. H. Bailey) L. H. Bailey, *C. baileyi* Britt. (since discounted as occurring in Illinois, because the voucher was misidentified [Ebinger et al. 2010]), *C. canescens* L., *C. crawfordii* Fern., *C. formosa* Dewey, **C. hirta* L., **C. praticola* Rydb., and **C. spicata* Huds. (asterisks '*' indicate non-native species). Twelve of the new *Carex* records were discussed in detail by Swink and Wilhelm (1994). At least two of the other additions to *Carex* were based upon an examination of old records rather than the discovery of new sites, for example, *C. deweyana* Schwein. (not seen in Illinois since 1954 [Mohlenbrock 2002]) and *C. folliculata* L. (not seen in Illinois since 1926 [Swink and Wilhelm 1994; Mohlenbrock 2002]), and several other additions were the result of nomenclatural changes that split species, such as *C. longii* Mack. and *C. radiata* (Wahlenb.) Small. In the Illinois portion of the Chicago area, Swink and Wilhelm (1994) also included *C. annectens* Bickn., not included in the state by Mohlenbrock (2002), perhaps in error.

Volume 23 of the Flora of North America (FNA) was published in 2002, and this contained an account of the sedge family, Cyperaceae, for all of North America north of Mexico. From this work, taking into account synonyms and nomenclatural changes but excluding the accepted subspecific taxa, one can derive another list of the sedges known and reported to occur in Illinois, including 17 genera and 225 species, 138 of which were species of *Carex*.

Table 1 summarizes and compares the numbers of species and genera of Cyperaceae in Illinois as presented by the four major references cited above.

Table 1. Summary of the numbers of species of Cyperaceae in Illinois among four standard references.

Genus	Jones (1963)	Mohlenbrock (1986)	Mohlenbrock (2002)	FNA (2002)
Bolboschoenus	Merged with *Scirpus*	Merged with *Scirpus*	2	2
Bulbostylis	1	1	1	1
Carex	122	141	159	138
Cladium	1	1	1	1
Cyperus	18	22	22	18
Dulichium	1	1	1	1
Eleocharis	18	16	17	18
Eriophorum	2	5	5	4
Fimbristylis	3	4	4	4
Fuirena	1	1	1	0
Hemicarpha	2	Merged with *Scirpus*	2	Merged with *Lipocarpha*
Isolepis	Merged with *Scirpus*	Merged with *Scirpus*	1	1
Kyllinga	Merged with *Cyperus*	Merged with *Cyperus*	1	1
Lipocarpha	1	1	1	3
Rhynchospora	5	6	6	7
Schoenoplectus	Merged with *Scirpus*	Merged with *Scirpus*	12	11
Scirpus	18	25	9	9
Scleria	3	5	5	5
Trichophorum	Merged with *Scirpus*	Merged with *Scirpus*	2	1
TOTALS	196	230	251	225

MATERIALS AND METHODS

Since 1994, I have collected more than 950 numbered herbarium specimens of Cyperaceae in Illinois, and these collections serve as the primary source of data for this study. In addition, the herbarium of the Illinois Natural History Survey (ILLS) at the University of Illinois, Champaign, was also used as a source of data concerning relatively recent collections of the family by other botanists, and it is also the primary location where the Hill vouchers have been deposited. In addition, the herbaria of the University of Michigan (MICH), Missouri Botanical Garden (MO), and New York Botanical Garden (NY) were also checked for Illinois specimens of the sedges in question.

Another source of information has been the published literature on the sedges of Illinois, including Jones (1963), Mohlenbrock (1986, 2002), and the Flora of North America (FNA; 2002) mentioned in the introduction. Additional information has been obtained from sedge scholars and colleagues with whom I work, especially Dr. Anton A. Reznicek of the University of Michigan, Ann Arbor, with whom I collaborated throughout the period of this study. Additional botanists are cited in the Acknowledgements in this paper.

Throughout this paper, an asterisk (*) indicates a non-native species in Illinois.

DISCUSSION

CAREX

The FNA list is certainly incomplete, because twenty species of *Carex* known to be in Illinois (Mohlenbrock 1986, 2002) were not credited for the state in this work. These are *C. aurea* Nutt., *C. brunnescens* (Pers.) Poir., *C. caroliniana* Schwein., *C. crawfordii* Fern., *C. cryptolepis* Mack., *C. disperma* Dewey, *C. flaccosperma* Dewey, *C. folliculata* L., *C. garberi* Fern., **C. hirta* L., *C. limosa* L., *C. lucorum* Willd., *C. oligosperma* Michx., *C. plantaginea* Lam., *C. platyphylla* Carey, *C. striatula* Michx., *C. texensis* (Torr.) L. H. Bailey, *C. tuckermanii* Boott, *C. vesicaria* L., and *C. virescens* Muhl. These twenty sedges are generally quite rare in Illinois, they are represented by few Illinois collections, and some may no longer occur in the state, but they have been verified previously to occur here.

Conversely, six *Carex* species that were not mentioned by Mohlenbrock (1986, 2002) were included in Illinois by the FNA treatment (2002). These included *C. aureolensis* Steud., *C. houghtoniana* Torr. ex Dewey, *C. missouriensis* P. E. Rothrock & Reznicek, *C. oklahomensis* Mack., *C. opaca* (F. J. Herm.) P. E. Rothrock & Reznicek, and *C. tincta* (Fern.) Fern. Subsequently, *C. tincta* was deleted from the state flora as a result of the misidentification of the voucher (Rothrock, Reznicek and Hipp 2009). Two of these species, *C. missouriensis* and *C. opaca*, were first reported for the state by Rothrock and Reznicek (2001). Three of these, *C. aureolensis*, *C. oklahomensis*, and *C. opaca* are discussed in greater detail below.

A summary of the thirty *Carex* species additions made since the publication of *Guide to the vascular flora of Illinois* by Mohlenbrock (1986) is presented in Table 2. This includes two (*C. baileyi, C. tincta*) that have been discounted because of specimen misidentifications, resulting in a total 28 additional species reported in the state since the 1986 treatment. The table includes the new records discussed in this paper.

Table 2. Summary of *Carex* species additions to the flora of Illinois since Mohlenbrock (1986). Simple name changes without a change in species circumscription are not included, nor are subspecific taxa. * = non-native species; S&W 1994 = Swink & Wilhelm (1994); M 1986 = Mohlenbrock (1986); M 2002 = Mohlenbrock (2002); FNA 2002 = Flora North America vol. 23 (2002); H&E 2002 = Herkert and Ebinger (2002).

Taxon	References	Notes
Carex arkansana (L.H.Bailey) L.H.Bailey	M 2002; FNA 2002; H&E 2002; see this paper	Recent discovery 1992. Endangered in Illinois
Carex aureolensis Steudel	FNA 2002; see this paper	Name change; [segregated from *C. frankii*; both species currently recognized]
Carex baileyi Britt.	M 2002; Ebinger et al. (2010)	Recent discovery, but based upon misidentification; *species not present*
Carex brunnescens (Pers.) Poir.	S&W 1994; M 2002; H&E 2002	Recent discovery 1985. Endangered in Illinois
Carex canescens L.	S&W 1994; M 2002; FNA 2002; H&E 2002 [var. *disjuncta* Fern.]	Recent discovery 1988. Endangered in Illinois [var. *disjuncta* Fern.]
Carex cherokeensis Schweinitz	see this paper	Recent discovery 2000
Carex corrugata Fern.	M 2002; FNA 2002; see this paper	Recent discovery 1990
Carex crawfordii Fern.	M 2002; H&E 2002	Recent discovery 1991. Endangered in Illinois
Carex X *deamii* F.J. Herm.	Hess and Shildneck (1982); M 2002; FNA 2002	Recent discovery 1982
Carex deweyana Schwein.	S&W 1994; M 2002; FNA 2002	Old records – most recent 1954 Probably extirpated in Illinois
Carex echinata Murray	S&W 1994; M 2002; FNA 2002	Recent discovery 1988. Endangered in Illinois
Carex echinodes (Fern.) Rothrock, Reznicek & Hipp	S&W 1994; FNA 2002; see this paper	Name change [segregated from *C. tenera* Dewey – both species currently recognized]
Carex folliculata L.	S&W 1994; M 2002	Old records – most recent 1926. Probably extirpated in Illinois
Carex formosa Dewey	S&W 1994; M 2002; FNA 2002	Recent discovery 1985. Endangered in Illinois
**Carex hirta* L.	M 2002	Recent discovery 1991 [based on *Gardner 49* at ILLS]
Carex houghtoniana Torr. ex Dewey	FNA 2002	Recent discovery 1999; first report FNA 2002. Either native or introduced
Carex inops L. H. Bailey	M 2002 and H&E 2002 as *Carex heliophila* Mack.; FNA 2002 as *C. inops* subsp. *heliophila* (Mack.) Crins	Name change and recent discovery 1985. Endangered in Illinois [var. *heliophila*]
Carex longii Mack.	S&W 1994; M 2002; FNA 2002	Name change [segregated from *C. albolutescens* Schwein.– both species currently recognized]

Taxon	References	Notes
Carex lucorum Willd.	M 2002; H&E 2002; Ebinger et al. (2010)	Recent discovery 1981. Voucher misplaced, no extant locations known; report possibly in error
Carex mesochorea Mack.	S&W 1994; M 2002; FNA 2002	Apparently overlooked by M 1986 or included in *C. cephalophora* Muhl. ex Willd., ISM has collections from IL dated 1952
Carex missouriensis P.E.Rothrock & Reznicek	Rothrock and Reznicek (2001); FNA 2002	Recent discovery – new species
**Carex nebrascensis* Dewey	S&W 1994; M 2002; FNA 2002	Recent discovery ? apparently first reported by S&W 1994
Carex oklahomensis Mack.	FNA 2002; see this paper	Recent discovery 2002. Either native or introduced
Carex opaca (F.J.Herm.) P.E.Rothrock & Reznicek	Rothrock and Reznicek (2001); FNA 2002; see this paper	Name change; [segregated from *C. bicknellii* Britton, both species currently recognized]
**Carex praticola* Rydb.	S&W 1994; M 2002; FNA 2002	Recent discovery 1989 [?]
Carex radiata (Wahlenb.) Small	S&W 1994; M 2002; FNA 2002	Name change [incl. in *C. rosea* in M 1986; both currently recognized]
**Carex spicata* Huds.	S&W 1994; M 2002; FNA 2002	Recent discovery 1982
Carex tincta (Fern.) Fern.	FNA 2002; Rothrock, Reznicek and Hipp 2009	Recent discovery, but based upon misidentification; *species not present*
Carex triangularis Boeckler	see this paper	Recent discovery 2004
Carex willdenowii Schk. ex Willd.	M 2002; FNA 2002	Recent discovery 1984. Threatened in Illinois

Carex arkansana (L. H. Bailey) L. H. Bailey (Arkansas sedge)

Carex arkansana was first reported for Illinois by Mohlenbrock (1999) based upon its first finding in 1992 in Saline County by John Taft. This location was at the Illinois Natural Areas Inventory (INAI) Site Krigia Flats, INAI # 1457, north of US Rt. 45 and west of the Middle Fork of the Saline River, Harrisburg. Subsequently, additional sites have been found, one of which contained thousands of plants. This sedge is listed as Endangered in Illinois (Herkert and Ebinger 2002; Illinois Endangered Species Protection Board [IESPB]. 2009). **IL: SALINE CO.:** Harrisburg; south side of US Rt. 45, 0.1-0.4 mi W of Middle Fork of Saline River; Sons of Liberty Gun Club, 4 May 1995, *Hill 26445* (ILLS); Eldorado / Texas City, southwest side of US Rt. 45, southwest of original channel of the North Fork Saline River, from 37.88396 ° N. Lat., 088.38795 ° W.Long. south to edge of agricultural land at 37.88199 ° N. Lat., 088.38951 ° W.Long., 9 Jul 2008, *Hill 37790* (ILLS, MICH, MO, NY); Eldorado / Texas City, approximately 472 m north-northeast of intersection of US Route 45 and North Fork Saline River, southeast of US Route 45, 37.89179 ° N.Lat., 088.38183 ° W. Lat.; 37.89136° N. Lat., 088.38205° W. Long., 10 Jul 2008, *Hill 37818* (ILLS); Eldorado / Texas City, approximately 487.7 m north of Cottonwood Road, 7.6 m west of US Route 45, 37.883778 ° N.Lat., 088.388958 ° W.Long., 7 Aug 2008, *Hill 37868* (ILLS); Eldorado / Texas City, approximately 335 m north-northeast of intersection of US Route 45 and North Fork Saline River, 15 m southeast of US Route 45, 37.89127 ° N.Lat., 088.38222 ° W. Long., 5 May 2009, *Hill 38031* (ILLS, MICH, MO, NY).

***Carex aureolensis* Steudel (Goldenfruit sedge)**

Carex aureolensis was first reported for Illinois by Ford and Reznicek (2002). Formerly confused with *Carex frankii* Kunth, it is quite a distinct species that is colonial-rhizomatous and has significant structural differences in its scales, as well as being more southern in range. In October, 2001, at the suggestion of A.A.Reznicek, I went through all of the *C. frankii* specimens at ILLS and annotated those that were actually *C. aureolensis*, discovering that the species is actually widespread in southern Illinois. In 2008 P. Marcum and I presented a poster at the ISAS meetings summarizing the findings on this species, recognized in 11 Illinois counties at that time (Marcum and Hill 2008). Many specimens are at ILLS; a few representative collections are presented here, most originally identified as *Carex frankii*. **IL: ALEXANDER CO.:** north of Fayville, 30 Jun 1954, *Evers 44502* (ILLS); **GALLATIN CO.:** On summit of Gold Hill, south of New Shawneetown, 16 Oct 1956, *Evers 52746* (ILLS); **JACKSON CO.:** Shawnee National Forest, Oakwood Bottoms, Murphysboro Ranger District, Compartment 16, 24 Jun 1993, *Philippe & Gehlhausen 22262* (ILLS); **MASSAC CO.:** 2 miles southeast of Mermet, 30 Jun 1954, *Evers 44425* (ILLS); **PERRY CO.:** Southwest of Old Du Quoin, 5 miles east of U.S. 51, 30 May 1990, *Ulaszek 1464* (ILLS); **POPE CO.:** Pine Hollow, 2.5 miles east of Dixon Springs, 18 Aug 1931, *Schopf 1372* (ILLS); **SALINE CO.:** approximately 594 m north-northeast of intersection of US Route 45 and North Fork Saline River, 6.1 m southeast of US Route 45, 37.89289° N.Lat., 088.38031° W. Long., 7 Jul 2008, *Hill 37817* (ILLS); approximately 640 m north-northeast of intersection of US Route 45 and North Fork Saline River, 30.5 m southeast of US Route 45, 37.89294° N.Lat., 088.37992° W. Long., 10 Jul 2008, *Hill 37822* (ILLS); **UNION CO.:** 5 miles east of Dongola, 25 Aug 1960, *Evers 66961* (ILLS); **WILLIAMSON CO.:** Paineville, 0.8 mile east of Herrin, south side of East Herrin Road, north of Road 1450 North, 5 Jun 2002, *Hill 34684* (ILLS, MICH, MO, NY).

***Carex cherokeensis* Schweinitz (Cherokee sedge)**

This is the first report of *Carex cherokeensis* for Illinois. I discovered this on 3 May 2000 at the south end of Tamms, along the west side of IL Rt. 127 just west of the original Cache River channel in a long low-lying area between the highway and crop fields. A second population was found in 2003 in Union County by David Ketzner and Dennis Keene. **IL: ALEXANDER CO.:** south end of Tamms, west side IL Rt. 127, 37 ° 14 ' 06 " N; 89 ° 16 ' 12 " W., 3 May 2000, *Hill 32294* (ILLS, MICH, NY); same location, 6 Jun 2002, *Hill 34719* (ILLS, MICH); **UNION CO.:** south of Ware at Union County State Conservation Area, east of State Route 3, north of Refuge Road along Line C Ditch, 37° 24’ 37” N., 089° 23’ 15” W., 23 Jul 2003, *Ketzner & Keene 3301* (ILLS).

***Carex corrugata* Fern. (Corrugated sedge)**

Carex corrugata has apparently been known in Illinois previously as *Carex amphibola* Steud. var. *globosa* L. H. Bailey (Mohlenbrock 2002) but it has been overlooked in most treatments of the Illinois flora. It is actually not uncommon in floodplain forests in southern Illinois, and it was included in the state by Naczi and Bryson (2002). It is especially common in the southern states (Bryson, pers. comm.). As far as can be determined, it was first reported for Illinois by R. Naczi in his Ph.D. dissertation (Naczi 1992), and was collected by him in Illinois in 1990 (Naczi, pers. comm.), though it was collected previously by other collectors but not recognized as this species. Representative collections include:

IL: JACKSON CO.: Just east of landfill, west of Crab Orchard Creek, 3 May 1991, *Taft 836* (ILLS); Murphysboro, CH 5 (20th Street) bridge over the Big Muddy River, 19 May 1998, *Hill 30257* (ILLS, MO, NY); **PULASKI CO.:** 2.1 miles southwest of Olmsted along east side of Rt. 37, 26 May 1990, *Naczi 2492* (MICH); **UNION CO.:** Ware (south), Illinois Rt. 3 east side, 3.15 mile south of Illinois Route 146, Mississippi River floodplain, 37° 24.149' N., 89° 23.328' W., 16 May 2001, *Hill 33800A* (ILLS, MICH); Ware (south), Illinois Rt. 3 east side, north side of bridge over Running Lake Ditch, 1.95 miles south of Illinois Rt. 146, Mississippi River floodplain, 22 May 2001, *Hill 33815* (ILLS); **WABASH CO.:** Ridgeway Trail (west side, and east side of Coffee Creek) Beall Woods State Park, on Illinois Rt. 1 east of Keensburg, 6 miles south of Mount Carmel, banks of the Wabash River, 20 May 2004, *Hill 35881* (ILLS).

***Carex echinodes* (Fern.) Rothrock, Reznicek & Hipp [= *Carex tenera* Dewey var. *echinodes* (Fern.) Wiegand] (Spiny sedge)**
Carex tenera, the Remote sedge, is rather common in Illinois, but it appears that the first reports of var. *echinodes* (known first as *C. straminea* Willd. ex Schkuhr var. *echinodes* Fern.) were published by Swink and Wilhelm (1994) and later by Mastrogiuseppe et al. (2002). Recently the variety has been raised to the species level, as *Carex echinodes* (Fern.) Rothrock, Reznicek & Hipp (Rothrock, Reznicek and Hipp 2009). It differs from the typical variety by its smooth leaf sheaths and its larger perigynia with more tapering, elongate, spreading ('spiny') beaks. Only three Illinois specimens identified as this variety are in the ILLS herbarium. **IL: COOK CO.:** Palos Hills, east side US Rt. 45 (96th Ave), Crooked Creek Woods, 11 Jun 1997, *Hill 29302* (ILLS, MICH, NY); Palos Hills, southwest corner of Belly Deep Slough, US Rt. 45 (96th Ave), west side of road, 11 Jun 1997, *Hill 29322* (ILLS, MICH); **CARROLL CO.:** Savanna Army Depot, Blackhawk 7.5 minute quadrangle, bottomland woods at base of fill for railroad tracks, 16 Jul 1996, *Philippe 27806* (ILLS).

***Carex oklahomensis* Mack. (Oklahoma sedge)**
Carex oklahomensis was first reported for Illinois by Standley (2002) based upon my collection made that same year. Known initially from only a single site bordering a southern flatwoods in Williamson County, it has since been found to occur in Saline County as well. All known populations are likely to be extirpated by highway construction or expansion. This species may either be native in Illinois or it may be increasing its range eastward from adjacent states bordering on the west. **IL: SALINE CO.:** Eldorado, opposite junction Gandertown Road and US Rt. 45, approximately 6.1 m west of US Rt. 45, 2 Jun 2009, *Hill 38086* (ILLS, MICH); Eldorado, approximately 207.3 m north-northeast of junction Carter Farm Road and US Rt. 45, 6.1 m west of US Rt. 45, 2 Jun 2009, *Hill 38100* (ILLS, MICH,); **WILLIAMSON CO.:** west of Burlington Northern railroad, 0.5 mile east of Herrin, Paineville, North right-of-way of East Herrin Road, 15 May 2002, *Hill 34611* (ILLS, MICH, NY); same location,11 Jul 2002, *Hill 34855* (ILLS, MICH); same location, 11 Jul 2008, *Hill 37829* (ILLS, MICH).

***Carex opaca* (F. J. Herm.) P. Rothrock & Reznicek (Darkened sedge)**
Carex opaca was raised to species rank and reported for Illinois in 2001 (Rothrock and Reznicek 2001). The species was previously known as *Carex bicknellii* Britton var. *opaca* F. J. Herm. but it was usually found in herbaria as just *C. bicknellii*. Known only in six states (Arkansas, Illinois, Kansas, Mississippi, Missouri, Oklahoma), it grows in wet,

poorly drained open sites. Few specimens have been collected in Illinois, and my collection was a new county record. ILLS specimens are included here. **IL: SAINT CLAIR CO.:** east of Fayetteville, 6 Jun 1962, *Evers 73553* (ILLS); same location, 30 May 1974, *Evers 113139* (ILLS); **SALINE CO.:** Harrisburg; 0.2 mile north of US Rt. 45, 0.3 mile southwest of Middle Fork of the Saline River, just south of Krigia Flats Natural Area, 30 May 2000, *Hill 32379* (ILLS, MICH); **WASHINGTON CO.:** at Venedy Station, along railroad, 20 Jun 1952, *Evers 33943* (ILLS); same location - south side of Highway 177, between Highway and railway tracks, at Venedy Station, about 0.25 mile east of road to Venedy, 9 Jun 1999, *Reznicek & Reznicek 10856* (ILLS, MICH).

***Carex socialis* Mohlenbrock & Schwegman (Social sedge)**

Carex socialis is not new to Illinois, and, in fact, it was described from a collection near the Ohio River in southern Illinois (Mohlenbrock and Schwegman 1969; Hill 2006). The most recent treatment (Ball 2002) indicated that this sedge occurs in thirteen states, namely, Alabama, Arkansas, Georgia, Illinois, Indiana, Kentucky, Mississippi, Missouri, North Carolina, Oklahoma, South Carolina, Tennessee, and Texas. As with most other species, it becomes scarce at the margins of its range. Searches in Illinois continue to reveal additional populations. *Carex socialis* has been reported to occur historically in Jackson, Johnson, Massac, Pulaski, and Union counties (Mohlenbrock 1986, 2002, Mohlenbrock and Ladd 1978), and to this list can now be added Alexander, Gallatin, Saline, and Wabash Counties (specimens in the ILLS herbarium) for a total of nine counties. Surveys for it in 2008-2009 showed it to be quite common in some places especially in Saline County. Several noteworthy recent collections not presented in Hill (2006) are provided here. **IL: SALINE CO.:** Eldorado, approximately 100.6 m southwest of Garner Road, 18.3 m west of US Rt. 45, 37.86547° N, 088.40117° W., 10 Jul 2008, *Hill 37826* (ILLS, MICH, MO, NY); same location, 2 Jun 2009, *Hill 38112* (ILLS, MICH); Eldorado / Texas City, approximately 792.5 m north of Cottonwood Road, 24.4 m northwest of US Route 45, 37.88656° N.Lat., 088.38731° W., 7 Aug 2008, *Hill 37871* (ILLS, MICH); Eldorado / Texas City, approximately 731.5 m north of Cottonwood Road, 29 m southeast of US Route 45, 37.88427° N.Lat., 088.38722° W., 5 May 2009, *Hill 38047* (ILLS, MICH, MO, NY), **WABASH CO.:** Ridgeway Trail (west side, and east side of Coffee Creek) Beall Woods State Park, on Illinois Rt. 1 east of Keensburg, 6 miles south of Mount Carmel, banks of the Wabash River, 20 May 2004, *Hill 35879* (ILLS, MICH).

***Carex stipata* Muhl. ex Willd. var. *maxima* Chapman ex Boott (Great stipate sedge)**

While *C. stipata* var. *stipata* is common and well-known in Illinois, var. *maxima* is not. Included in the Illinois flora by Mohlenbrock (1986), it was not included in his next treatment of the flora (Mohlenbrock 2002) nor for Illinois by Standley (2002). It is distinguished from the typical variety by its larger size, longer perigynia, and longer beaks, as well as by its more southeastern distribution (Standley 2002). This record serves to confirm its presence in the state. **IL: WILLIAMSON CO.:** North side of Imhoff Lane, north of East Herrin Road, 0.35-0.5 miles west of Johnston City, 0.1-0.3 mile west of Interstate Rt. 57, 37° 49' 00" N., 088° 57' 30" W., 4 Jun 2002, *Hill 34663* (ILLS, MICH, NY).

Carex texensis **(Torr.) L. H. Bailey (Texas sedge)**
There are nine collections of this species from six Illinois locations in the ILLS herbarium. Concerning this species, Mohlenbrock (1986) stated: "occasional in the s. ½ of Ill." and Mohlenbrock (2002) stated: "rare and scattered in Ill.; apparently absent from the n. 1/3 of the state". Swink and Wilhelm (1994), while indicating its absence in the Illinois portion of the Chicago area, suspected that this species (in Indiana) was introduced from farther south. Ball (2002) did not indicate its occurrence in Illinois, but he remarked that it is often mistaken for *C. retroflexa* Muhl. ex Willd. and vice versa. The Illinois records suggest that it is, indeed, in the state and that it is widely distributed. It may or may not be native here, however. **IL: JACKSON CO.:** Mesic woodland behind the Carbondale Annex, below Carbondale Reservoir and the prairie restoration site, 7 Jun 1992, *Basinger 3776* (ILLS); Along a paved trail around Thompson Lake on the campus of Southern Illinois University at Carbondale, 7 May 1993, *Basinger 4994* (ILLS); same location, 18 May 1993, *Basinger 5142* (ILLS); **OGLE CO.:** Oregon, west side of Illinois Rt. 2 in vicinity of pasture road west of large stone gate, 0.5 mile north of Mud Creek Road, 17 May 2005, *Hill 36252* (ILLS, MICH); **PEORIA CO.:** Peoria, Springdale Cemetery, 30 Jun 1950, *Chase 11181* (ILLS); same location, 18 May 1962, *Chase 16942* (ILLS); **SHELBY CO.:** IDOT U.S. Route 51 Project Area, 39.31076° N., 089.08163° W., 3 Jun 2008, *Murphy 2697* (ILLS); **WILLIAMSON CO.:** Crab Orchard National Wildlife Refuge, T. 10S, R. 1E, SW1/4 NW1/4 Sect. 34, 8 May 1983, *Ulaszek 157* (ILLS); same location, 10 Jun 1983, *Ulaszek 242* (ILLS).

Carex tonsa **(Fern.) E. P. Bicknell var.** ***rugosperma*** **(Mack.) Crins (Roughseed sedge)**
Carex tonsa was included in Illinois by Mohlenbrock (1986, 2002) without the var. *rugosperma*. Swink and Wilhelm (1994) discussed some of the problems in nomenclature in the species as well as in the similar *C. umbellata* Schkuhr ex Willd. Crins and Rettig (2002) accepted the var. *rugosperma* as distinct and included it within Illinois. While this group appears to have some taxonomic and nomenclatural difficulties, it may be useful to present the ILLS data on its distribution in the state based on several confirmed specimens. **IL: CASS CO.:** Beardstown; east side of U.S. Rt. 67, about 3 miles south of Beardstown, residential area, 14 Jul 2006, *Hill 36986* (ILLS, NY); **LAKE CO.:** Cove Hollow, west of Cedar Lake, T. 10S, R. 2W, NE1/4 SW1/4 Sect. 23, 10 May 1988, *Philippe 13119* (ILLS); **LA SALLE CO.:** Starved Rock State Park, west side of La Salle Canyon, on narrow peninsula between that and Tonti Canyon, north of Illinois Rt. 71, south side of Illinois River, 41.3117° N., 88.9713° W., 23 Jul 2003, *Hill 35346* (ILLS, MICH); **MASON CO.:** Sand Ridge State Forest, 40.39268° N., 89.88023° W., 10 May 2004, *Busemeyer et al. 1677* (ILLS); **POPE CO.:** Lusk Creek, south of Little Bear Branch and north of Bear Branch, 23 May 1988, *Philippe 13209* (ILLS).

Carex triangularis **Boeckeler (Triangular sedge)**
This is the first report for *Carex triangularis* in Illinois. The species has a limited distribution in only nine states (Arkansas, Kansas, Louisiana, Mississippi, Missouri, Oklahoma, Tennessee, Texas and now Illinois). According to Standley (2002), the red-dotted perigynia of this species separates it from the other similar taxa in its section, including *C. annectens* (Bickn.) Bickn. and *C. vulpinoidea* Michx. It is probably more widely distributed than this single record suggests due to misidentifications. **IL: MASSAC CO.:** just west of boundary of Sielbeck Woods State Natural Area, Ohio River

Floodplain, vicinity of Upper Salem Road, about 2 miles northwest of Metropolis, 27 May 2004, *Hill 35885A* (ILLS, MICH, NY).

***Carex tribuloides* Wahlen. var. *sangamonensis* Clokey (Blunt broom sedge)**
Carex tribuloides is a very common species in Illinois, but the variety *sangamonensis* is often overlooked or ignored and was not included in Mohlenbrock (1986, 2002). It is of interest in Illinois partly because its type was collected in Macon County in low-lying areas along the Sangamon River, though it is primarily a southern plant extending south to the Gulf Coast. This variety has been accepted as distinct by Mastrogiuseppe et al. (2002) and occurs (as expected) in Illinois. It differs from the typical variety by its perigynia that are 2.2 – 2.8 (– 3) times as long as wide, those of the typical variety being 3 – 5 times as long as wide. Only two collections are in ILLS under this name. **IL: ALEXANDER CO.:** Illinois Rt. 3, McClure, west side, between highway and agricultural land, opposite VFW post at slough, 12 Jun 2001, *Hill 33860* (ILLS, MICH); **UNION CO.**, Bordering Wolf Lake, north of town of Wolf Lake, 25 Jun 1954, *Buser 5082* (ILLS).

CYPERUS

One range extension.

***Cyperus iria* L. (Rice-field Flatsedge)**
Cyperus iria has been known in Illinois for some time (Mohlenbrock 1986, 2002) as an adventive sedge of meadows and rice fields. It was first reported in Alexander County (Mohlenbrock 1986) then in Alexander and Pulaski cos. (Mohlenbrock 2002). This species appears to be spreading as a weed in the state as rice growing expands as well as in wet landscape plantings, and new records are here reported for Coles and Union counties. **IL: COLES CO.**: Ashmore: Lincoln Springs Resort on north side of Route 16, just east of Embarras River, weed in landscape planting, 30 Aug 2007, *Tucker 15115* (EIU, ILLS); **UNION CO.:** IL Rt. 3, Ware (south), west side, 0.35 mile north of Refuge Drive, rice growing area, Mississippi River floodplain, 26 Oct 2001, *Hill 34412* (ILLS, MICH).

LIPOCARPHA

One addition to the flora of Illinois.

***Lipocarpha aristulata* (Coville) G. Tucker (Awned Lipocarpha)**
Lipocarpha aristulata is here reported in Illinois for the first time. I found it in Illinois in June 2002 in Williamson County during a botanical survey. It has been reported from Missouri and states farther west (Tucker 2002) and its habitat in Illinois, in potholes on disturbed periodically wet cinders and sand along a dismantled railroad parallel to a highway, strongly suggests that this is not native to Illinois. This annual sedge is very small and inconspicuous (2 – 12 cm tall) but individuals can be locally numerous. It can easily be mistaken for the much more common *Lipocarpha micrantha* (Vahl) G. Tucker, from which it differs by a relatively well-developed inner (second) scale that is 0.5 – 0.8 mm in contrast to the lack of a scale or presence of one only 0.1 – 0.2 mm in *L. micrantha*. So far it has been found only at the single site: **IL: WILLIAMSON CO.:** Along abandoned railroad grade (and powerline right-of-way), south side of East Herrin Road at eastern

corporate limits of Herrin, 5 Jun 2002, *Hill 34671* ILLS, MICH, MO, NY); same location, 11 Jul 2008, *Hill 37830* (ILLS, MICH, MO).

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Observations of Hall's Bulrush (*Schoenoplectus hallii*) (Cyperaceae) in Mason County Illinois in 2009

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ABSTRACT

Historical locations of *Schoenoplectus hallii* in Mason County, Illinois were visited in 2009 and compared to trips made in previous years. Searches for the species were conducted at potential new sites with suitable habitat. Of the 24 sites visited, Hall's bulrush was documented at 10 sites. Population estimates ranged from a few juvenile plants to sites that contained tens and hundreds of thousands of individuals. Associated species were similar to those recorded in previous studies. Presence of Hall's bulrush in Mason County is dependent upon water levels on the nearby Illinois River and the rise of groundwater to the surface. During years when water levels on the Illinois River are above flood stage due to precipitation amounts in excess of monthly and annual averages, habitat may persist at some sites for 1-2 years following high total rainfall events. Sites at Sand Lake are somewhat anomalous in that ground water reserves in the area are so large that *S. hallii* may be present during years when precipitation and water levels on the Illinois River are at or well below monthly and yearly averages. During years when precipitation and water levels on the Illinois River exceed monthly and yearly averages, Hall's bulrush may be absent in the Sand Lake area due to flooded conditions. We recommend continued monitoring of Hall's bulrush sites in Mason County and other localities in Illinois using GPS equipment and advocate the development of a standardization protocol for obtaining population estimates of the species.

INTRODUCTION

Schoenoplectus hallii (A. Gray) S.G. Smith (Hall's bulrush) is a rare annual/short-lived perennial sedge that is a widely scattered obligate wetland species that currently occurs in a wide variety of habitats across nine states in the Midwest and central Plains (McKenzie et al. 2007). Due to its rarity, scattered distribution, and numerous threats, *S. hallii* is a species of conservation concern (Beatty et al. 2004) and has been considered as a possible candidate for listing under the Endangered Species Act (McKenzie et al. 2007). Detailed information on the species' status, historical and current distribution, life history requirements, threats to its habitat, status in each state where it occurs, suggested management actions, and research needs is provided in Beatty et al. (2004) and McKenzie et al. (2007). Hall's bulrush is associated with habitats that have fluctuating water levels (Robertson et al. 1994, McClain et al. 1997, McKenzie 1998, Beatty et al. 2004, Smith and Houpis 2004, McKenzie et al. 2007). The species benefits from an extensive and persistent seed bank that likely contributes to its potential for population regeneration (Smith et al. 2006).

Although more sites have been documented for the species in Illinois than in any other state (McKenzie et al. 2007), it is listed as threatened by the Illinois Endangered Species Protection Board (2009). The largest number of populations of Hall's bulrush in Illinois occurs in Cass and Mason counties (Robertson et al. 1994). Numerous collections of *S. hallii* have been taken from these counties since 1957 and 1958 when R. Rexroat and G. Winterringer recorded the species southeast of Beardstown (Mohlenbrock 1976, Robertson et al. 1994). The species was noted in abundance at a site in western Cass County by J. Schwegman in 1975 (Schwegmann 1984) and P. Shildneck collected the species in Mason County in 1985 (Robertson et al. 1994). Following the large flood event in Illinois in 1993, K. Robertson, L. Phillippe and S. Gehlhausen discovered numerous populations of Hall's bulrush in Cass and Mason counties (Robertson et al. 1994). In 1994 and 1995, W. McClain, R. McClain and J. Ebinger conducted a survey of the flora of temporary sand ponds in Cass and Mason counties and commented on the occurrence of Hall's bulrush at selected sampling sites (McClain et al. 1997). Additionally, P. McKenzie, J. Schwegmann, J. Ebinger, W. McClain, and G. Bade noted large populations of the species in 1995 in Mason County at some of the same sites surveyed by McClain et al. (1997) (McKenzie 1998). M. Smith recorded observations on *S. hallii* in Mason County in 2000 while conducting a study on achene morphology for the species (Smith et al. 2006).

DESCRIPTION OF THE STUDY AREA

Mason County is situated within a region of Illinois characterized by extensive and deep sand deposits and large underground aquifers. It is bounded on the west by the Illinois River and on the south by the Sangamon River, both of which may have a major impact on the groundwater levels in the southwestern portion of the county. The geography, topography, climate, and relationship between the geology and the underlying water table of the region have been well summarized by Walker et al. (1965), Sanderson and Buck (1995), McClain et al. (1997), and Hlinka et al. (1999).

MATERIALS AND METHODS

On 23-24 September 2009, the authors visited 24 sites in Mason County where *S. hallii* had been previously reported or areas where wet, sandy soil suggested that habitat conditions were suitable for germination and growth. This followed the fourth highest year for precipitation in Illinois (Illinois State Climatologist Office 2010; http://www.isws.illinois.edu/atmos/statecli/).

The purposes of our visit were to: 1) provide additional observations on *S. hallii* populations in Mason County, 2) compare these findings with previous surveys, 3) collect fresh plant tissue for an ongoing genetic study on *S. hallii, S. saximontanus* (Fernald) J. Raynal and potential hybrids between the two taxa currently being conducted at Southern Illinois University in Edwardsville, 4) collect achenes, if available, for permanent cold storage, 5) identify any potential new threats to the species, 6) outline recommendations for additional research, and 7) suggest management recommendations that may ensure the persistence of this species in Illinois.

Site information shown in Table 1 was compiled using the following method: Location of population sites recorded in 2009 using a GPS system, and those reported in Element Occurrence Records (EORs) maintained by the Illinois Natural History Survey (INHS), were marked on a map of Mason County using Google Earth version 5.1.3 (Google.com 2010) by entering longitude/latitude coordinates. When other sites (e.g., those reported in Robertson et al. 1994) were reported using directions based on locations along state or county roads, these sites were correlated to the 2009 data using the measuring tool in Google Earth.

To form a basis for comparison of our observations with historical records, we collected data from all available resources (publications and EORs) and recorded them in Table 1. Years for which data were available about *S. hallii* population sites and sizes were compared with respect to precipitation at the Havana, IL station (http://www.ncdc.noaa.gov /oa/ncdc.html) and flood stage data from the US Army Corps of Engineers gauge station at River Mile 119.6, which is 100ft downstream from the bridge at Highway 136 [(http://www2.mvr.usace.army.mil/WaterControl/stationinfo2.cfm?sid=HAVI2&fid=HAVI2&dt=S) (Fig. 1A & B)].

Plant tissue for genetic analyses was taken from 20 separate plants per site and placed in small collection bags with silica gel. Voucher specimens were collected by McKenzie and will be housed at the Missouri Botanical Garden (MO) (P.M.McKenzie #s **2416-2424**). GPS readings were taken at each collection site (NAD 83). A rough population estimate was taken at each locality and main plant associates recorded. Achenes were collected by T. Kelley on 7 October 2009 and donated to the Center for Plant Conservation at MOBOT, St. Louis, Missouri for permanent cold storage. Botanical nomenclature follows Yatskievych (1999) or Yatskievych & Turner (1990).

RESULTS AND DISCUSSION

Schoenoplectus hallii was observed at 10 sites in Mason County including localities where the species had been historically recorded [e.g., previous collections by Schwegman in 1974, (Schwegman 1984), McClain et al. in 1994 and 1995 (McClain et al. 1997), McKenzie et al. in 1995 (McKenzie 1998, McKenzie et al. 2007), Smith et al. in 2000 (Smith et al. 2006) and various others as reported in EORs 1, 3, 9, & 16-21; Table 1], but the species was conspicuously absent at others. We surveyed all 11 sites from which collections were made by Phillippe and Gehlhausen in 1993 (Robertson et al. 1994). Of these, only five had plants in 2009, and two of the sites reported to have *S. hallii* in 1994 and 1995 (McClain et al. 1997) had none in 2009. Populations at positive sites ranged from a few immature individuals to hundreds of thousands of mature plants that formed large colonies and covered several acres.

Plant associates recorded at *S. hallii* sites were similar to those recorded by Robertson et al. (1994) and McClain et al. (1997) and included *Alisma subcordatum* Raf., *Ammannia coccinea* Rottb., *Bacopa rotundifolia* (Michx.) Wettst., *Bidens cernua* L., *C. acuminatus*

Torr. & Hook., *C. erythrorhizos* Muhl., *C. esculentus* L., *Cyperus odoratus* L., *C. strigosus* L., *Eleocharis ovata* (Roth) Roem. & Schult., *Digitaria sanguinalis* (L.), Scop., *Echinochloa crusgalli* (L.) P. Beauv., *E. muricata* (P. Beauv.) Fernald, *Gnaphalium obtusifolium* L., *Heteranthera limosa* (Sw.) Willd., *Juncus brachycparus* Engelm., *Leersia oryzoides* (L.) Sw., *Lindernia dubia* (L.) Pennell, *Lipocarpha micrantha* (Vahl) G.C. Tucker, *Mollugo verticillata* L., *Panicum capillare* L., *P. dichotomiflorum* L., *Polygonum amphibium* L., *P. lapathifolium* L., *P. pensylvanicum* L., *Rotala ramosior* (L.), Koehne, *Rorippa* sp., *Schoenoplectus mucronatus* (L.) Palla, *S. tabernaemontani* (C.C. Gmel.) Palla, *Setaria faberi* R.A.W.. Herrm., *Typha latifolia* L., and *Xanthium strumarium* L.

As previously reported, large populations occurred in fields that had been planted in *Zea mays* L. or *Glycine max* (L.) Merr. the previous year. One population was discovered in a *Triticum aestivum* L. stubble field. Associates at this site were similar to those at other localities except for the presence of *Chenopodium album* L., *Conyza canadensis* (L.) Cronq., *Physalis* sp., and *Setaria viridis* (L.) P. Beauv. Site 5 (see Table 1), 2.3 miles north of Bath on the W side of IL78, had 12 plants of the federally listed *Boltonia decurrens* (Torr. & A. Gray) A.W. Wood as an associate.

Populations of *S. hallii* at collection sites varied in population size, density and maturity. Although most populations had an abundance of mature achenes, other sites had young plants that lacked flowers or had immature fruit (Table 1, site 24). Moisture at collection locations ranged from moist sand without visible standing water to sites where areas were completely flooded with as much as ~ 36 in of water (e.g., site 6, south of Havana at the NE corner of the intersection of IL97 and county road 1500N, in an area historically known as Negro Lake but now referred to as Sand Lake). Most Hall's bulrush plants at this site were under water, but there were a few fertile culms just above the surface (Figure 2). Phillippe & Gehlhausen (Robertson et al. 1994, p.13, collection # 22984) reported that plants were growing in water ~2ft deep at the same locality (i.e., site 6, EOR # 1, Table 1) in 1993.

Underground aquifers and ground water levels in western Mason County are influenced by precipitation and water stages on the nearby Illinois River (Visocky 1965, McClain et al. 1997, Hlinka et al. 1999; Fig. 1A-B). During years when precipitation is unusually high (i.e. roughly above once every 50-250 year recurrence events; Visocky 1965; Fig. 1A-B), groundwater flooding occurs where ground-water levels rise above the land surface and create surface water and overland flooding (McClain et al. 1997, Hlinka et al. 1999). This overland flooding creates numerous temporary ground-water lakes and sand ponds that can exceed 3,672 ha in areal coverage, as occurred in Mason County following the flood of 1993 (McClain et al. 1997). During years when water levels on the Illinois River are above flood stage due to precipitation amounts in excess of monthly and annual averages (Figure 1), excess water may persist at some sites for 1-2 years following high total rainfall events (Hlinka et al. 1999).

Our observations of populations of Hall's bulrush on 23-24 September 2009 were similar to those recorded by other researchers following years of above average precipitation. During years when overland flooding occurs in the sandy soil of the region, germination and growth conditions are ideal for *S. hallii* (Baskin et al. 2003) and the species can be found in the tens to hundreds of thousands of plants covering several acres (Robertson et al. 1994, McKenzie 1998, McClain et al. 1997, McKenzie et al. 2007). This is particularly true for sites 3, 4 & 5 (Table 1) that are within 1.7, 2, & 0.5 mi, respectively, of the Illinois River. We estimated hundreds of thousands of *S. hallii* plants at each of these sites during our visit in 23-24 September 2009. During years of average to below average precipitation, water levels in underground aquifers do not reach the surface such that wet sand habitat is unavailable and *S. hallii* can be completely absent (sites 1, 10, 11, 17, 23 or corresponding EORs 16-19, 20, Table 1). Additionally, during drier years, most sites in the region are cultivated for various agricultural crops, which is not possible during overland flood events (Robertson et al. 1994, McKenzie 1998, McClain et al. 1997, Beatty et al. 2004, McKenzie et al. 2007).

Although there is a general correlation between precipitation and water levels on the nearby Illinois River with abundance of *S. hallii*, there are some anomalous observations where the possible explanations for the presence or absence of the species at a particular site are not as apparent. For example, sites 15 and 16 (Table 1) were flooded during our visit in 23-24 September 2009 and no Hall's bulrush plants were visible. There were, however, thousands of *S. hallii* plants at site 16 in 2000 when the species was absent from other localities (Table 1). This is likely due to the overflow of ground water levels on some portions of the Sand Lake area following the above average rainfall in 1998 (Fig. 1-B) was sufficiently large enough for limited habitat to persist into 2000.

In respect to precipitation and flooding, the reasons for the absence of Hall's bulrush at some sites (e.g., 10-13, 17, 19 & 23, Table 1) during our visit in 23-24 September 2009 are not readily apparent. Flood stages and precipitation were very similar in 1993 and 2009 (Fig. 1A & B), so we inferred that habitat availability for *S. hallii* had declined during the intervening 16 years. This was particularly noticeable at some of the historical shallow roadside ditch habitats. Some ditches along roadside sites that provided historical habitat for Hall's bulrush had been widened and increased in depth. This manipulation led to the noticeable incision and erosion of some ditches. Increased ditch maintenance in Mason County may have been a result of flood management recommendations following the catastrophic flood in the county in 1993. Hlinka et al. (1999) analyzed interactions between ground and surface water at Sand Lake in Mason County following the 1993 flood and noted that the elevation of "transportation roadways" had been increased to reduce impacts of future floods. Hlinka et al. (1999) also recommended that future potential impacts from flooding around Sand Lake could be lessened by taking steps to ensure that there were mechanisms (e.g., pumping, improved drainage) in place to facilitate the discharge of excessive surface water into the Illinois River. While the deepening and widening of ditches in Mason County to facilitate runoff during years of above-average precipitation has impacted roadside populations of *S. hallii*, it is not known what effect such drainage operations will have on the species in adjacent agricultural fields. Sanderson and Buck (1995) studied groundwater levels in the Havana Lowlands that include sites for *S. hallii* and determined that underground aquifers in the area were of such magnitude that increased groundwater withdrawls over a 30-year period were insufficient to significantly decrease the resource. Nonetheless, the area has been identified as a major locality for human population growth due to its large underground aquifer; its under-utilized coal, sand and gravel resources; and its proximity to major highways and larger cities (Walker et al. 1965). Additionally, Sanderson and Buck (1995) calculated that agricultural irrigation in Mason and adjacent southern Tazewell counties had increased from about 130 acres in 1954 to an estimated 117,000 acres in 1989.

In our attempt to determine the commonality of some sites we visited in 23-24 September 2009 with historical collections and EORs listed in the INHS Database, we noticed that it was extremely difficult to compare collection sites due to: 1) incorrect label data with inaccurate county road numbers, 2) inconsistency in how sites within a certain radius of one another were lumped into a single locality, 3) EORs were lacking from some sites listed in Table 1 (e.g., sites 2, 4-5, 13-14, 18, 21-22) but which were far enough apart from other localities that they should have been listed separately, and 4) the use of different names for the same apparent locality. In the latter case, Negro Lake listed in Robertson et al. (1994: p.13, Phillippe & Gehlhausen collection # 22984) is now referred to as Sand Lake (see sites 6, 7, 15, and 16 in Table 1; these are listed as EOR number 1 in the INHS Database). Some of our collection sites did not equate well with established EORs because: 1) a few localities were close enough that they would likely be lumped into a single location in the INHS database, 2) as far as we could ascertain, they were new records for the species separate from previous collections, and 3) in some cases we made collections at sites that were within 0.2-0.7 mi. of one another to maximize sample size for our genetics study.

Despite the large numbers of plants of *S. hallii* observed at localities in Mason County in 2009, all sites we visited are on private property and subject to further agricultural, industrial or residential development. Consequently, we recommend that the following actions be undertaken: 1) continue monitoring of known sites, especially following years of above-average rainfall, 2) initiate a seed bank ecology study at selected sites similar to a study conducted by M. Smith in Missouri (Smith 2001, 2002, 2003), 3) evaluate the potential effects of ditch maintenance and roadway elevation on area drainage patterns, 4) further assess changes in area human demographics and projected increased demands on water withdrawal for irrigation, and anticipated expansion for agricultural, industrial, mineral, and residential development, and 5) evaluate the potential of site maintenance and management at selected sites through conservation agreements or easements.

Based on analysis of water levels on the Illinois River and precipitation data from 2009, we predict that *S. hallii* will be abundant at sites closest to the Illinois River in 2010 (e.g., sites 3, 4, 5 & 9), but will be absent at some localities around Sand Lake due to flooded conditions. We also predict that in future years when total precipitation levels are at or below monthly/yearly averages, water levels at the Sand Lake site (including most of Section 8, extreme SE ¼ of Section 7, NE ¼ of Section 18 and NW ¼ of Section 17 in Township 21N and R8W) may be low enough to provide habitat for Hall's bulrush, even when the species is absent at other sites where there is insufficient moisture for germination and growth.

Finally, we recommend that GPS equipment be used to pinpoint the location of known sites and to record any new sites discovered. If site boundary cannot be recorded using the GPS, due to either time constraints or the inaccessibility of the habitat, an estimate of the extent of the area covered by the population would be helpful in developing shape files for mapping. Additionally, we recommend a standardization protocol be established in estimating population levels of each site. Even such rough categories as 10s, 100s, 1000s, 10,000s or 100,000s would provide more meaningful information than simply recording the presence of the species.

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Table 1. *Schoenoplectus hallii* sites and population sizes in Mason County, IL surveyed in 2009, with reference to collections in 1993[a], and observations from 1985[d], 1994[d], 1995[b], 1998[d], 1999[d], 2000[c], 2001[d] & 2004[d]. NP = No plants, PP = plants present, FP = few plants, NR = Not reported (Robertson et al. 1994)

Site	Longitude	Latitude	2009	Coll #	1993	Coll #	[d]EOR	Observations
1	40 06 15	90 09 57	100s	2416	1000s	22977	19	1998 NP site dry[d], 2004 NP, site dry[d]
2	40 06 17	90 11 35	100s	2417	NR		--	
3	40 07 58	90 11 20	100,000s	2418	100s*	--	9	*Schwegman July 1993; 1998 NP site dry[d]
4	40 08 3.3	90 10 44	100,000s	2419	NR	--	--	1995 100,000s, McKenzie #1651[b]
5	40 13 19	90 07 13	100,000s	2420	NR	--	--	2009, 12 *Boltonia decurrens* plants
6	40 16 31	90 02 16	10,000s	2421	100s	22984	1	1985 PP[d],1999 PP[d], 2000 NP[c], 2001 FP[d] , partially flooded in 2009
7	40 16 31	90 02 23	1000s	2422	NR	--	1	2000 NP[c] , partially flooded in 2009
8	40 17 35	89 53 02	100,000s	2423	1000s	23357	18	
9	40 11 32	90 06 02	1000s	2424	1000s	22978	20	1994 1000s[d], 1995 1000s, McKenzie #1654[b], 1998 NP site dry[d]
10	40 12 55	89 45 27	NP	--	100s	23361	16	1998 NP site dry[d], 2004 NP site dry[d]
11	40 17 50	89 53 24	NP	--	1000s	23337 23365	18	2004 NP, site dry and mowed[d]
12	40 17 20	90 01 08	NP	--	many	23353	--	1995 100s, McKenzie #1661[b]
13	40 16 27	90 01 09	NP	--	NR	--	--	1995 1000s, McKenzie #1660[b]

Site	Longitude	Latitude	2009	Coll #	1993	Coll #	[d]EOR	Observations
14	40 16 49	90 00 0.4	NP	--	NR	--	--	1994-95 PP (McClain et al. 1997 site #3), 2000 NP site dry[c]
15	40 16 28	90 02 14	NP	--	NR	--	1	2000 NP[c], site flooded in 2009
16	40 16 28	90 02 21	NP	--	NR	--	1	1994-95 PP (McLain et al. 1997 site #2); 2000 1000s[c], site flooded in 2009
17	40 15 10	90 01 15	NP	--	25	23366	21	1998 NP site dry[d], 2004 NP site dry[d]
18	40 06 19	90 11 36	NP	--	NR	--	--	
19	40 06 52	90 12 33	NP	--	33+	22945	3	1989 PP[d], *Schwegman 1995 1000s plants, 1998 NP site dry[d]
20	40 11 29	90 05 52	NP	--	NR	--	20	0.66 mi from site 9
21	40 07 58	90 09 21	NP	--	NR	--	--	
22	40 06 19	90 12 19	NP	--	NR	--	--	
23	40 17 44	89 51 34	NP	--	500	23334	17	1998 NP site dry[d], 2004 NP site dry and mowed[d]
24	40 17 30	89 53 07	few juvenile	--	NR	--	18	Plants young, no inflorescences (<.2 mi from Site 8 on other side of 2500E)

*Reported by Schwegman, but not collected

[a] Robertson et al. 1994; collection by Phillippe & Gehlhausen; specimen housed at University of Illinois at Urbana/Champaign (ILLS)

[b] McKenzie 1995; specimen housed at the Missouri Botanical Garden (MO)

[c] Smith et al. 2006

[d] Illinois Natural History Database EOR (Element of Occurrence Record)

Figure 1. Illinois River flood gauge data and annual precipitation recorded at Havana, IL, for selected years. (A.) Mean annual water level (feet) taken from the USACE gauge at Illinois River Mile 119.6. The horizontal dashed line indicates flood stage. (B.) Total average precipitation (inches) (bars with left angled lines), and the mean annual deviation from the 100 year average (solid bars).

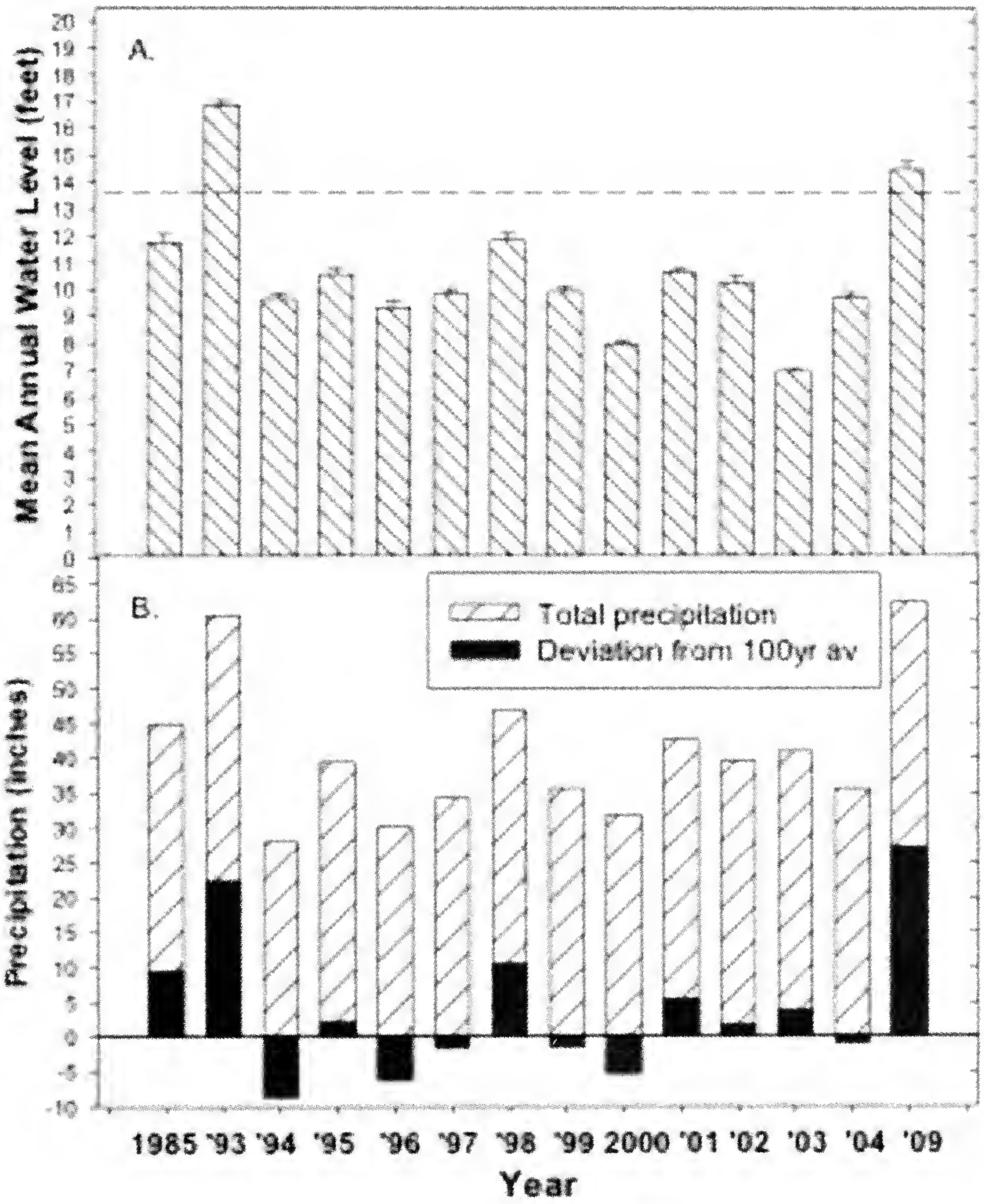
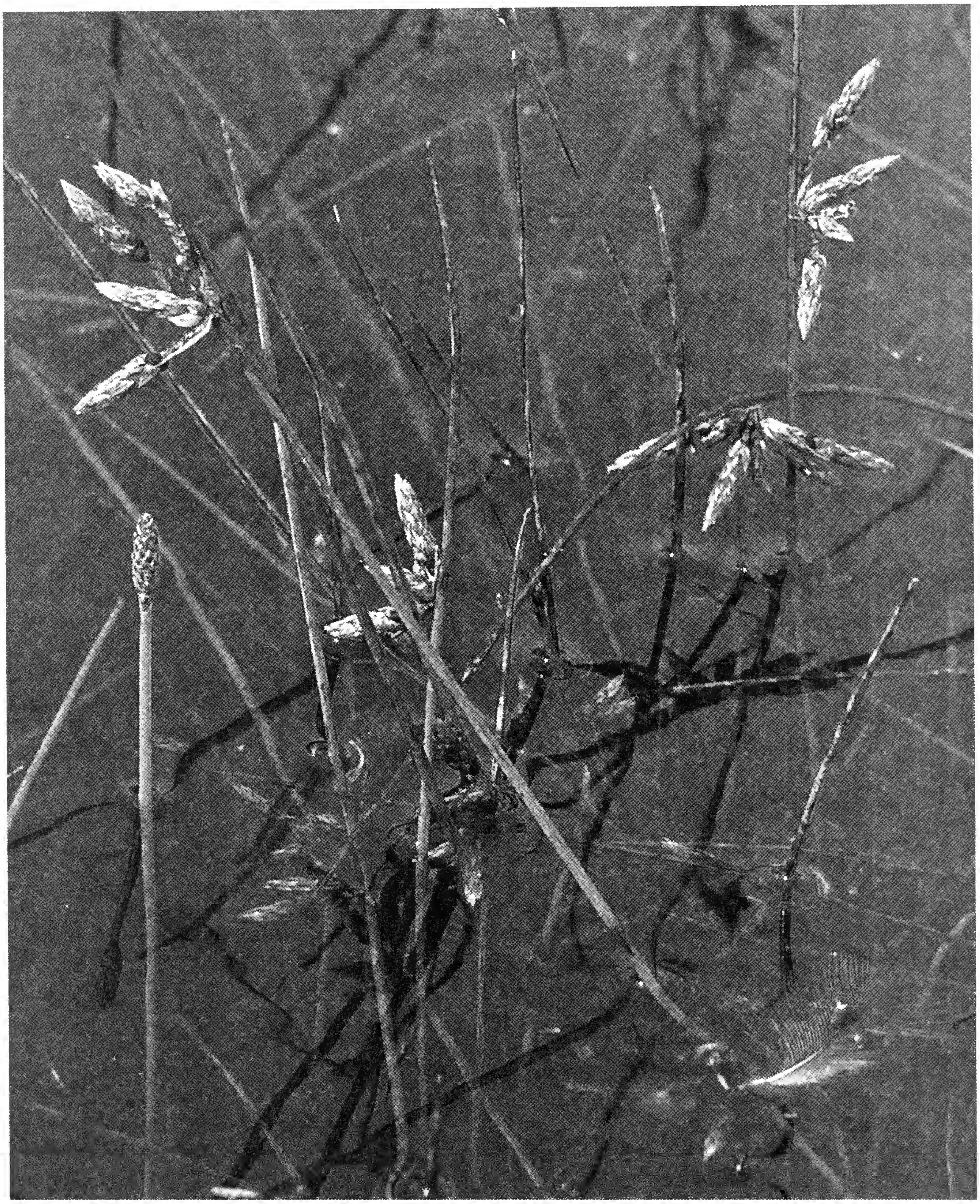


Figure 2. Inflorescences and achenes of *S. hallii* shown above water level at Site 6. Photo by Tim Kelley.



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Multiyear Study of Factors Related to Flowering Phenology and Reproductive Yield of *Baptisia alba* in Northeastern Illinois

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ABSTRACT

Factors related to flowering phenology and the reproductive yield of the white wild indigo, *Baptisia alba* (Fabaceae), were investigated in a multiyear study. The study site was a 7.1 ha reconstructed prairie located in northeastern Illinois. Factors considered were pre-dispersal seed predation by the *Apion rostrum* (Apionidae), pollination, and weather. First flowering time (FFT) and flower duration were measured from 2007-2009, as were components of reproductive yield and pod infestation from 2003-2009. Earlier flowering *B. alba* showed a longer flowering duration and were larger based on racemes/plant. However, only during 2009 did these plants have more inflated pods/flower, an indicator of pollination success, and matured significantly more seeds. Larger *B. alba* tended to produce a higher number of mature seeds, but also tended to attract more weevils. Across years, *A. rostrum* infestation of pods was significantly related to fewer mature seeds/plant. Likewise, warmer departures from local average daily temperature during June-July when pods were developing was associated with reduced seeds matured/flower. Seed development may be sensitive to heat as encountered later in the summer. Escaping the heat of summer can explain why most *B. alba* flower earlier, although at a possible cost of seed depredation. Trends in pod infestation did not indicate that larger, earlier FFT plants saturate *A. rostrum*. A longer flowering duration by these plants may preclude benefits of mass flowering in lowering pod infestation by weevils. Smallness did not appear to have benefits in seeds matured/plant. Later FFT by these plants may be the consequence of needing a longer time to secure resources prior to flowering.

INTRODUCTION

The white wild indigo, *Baptisia alba* L. (Vent.) (= *B. leucantha*), is a widely distributed legume in prairie and open woods of the Midwest (Swink and Wilhelm 1994). The perennial blooms prolifically during late spring, producing a central raceme and often 10 or more satellite racemes. In northeastern Illinois, the location of the current study, most *B. alba* bloom during a two-week period in June. However, some plants bloom much later, beginning after mid July.

This asynchronous flowering is often linked to plant size, with larger plants blooming earlier (Bolmgren and Cowan 2008, Bustamante and Burquez 2008, Pettersson 1994). An earlier first flowering time (FFT) may enable larger plants to bloom longer, exposing plants to more pollinators, but also to pre-dispersal seed predators and the effects of weather (O'Neil 1999). These selective pressures on FFT vary over time and space (Brody 1997, Evans et al. 1989, Kolb et al. 2007, Ollerton and Lack 1990). Thus, the advantage of a particular flowering phenology to a perennial may only be realized over the course of multiple seasons.

In a two-year study of *B. alba*, larger plants with more racemes flowered earlier and tended to yield more mature seeds, although the difference in yield was never significant (Petersen et al. 2010*s*). A hypothesis forwarded by the study was that sporadic reproductive successes related to FFT of plants of varying size are strong enough to select for variable flowering phenology in *B. alba*.

Baptisia alba begins a cycle of reproductive growth as the soil warms during spring and new shoots emerge. *Bombus* are the major pollinators. Pods inflate from flowers that have been pollinated (Haddock and Chaplin 1982). Many, if not all of the pods are aborted as they mature (Petersen and Sleboda 1994). Abortion appears to be selective, targeting pods with fewer seeds. Pre-dispersal seed predation by the weevil, *Apion rostrum* Say (Apionidae), is influential to this loss. Pods mature during August to September, with seeds being dispersed as pods dehisce and fragment. Above ground growth of *B. alba* senesces in autumn.

Apion rostrum is the only known pre-dispersal seed predator of *B. alba* in the prairie under study in this paper, the Russell Kirt Tallgrass Prairie located in northeastern Illinois. Overwintering adults appear first in May on an earlier blooming congener, *Baptisia bracteata* Muhl. ex Ell. and then on *B. alba* (Petersen et al. 2006). The weevils mate and females begin ovipositing eggs within developing pods. After a period of oviposition, the adult weevils disappear, suggesting the species is univoltine. The larvae within pods consume seeds for nutrition, often devouring all within a pod. The adult stage is reached by August, with adults dispersing from opened pods by early autumn. Presumably adults overwinter in the soil since burning does not prevent the subsequent reappearance of the weevils.

In the following study, we investigated how patterns of flowering phenology and reproductive yield shown by *B. alba* are related to seed predation, pollination and weather using data from 2003-2009. We were interested if a long-term study would uncover relationships, unclear from short-term studies, which explain the variable reproductive patterns of the legume.

METHODS

Reconstruction of the 7.1 ha Russell Kirt Tallgrass Prairie was begun in 1984. The prairie was burned entirely each year until 2008, but has since been selectively burned. *B. alba* plants selected for study were from a section of the prairie which was burned in entirety from 2003-2008, and not burned in 2009. The prairie flora is characterized by the graminoids big bluestem (*Andropogon gerardii* Vitman), Indian grass (*Sorghastrum nutans*

(L.) Nash), and prairie dropseed (*Sporobolus heterolepis* Gray), and in excess of 100 species.

Sampling methods were similar for all seven years. *B. alba* were tagged for study as they began to flower. FFT and last flowering time were recorded for years 2007-2009. Common measurements for all years were racemes/plant, flowers/plant, pods inflated/plant (except for 2005), pods ripened/plant, seeds matured/plant, and *A. rostrum*/pod. Mature seed and weevil counts were taken from ripened pods. Five regularly spaced pods/raceme were selected for sampling. If a raceme had fewer than 5 pods, then all of the pods were inspected for seeds and weevils. Racemes/plant provided a measure of plant size and *A. rostrum*/pod a measure of weevil infestation. *Apion rostrum*/plant , evaluated by the product of inflated pods/plant and *A. rostrum*/pod, was used to examine if larger plants attracted more weevils overall. Inflated pods were used instead of mature pods to account for pod, and subsequent weevil, loss prior to ripening. Seeds matured/plant provided a measure of reproductive yield, pods inflated/flower a measure of pollination efficiency, and seeds matured/flower a measure of flower reward to a plant.

Weather data were obtained from O'Hare International Airport (http://www.crh.noaa.gov/) which is located 20km northeast of the site. Data for year 2004 were unavailable. Chosen measurements were departures in daily temperature (DPTR) and precipitation (DPPC) from averages due to the likely influence of these parameters on above-ground growth during March-August, and on pollination activity and seed maturation during June and July.

Despite use of transformations, normality and homogeneity of variance could not be safely assumed with most data within a year or among years. Spearman rank correlation was used to detect relationships among variables. Statistica (StatSoft 2001) was used in all analyses.

RESULTS

Table 1 summarizes parameters of flowering, reproductive yield, and weevil infestation according to year. In most years, *B. alba* experienced substantial pod loss from inflation through ripening resulting in highly variable counts of seeds matured per plant and flower. Years 2005-2007 showed warmer departures from normal (Table 2). This pattern included months June-July with year 2005 being especially dry.

Baptisia alba that flowered earlier, also flowered for a longer duration (Table 3). These plants were larger based on counts of both racemes and flowers. An earlier FFT was significantly related to more seeds matured/plant for years 2007 and 2009, but not for year 2008 when the mean count of weevils/pod was higher. FFT showed contrasting relationships to *A. rostrum*/pod. Only during 2009 was *A. rostrum*/pod significantly related to flowering duration. Pods inflated/flower tended to be negatively correlated to FFT, significantly so for 2009. No significant correlations were found between flowering duration and pods inflated/flower. Rewards of seeds matured per flower appeared only during 2009 when earlier flowering *B. alba* and those flowering for a longer duration produced significantly more seeds.

The relationship between seeds matured/plant and racemes/plant was always positive and significantly so in 4 of the 7 years (Table 4). Count of seeds matured/plant showed a contrasting relationship to *A. rostrum*/pod. Correlation coefficients between seeds matured/ plant and pods inflated/flower were always positive but only significantly so in 3 of 6 years where data were available. While *B. alba* with more racemes tended to attract more weevils, the levels of infestation/pod varied greatly among years.

From 2003-2009, warmer departure from average June-July temperatures was associated with reduced seeds matured/flower (Table 5). Seeds matured/plant were negatively correlated to the count of *A. rostrum*/pod, and seeds matured/flower were positively linked to racemes/plant and seeds matured/plant.

DISCUSSION

The hypothesis that earlier FFT by *B. alba* helps in securing pollinators received marginal support. As an indicator of pollination activity the ratio of pods inflated/flower, though always negatively correlated to FFT, was only significantly so during 2009. Findings did not support that larger, earlier flowering plants can saturate pod infestation by *A. rostrum* as two years of three failed to show an expected positive relationship between FFT and *A. rostrum*/pod. When considering a longer flowering duration, these plants may only function to attract and retain ovipositing weevils.

Reward in seed yield by earlier flowering, longer flowering, and generally larger *B. alba* only occurs during the occasional seasons when weather is especially favorable to reproductive growth. The negative relationship between seeds matured/flower and June/July DPTR may indicate why most *B. alba* flower earlier. A higher reward in seeds matured/flower is unlikely to occur later in the season. The adverse effect of extreme weather on seed yield has been observed among other legumes (Evans et al. 1989, Mduma et al. 2007, Siemens and Johnson 1995, Young et al. 2007).

Although later flowering plants may avoid more intense predator pressures by *A. rostrum* during some years, the reward in seed yield is yet to be seen. Smaller *B. alba* may be younger or otherwise limited in above-ground growth, and lacking in the nutritional reserves to bloom earlier. More extreme temperatures as the season progresses may limit any benefit in seed yield to a later FFT and explain the shorter flowering duration. The fitness of these late bloomers may be maximized by reproducing to a lesser degree than not at all.

Pre-dispersal predation should be expected to reduce seed yield in *B. alba* that has one flowering episode per season. Data from across seasons indicate *A. rostrum* has a major negative effect on seed yield of *B. alba*. However, the weevil's selective role in affecting the flowering time of *B. alba* is not clear. *A. rostrum* is known to be a major seed predator of other *Baptisia* species, including those growing in warmer climates (Evans et al. 1989, Haddock and Chaplin 1982, Horn and Hanula 2004). The weevil's ability to adapt to congeneric hosts seems evident. Hence in northeastern Illinois, *A. rostrum* should synchronize its oviposition time with pod formation of its two hosts, *B. alba* and *B. bracteata*. The observation that *B. alba* with later FFT were also infested demonstrates the plasticity the weevil shows in oviposition period. Even among the few *B. alba* that flowered late, positive pod infestation is proof that there were a few ovipositing weevils to take advantage of these plants.

The major selective determinant on flowering time and duration of *B. alba* appears to be weather. Limited sampling seasons may have prevented reaching conclusions on how weather at different times of the growing season can affect the reproductive phenology of the legume. Continued study should further elucidate determinants affecting flowering phenology of *B. alba*.

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Table 1. Summary (mean ± standard error; n) of flowering phenology, growth parameters, and *Apion rostrum*/pod for *Baptisia alba*. The sample size which is enclosed in parentheses, is provided next to the first parameter listed for a year and applies to remaining measurements unless otherwise noted. Symbols: FFT = first flowering time.

Parameter	Year						
	2003	2004	2005	2006	2007	2008	2009
FFT					11.6 ± 1.3(63)	15.7 ± 1.5(61)	13.8 ± 1.2(91)
Flowering duration					17.8 ± 0.7	16.1 ± 0.8	19.4 ± 0.8
Racemes/plant	3.0 ± 0.7(38)	4.1 ± 0.3(38)	2.8 ± 0.2(40)	3.4 ± 0.4(40)	3.9 ± 0.3	3.2 ± 0.3	3.9 ± 0.3
Flowers/plant	134.0 ± 13.5	101.7 ± 10.0	70.5 ± 6.6	74.7 ± 6.8	71.1 ± 7.6	57.9 ± 5.8	88.2 ± 6.7
Pods inflated/plant	50.8 ± 6.2	53.6 ± 7.7		39.4 ± 4.6	44.2 ± 6.4	27.8 ± 3.2	60.0 ± 4.8
Pods matured/plant	9.7 ± 2.9	47.4 ± 7.3	2.2 ± 0.9	10.2 ± 1.5	9.3 ± 3.4	0.7 ± 0.3	31.0 ± 3.2
Seeds matured/plant	37.7 ± 14.9	366.0 ± 64.2	3.3 ± 2.0	19.3 ± 4.3	30.8 ± 13.5	2.7 ± 2.0	228.1 ± 36.3
A. rostrum/pod	1.9 ± 0.3(15)	1.5 ± 0.2(37)	2.7 ± 0.4(14)	3.9 ± 0.2(35)	2.9 ± 0.25(39)	3.4 ± 0.4(11)	2.42 ± 0.22
Inflated pods/flower	0.40 ± 0.04	0.72 ± 0.16		0.52 ± 0.03	0.59 ± 0.03	0.52 ± 0.02	0.66 ± 0.02
Seeds matured/flower	0.33 ± 0.15	4.8 ± 1.4	0.03 ± 0.02	0.22 ± 0.07	0.24 ± 0.07	0.08 ± 0.07	1.96 ± 0.25

Table 2. Select local weather measurements by year taken from O'Hare International Airport, IL. Symbols: DPTR = departure from average daily temperature; and DPPC = departure from average daily precipitation.

Measurement	Year					
	2003	2005	2006	2007	2008	2009
March-August DPTR (°C)	-4.3	10.8	13.1	15.9	0.3	-2.7
March-August DPPC (cm)	0.12	-11.29	-0.79	3.33	0.65	5.52
June-July DPTR (°C)	-2.00	4.61	1.83	1.94	1.83	-2.50
June-July DPPC (cm)	-1.18	-4.43	0.61	-0.99	1.80	1.57

Table 3. Spearman rank correlation comparing first flowering time (FFT) and flowering duration to variable of plant reproductive yield and pod infestation by *Apion rostrum* for years 2007-2009. Subscripts in parentheses beside correlation coefficients indicate sample sizes deviating from the rest. Symbol: *denotes significance ($P \leq 0.05$).

Parameter	First Flowering Time			Flowering duration		
	2007	2008	2009	2007	2008	2009
Flowering duration	*-0.53	*-0.73	*-0.88			
Racemes/plant	*-0.46	*-0.50	*-0.68	*0.61	*0.64	*0.72
Flowers/plant	*-0.53	*-0.45	*-0.69	*0.76	*0.58	*0.77
Seeds matured/plant	0.13	0.01	*-0.62	0.22	0.24	*0.63
Apion rostrum/pod	*0.32$_{(39)}$	0.22$_{(11)}$	*-0.61	0.17$_{(39)}$	-0.14$_{(11)}$	*0.60
Pods inflated/flower	-0.07	-0.08	*-0.25	0.15	0.23	0.13
Seeds matured/flower	0.18	0.02	*-0.51	0.16	0.23	*0.49
Sample size by year	63	61	91	63	61	91

Table 4. Spearman rank correlation comparing variables of plant reproductive yield and pod infestation by *Apion rostrum* for years 2003-2009. Subscripts in parentheses beside correlation coefficients indicate sample sizes deviating from the rest. Symbol: *denotes significance ($P \leq 0.05$).

Variable 1	Year						
Variable 2	2003	2004	2005	2006	2007	2008	2009
Seeds matured/plant							
Racemes/plant	0.10	*0.42	0.18	*0.37	*0.27	0.04	*0.89
Flowers/plant	0.29	*0.34	0.28	*0.48	*0.27	0.16	*0.76
Apion rostrum/pod	*$0.50_{(15)}$	*$-0.50_{(37)}$	$-0.08_{(14)}$	$-0.23_{(35)}$	$-0.08_{(39)}$	$-0.35_{(11)}$	*0.75
Pods inflated/flower	*0.49	*0.44		0.23	0.13	0.41	*0.38
Racemes/plant							
Flowers/plant	*0.75	*0.70	*0.83	*0.90	*0.83	*0.85	*0.93
Apion rostrum/pod	-0.44	-0.03	0.17	<0.01	0.22	-0.50	*0.63
Apion rostrum/plant	0.28	*0.56	0.17	*0.68	*0.46	0.34	*0.79
Sample size by year	38	38	40	40	63	61	91

Table 5. Spearman rank correlation of yearly *Baptisia alba* averages of reproductive yield and pod infestation by *Apion rostrum*, and local select weather patterns from 2003-2009 measured at O'Hare International Airport, IL. Weather data from year 2004 are missing. All n = 7 except for correlations involving weather measurements where n = 6. Symbols: *Denotes significance ($P \leq 0.05$); DPTR = departure from average monthly temperature; and DPPC = departure from average monthly precipitation.

Parameter	Racemes/plant	Seeds matured/plant	*Apion rostrum*/pod	Pods inflated/flower	Seeds matured/flower
Racemes/plant		*0.86	-0.68	0.35	*0.89
Seeds matured/plant			*-0.79	0.64	*0.96
Apion rostrum/pod				-0.41	-0.71
Pods inflated/flower					0.64
March-August DPTR	0.49	-0.37	0.71	0.36	-0.43
March-August DPPC	0.49	0.54	-0.20	0.82	0.71
June/July DPTR	-0.52	-0.67	0.41	-0.05	*-0.81
June/July DPPC	-0.09	-0.09	0.43	0.41	0.20

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A Unique Solution to Chicago's Water Pollution: Tunnels and Reservoirs

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ABSTRACT

For more than 125 years Chicago has been diverting water from Lake Michigan to serve its domestic/industrial water needs, to dilute the city's polluted waters, and to enable navigation to Chicago from the Illinois River system. These diversions created a series of controversies with other lake states and seven of these controversies have gone to the U.S. Supreme Court. The city of Chicago has faced serious water pollution problems since the 1870s and made adjustments to use lake waters to move its polluted waters down the Illinois River. Heavy rains brought in-city flooding and to relieve the flooding, polluted waters were often released into Lake Michigan, an undesirable act since the lake is the city's source of water. In the 1960s the city proposed a costly solution, construction of 110 miles of large water storage tunnels under the city. This unique tunnel and reservoir project (TARP) has been built largely with federal funding, and has been found to handle most rainstorms except for infrequent storms having multi-hour rainfall amounts in the 100-year category. In summary, TARP has been found to be a very valuable system for reducing urban flooding and the spread of pollution into the lake or down the Illinois River. It addresses the hydrology and water quality of a large region. Now the Asian Carp is causing a new controversy affecting the diversion and water treatment.

INTRODUCTION: HISTORY OF THE DIVERSION

Chicago developed alongside Lake Michigan in the 19th Century and was built in the basin of a small river, later named the Chicago River, that flowed into the lake. All wastes were dumped into the river for decades, an act that polluted the lake and often the city's source of drinking water. A major epidemic resulted in 1885 and 90,000 residents died. The first action of the city was to move its water intakes 2 miles out in the lake (with tunnels back to the city) to try to escape the polluted waters (Neil and Dalton, 1980).

The city sought other solutions for drainage of its polluted river waters. One chosen was 1) to use the Illinois & Michigan Canal (I & M) from the Chicago River's southern headwaters to drain city waters into the headwaters of the Illinois River, located 45 miles away, and 2) to build a dam where the river exited into the lake (Fig. 1). The I&M Canal was deepened in 1865 to facilitate drainage, and the lake water could be diverted and pumped downstream. Lake waters came at the site where the river ran into the lake. St.

Louis and other cities downstream along the Illinois and Mississippi Rivers, fought this solution but the Supreme Court allowed Illinois continue the diversion into the Illinois River (Changnon et al., 1994).

After the epidemic of 1885, Chicago leaders acted to dilute the polluted water and reduce down river worries. Chicago began diverting large amounts of water from the lake at the river's mouth, typically 10,000 cfs. By 1900, to facilitate movement of this large volume of diverted water, and to facilitate barge movements on the canal-river system, the city built a much larger canal, the Sanitary and Ship Canal, from the south branch of the Chicago River to the Des Plaines River at Lockport where locks and a dam were built (Fig. 1). The Des Plaines River flowed into the Illinois River. The large flow of water through the Sanitary and Ship Canal, and ultimately into the Illinois River, also allowed passage of a large amount of shipping between downstream locales and Chicago.

The city also built a connection from the lake to the north branch of the river in1907 with a pumping station at Wilmette (Fig.1) to move the polluted water on the city's north side downstream. In 1910 the city built another canal (Calumet-Sag Channel)) that used the Calumet River to connect to the south end of the lake, and it served to move polluted water from the city's south side to the Sanitary Canal. Thus, there were three locations to access lake water so as to dilute the city's waste waters that ultimately flowed down the Illinois River (Fig. 1).

The large diversion of lake waters for water supply, for dilution of polluted waters, and for navigation raised concerns in other states around the Great Lakes, particularly as lake levels dropped during the dry 1920 and 1930s. The industries that used lake water and relied on shipping of large amounts of iron ore and coal on the Great Lakes were also deeply concerned. The lake states legally challenged Chicago's diversion through Congress. The disagreements ultimately went to the Supreme Court seven times during the 1930-1980 period (Changnon and Changnon, 1996). The Court's final resolution between Illinois and lake states in 1964 set the level for diversion at 3,200 cfs. This amount was for three uses: 1) domestic (Chicago and suburban) water supply (62%), 2) sewage dilution (22%), and 3) navigation (16%). The 3200 cfs, as measured in the Sanitary and Ship Canal, was to include diverted lake water and the runoff of the rain water that fell over the city.

Experience showed that when rains were 2 inches or more in one day, the river-canal drainage system could not handle the volume. Flooding then resulted and so the city quickly released the polluted stormwater into the lake. Rainwater became severely polluted because, at the time Chicago was built, the city took the least expensive option and installed a single set of drain pipes instead of a set for rain and a set for sewage. Vast amounts of polluted stormwater frequently existed and these were often released into Lake Michigan when heavy rains fell. These releases into the lake created major problems for the city's water supply.

A UNIQUE SOLUTION TO POLLUTION

Chicago faced continuing pressures during and after the 1940s to stop polluting Lake Michigan with its stormwater releases. These endangered Chicago's water supplies taken locally from the lake and in summer also led to beach closings. Then in the 1960s, the nation had a new theme—environmental protection emerged. This put additional pressure on any acts that polluted the Great Lakes, and so a new issue faced Chicago and its release of polluted stormwaters into Lake Michigan. Illinois also wanted all stormwaters to go down the Illinois River since this water was a part of the annual accounting of the total diversion amount. Thus, if Illinois released stormwater into the lake it could not count this water as part of the diversion and had to divert more lake water against its limit of 3,200 cfs.

In 1967 the Metropolitan Sanitary District (MSD) of Chicago proposed a unique solution: construction of a reservoir-tunnel system to store stormwaters underground in Chicago until the waters could be pumped up, treated, and then released into the canal-river system. The city also proposed upgrades of the water treatment plants and construction of new interceptor sewers (Neil and Dalton, 1980). This plan labeled the tunnel and reservoir project (TARP), would curb local flooding and prevent water pollution in the lake or river drainage system. It was really the only way Illinois could meet the 3,200 cfs diversion limit and its share of polluted waters that needed dilution. The TARP plan called for 131 miles of tunnels of 35-foot diameter to be built 150 to 300 feet below existing riverways and in Silurian dolomite rock, plus construction of three large surface reservoirs. These tunnels and reservoirs were intended to hold the polluted stormwater when heavy rains occurred over Chicago. After surface flood waters had receded, the stormwater in the tunnels was to be pumped up, treated at the sewage plants along the rivers and canal, and then released into the Des Plaines River. The city also developed a "Rain Blocker System", which cost $75 million. These devices were installed at street drains and were designed to slow the inflow from the sewer system during rains.

In 1977 the MSD got federal funds from EPA (furnished 75% of the total Phase 1 funding needed) and construction began. Actions to reduce pollution of the Great Lakes helped justify multi-billion dollars of federal funding. Phase 1 of the plan was aimed at pollution reduction and was to consist of 110 miles of tunnels to be done by 1979. Phase 2, which included 21 more miles of tunnels and 3 surface reservoirs, was primarily for flood relief and was scheduled to be done by 1982.

The deep tunnel project got its first funding in 1977, and in 1978 MSD was pressing the federal government for more funds to meet the projected costs of $3.7 billion (Injerd, 1993). In 1980 the MSD claimed the backflows to Lake Michigan would be eliminated by TARP. By 1987 some of Phase 1, 47 miles of tunnels, was completed. Phase 1 was nearing completion in the early 1990s, but the MSD predicted that Phase 1 would not be done until 1996, 17 years after the planned completion date. Phase 2 was then scheduled to be done by 1995, but was still not done in 2009. The city was still working to develop two large reservoirs.

During the 1970-1996 period the city had been experiencing 1 to 3 rain events each year that led to releases of stormwater into Lake Michigan to eliminate flooding. After completion of the Phase 1 tunnels in 1996, only four heavy rain events during 1997-2009 caused flooding in the city and led to releases of polluted stormwater into Lake Michigan. Two storms came in 2001, one of the wettest years on record (Changnon and Westcott, 2002). A record setting rainstorm in 2006 led to a lake release (Changnon, 2010), and a fourth comparable heavy rainstorm in 2009 required a release into Lake Michigan to halt in-city flooding. Each of these four storms had 6- to 12-hour rain amounts that matched the once in 100-year return interval. They also occurred when the tunnels were already partially full of water from prior rains. Thus, only four storms had backflows in 13 years compared to an annual average of 2 per year prior to 1997.

A NEW PROBLEM

A new problem facing the diversion, TARP, and the handling of heavy rains to reduce flooding and water pollution, surfaced in 2000. The appearance of an invasive species of fish, the large Asian Carp, occurred south of the Sanitary and Ship Canal as the carp had migrated northward up the Mississippi and Illinois Rivers. The voracious Asian Carp eats existing native fish species. Illinois and the other lake states feared the carp's entry into the Great Lakes, an act that could seriously damage the native fish population which is a source of income for fisheries around the lakes. Thus, the carp challenged the survival of many native species, as protected by the Endangered Species Act.

To stop the northward migration of the Asian Carp, Illinois installed during 2002-2004 two underwater electric fences across the Sanitary and Ship Canal. Regardless, certain lake states have called for closing the canal gates at Lockport and those three connecting to Lake Michigan (Fig. 1) to stop the northward movement of the carp into Lake Michigan. Chicago claimed that closing the locks at Lockport would halt valuable shipping along the canal and also result in frequent in-city flooding. Furthermore, with no releases into the river, high waters would flow over the lake locks allowing the carp to move into the lake (Chicago Tribune, February 2010).

The debate over what other actions to take has gone to the Congress and the President. Congress refused to support a proposal by the state of Michigan to disconnect the waterways between Lake Michigan and the Illinois River. Michigan sued Illinois during December 2009 in the Supreme Court to close the locks, but the court rejected the case. President Obama pledged $78.5 million to Great Lakes states to prevent the carp from spreading into the lakes (Farm Week, February 15, 2010). Monitoring over the past 3 years reveals no Asian Carp have been found in Lake Michigan or the Chicago River.

CONCLUSIONS

The expensive tunnel and reservoir system has been found to handle most rainstorms except for those having multi-hour rainfall amounts in the 100-year category. One reason for this problem is that most extremely heavy rain events in the Chicago climate occur during wet periods (Changnon, 1980). This causes the tunnel storage to be partly if not totally filled before most extreme rain events occur.

For more than 100 years Chicago has been diverting water from Lake Michigan to serve domestic/industrial water needs, the dilution of polluted waters, and navigation. There have been series of controversies surrounding Chicago's diversion of Great Lakes water. These led to several political-forced physical adjustments to the drainage of waters from Chicago (Changnon and Glantz, 1996). TARP was one of the major adjustments, a unique approach to stop releases of polluted waters into the lake and down the Illinois

River. In summary, TARP has been found to be a very valuable system for reducing flooding and the spread of pollution into the lake or down the Illinois River. Now the Asian Carp is causing a new controversy affecting the diversion and water treatment.

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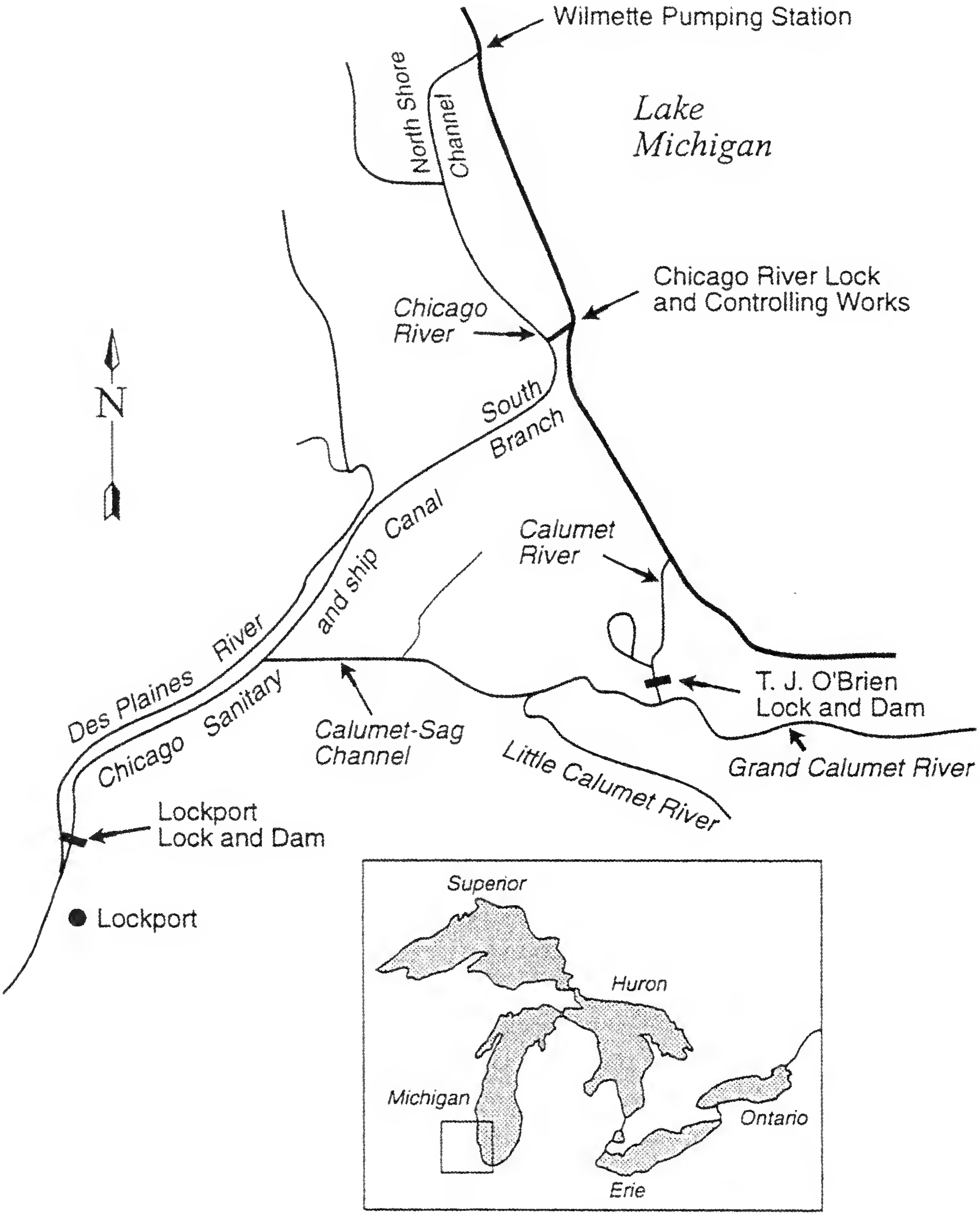
Figure 1. The primary rivers, canals, and water-controlling works in the Chicago area.



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Illinois' Twelve Most Damaging Storms

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ABSTRACT

The 12 most damaging storms in Illinois during the 1949-2008 period produced losses totaling $4.1 billion. Property losses were 84 percent of the total and crop losses were the rest. Two recent storms, one in April 2006 caused by multiple hailstorms and one in 2008 caused by heavy rains and flooding, were the two most damaging storms in the 60-year period. A wide variety of storm conditions caused the 12 storms including high winds, hail, tornadoes, heavy rains, flooding, high winds, freezing rain, and heavy snowfall. Eight of the storms occurred in recent years, since 1990, and the 12-storm losses peaked in 1999-2008 when $2.1 billion occurred, 51 percent of the 60-year total. The recent increase in major storms may reflect increased societal vulnerability due to growth in population and wealth, plus urban expansion. The increase may also reflect the change in climate due to global warming.

INTRODUCTION

High quality storm damage data have been collected in the U.S. since 1948 by the property and crop insurance industry. Insurance experts have adjusted the losses in each year to make them comparable to current year dollar values. A national assessment of all types of data about losses related to hazards in the U.S. found these insurance data to be the best measures in the U.S. (NRC, 1999).

The insurance loss data for Illinois have been assembled and analyzed for the 1949-2008 period to identify the 12 most damaging storms in Illinois. All storms causing more than $25 million (2008 dollars) in losses were identified, and the state's total was 68 for the 60-year period. The goal of this study was to examine the 12 most damaging storms so as to define the types of storm-producing conditions, the magnitude of their losses, and their temporal distribution during the 60- year period. Those impacted by major storm disasters should benefit from this information so as to better design and engineer recovery and relief activities. Those impacted by such storms include the disaster victims, damaged business owners, community leaders, public officials, tax payers, and the insurance industry.

An earlier study of severe storms in the Midwest (Changnon, 2002) found increases in storm-related losses during the 1990s. That study recommended follow-up studies in later years to see if the 1990s increase in losses continued. This might reflect a change in climate due to global warming.

STORM DIMENSIONS

The 12 most damaging storms in the state are listed in table 1. Most of the losses were to property. However, sizable crop losses also occurred from seven storms including those in April 1964, August 1987, July 1993, May 1998, May 2003, August 2007, and September 2008. Each of the 12 storms produced total property losses greater than $200 million. The 12-storm total loss was $4.148 billion. Crop losses totaled $660 million, which represented 16 percent of the total storm losses.

The most damaging storm was the result of numerous hailstorms on April 13-14, 2006. An unstable air mass developed across the Midwest on April 13 with upper air conditions conducive to the development of severe thunderstorms. Eight large hailstorms occurred including one supercell storm that spread hail along a path that was 16 to 20 kilometers wide as it traveled southeast from the Quad Cities, producing damages in Peoria, Bloomington, and Champaign (Changnon, 2009). In some areas, hailstones were 10 to 7.5 cm in diameter. Four other extensive hailstorms caused major damages in the Chicago area including in many suburbs. Losses in Illinois included $301 million to homes and personal property, $160 million to businesses, and $187 million to vehicles, and these totaled $$648 million (Changnon, 2009).

The second most damaging storm in Illinois occurred when the remnants of Hurricane Ike crossed the state on September 12-14, 2008. The deep low pressure center and strong inflow of moist air resulted in rainfall amounts of 5.5 to 8 centimeters across most of the northern half of the state. In the Chicago area rainfall amounts ranged from 5 to 7.5 inches in 12 hours, setting new records (Changnon, 2010). These rains created several damaging flash floods, followed by more widespread flooding along the Illinois and Mississippi Rivers.

The third most damaging storm in Illinois occurred on May 5, 1950. A deep low pressure system passed just north of Illinois, creating winds of 60 mph across central and northern Illinois and gusts exceeded 80 mph at several locations (Weather Bureau, 1950). Property was badly damaged in western and northern Illinois with many trees blown down, poles and wires downed, and numerous roofs removed. A bridge over the Illinois River was destroyed, and weather experts in 1950 estimated the storm losses as $500 million, slightly higher than the actual losses of $441 million (table 1).

Six different severe weather conditions were the cause of these 12 major storms. Three storms were due to a mixture of tornadoes, hail, and high winds. Two storms were caused only by hail and two others solely by high winds. Heavy rains and flooding caused two of the storms, and only one storm was due to winter storm conditions (snow and freezing rain). Assessment of the 68 storms causing $25 million or more in losses during 1949-2008 showed that the most frequent conditions were those with a mix of tornadoes, hail, and high winds. This storm type caused 22 storms.

Table 1. The twelve most damaging storms in Illinois during 1949-2008.

Rank	Losses, $ millions	Weather Conditions	Date
1	648	Hail	4/13-14/06
2	502	Heavy rains and floods	9/12-14/08
3	441	High winds	5/4/50
4	401	Snow, freezing rain, high winds	4/4-6/03
5	336	Heavy rains and floods	4/13-15/92
6	321	Tornado, hail, high winds	5/2-4/03
7	297	Floods, hail, high winds	7/8-9/93
8	273	High winds	8/23-24/07
9	248	Floods, hail, high winds	8/13/87
10	243	Tornado, hail, high winds	4/2-3/74
11	235	Hail	4/2/64
12	203	Tornadoes, hail, high winds	5/27-28/98

TEMPORAL DISTRIBUTIONS

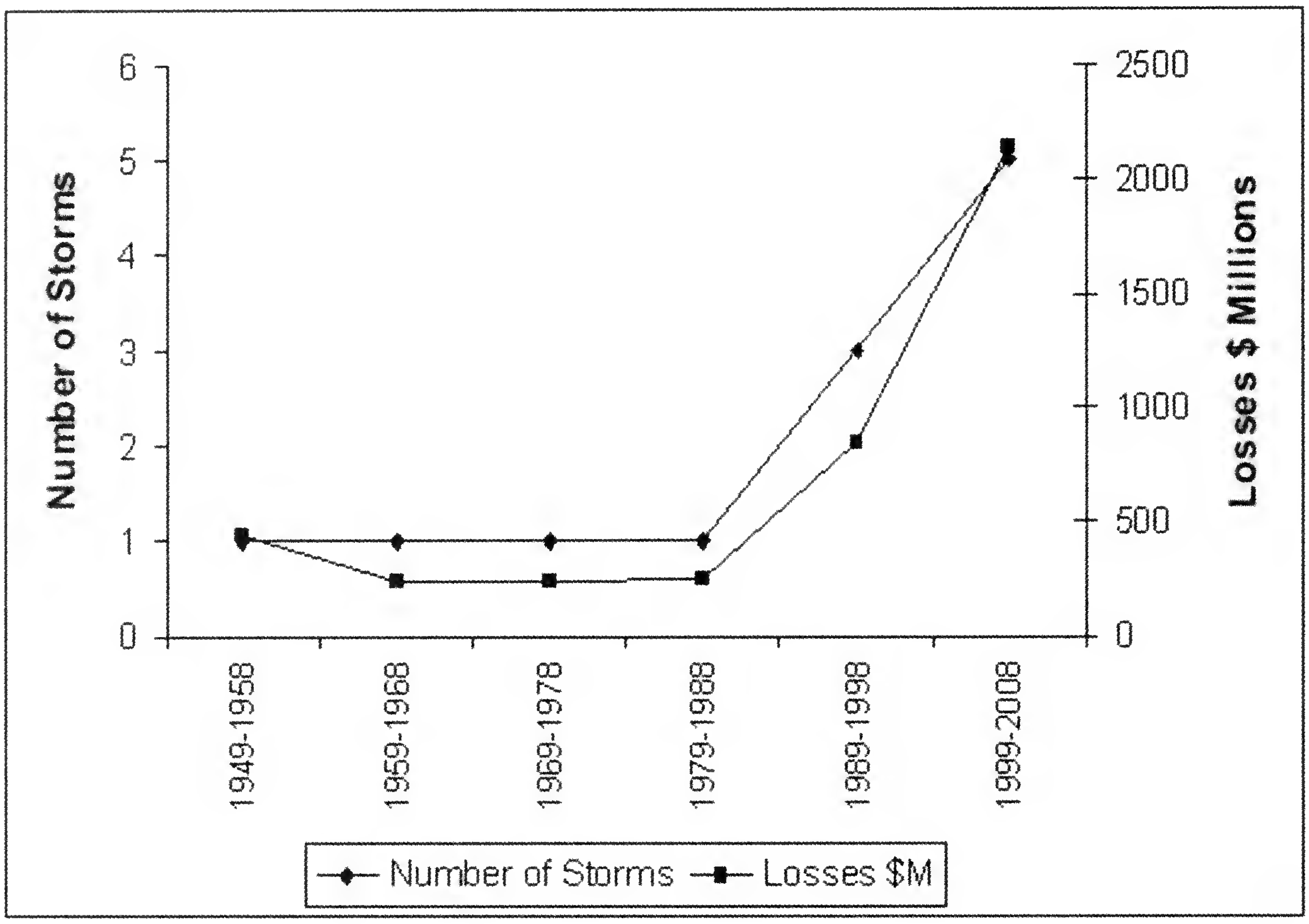
Assessment of the dates of the 12 storms showed that April led with 5 storms. May had 3, July 1, August had 2, and September 1. The frequency of storms by decades is shown in table 2, along with the amounts of loss.

Table 2. Number of storms and losses for six decades during 1949-2008.

Decade	Number of Storms	Losses, $ millions
1949-1958	1	441
1959-1968	1	235
1969-1978	1	243
1979-1988	1	248
1989-1998	3	836
1999-2008	5	2,145

The frequency of storms shows a marked increase with time beginning in 1989 (fig. 1). The frequency of the state's 12 most costly storms peaked at five in the 1999-2008 decade. Assessment of losses (fig. 1) also shows a dramatic increase after 1989. Very large losses occurred in the latest decade, 1999-2008. Three of the five storms during 1999-2008 occurred in the last three years, 2006-2008. Results show that increases in storms and their losses have continued after the 1990s, revealing the outcome after the earlier recommendation for a follow-up study (Changnon, 2002).

Figure 1. Temporal distribution of 12 most damaging storms and their losses during 1949-2008.



SUMMARY

The 12 most costly storms in Illinois during the 60-year period ending in 2008 were identified. Most of the damage was to property, and crop losses accounted for only 16 percent of the total loss of the 12 storms which was $4.148 billion. A wide variety of storm conditions caused the 12 events. Three storms resulted from a mixture of tornadoes, hail, and high winds. Two storms were due solely to hail and two solely to high winds. Heavy rains and floods caused two storms, and winter conditions (snow and freezing rain) caused one storm. The storms occurred mainly in the warm season. April had five storms, May had three, July had one, August had one, and September had one.

The temporal distribution of the 12 storms during the 1949-2008 period revealed distinct upward time trends in both storm incidences and their losses. Eight storms occurred in the 1989-2008 period, and losses in this period totaled $2.98 billion, 72 percent of the 60-year total. The distribution showed the highest values in the last 10 years, 1999-2008, an outcome that could reflect effects of global warming on the state's climate (Working Group II, 2007). The ever increasing losses could also be a result of the expanding societal vulnerability including growing population and wealth, plus expanding urban areas in Illinois which allow more storm damages to occur (Changnon, 2002). Regardless, the increases suggest Illinois should become prepared for more costly storm losses in the future.

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Severe Winter Weather in 2009-2010

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ABSTRACT

The winter of 2009-2010 was cold and stormy with excessive snowfall. The average winter temperature for Illinois was 3.6 degrees F below normal, and winter snow amounts varied from 8 inches at Cairo to more than 52 inches at Chicago. Snowfall totals in all parts of Illinois ranged from 27 to 86 percent above normal. Six severe snowstorms occurred in the December-February period and this was 2 more than normal. The northern half of Illinois had snow covering the ground from Christmas until February 28. These various severe conditions created costly impacts. Property losses totaled $159 million, the ninth highest winter loss on record. Damages to transportation systems were also severe, power costs were high, and the total losses and costs for the winter 2009-2010 were $530 million.

INTRODUCTION

The winter of 2009-2010 had weather conditions that created numerous costly impacts. The winter had six severe snowstorms. The total winter snowfall (Fig. 1) ranged from 8 inches at Cairo to over 52 inches in Chicago, and all parts of Illinois had snowfall totals well above normal. Amounts in northern Illinois ranked as eighth largest in the past 125 years. This was the fourth severe winter in a row in Illinois, and the third consecutive winter when more than 50 inches of snow fell in northeastern Illinois (Changnon and Kunkel, 2007; Changnon, et al., 2008; Changnon and Kristovich, 2009).

Continuous below freezing temperatures during January and February led to a snow cover in central and northern Illinois that persisted from late December unto the end of February. The number of days with snowfall exceeded normal values across Illinois. Monthly temperatures were below normal in all three months.

This report presents descriptions of conditions including temperatures, snowfall, snow cover, and storms during December 2009-February 2010. Values are presented for each month, and the values are compared to historic data to assess their climatological relevance. The second major section of the report assesses the numerous impacts created by the winter conditions. A national study of snowstorms found that damaging events occurred when snowstorms caused 6 or more inches of snow in 1 or 2 days (Changnon et al., 2008).

WEATHER CONDITIONS

The statewide snowfall averages were 11.7 inches in December, 6.3 inches in January, and 10.8 inches in February. The state's winter average total was 28.8 inches which is 9.8 inches above normal (Fig. 1). Monthly temperatures across Illinois averaged 1.1 degree below normal in December, 3.8 degrees below in January (18th coldest since 1895 when records began), and 5.3 degrees below in February.

December

December 2009 was cold and snowy with statewide snowfall totals averaging 3 to 6 inches above normal. Figures 2-3 present the patterns of snowfall for the three major December snowstorms. One snowstorm in December is the normal number. The first storm on December 7-9 resulted from a blizzard that had begun in the High Plains and moved east across northern Illinois. High winds with gusts of 50 to 60 mph occurred in the area where 2 to 10 inches of snow fell (Fig. 2). Several highways and rural roads were blocked in northwestern Illinois. The second December storm occurred in extreme northern Illinois on December 21-22 (Fig. 2). A Christmas snowstorm then occurred on December 25-26, with amounts over 10 inches in northeastern Illinois (Fig. 3). High winds occurred in the area with 4 inches or more snow, creating blizzard conditions. December 2009 rated as the 14th coldest and 11th wettest across the United States (Weatherwise, 2010).

January

January 2010 had continuously below normal temperatures which kept the snow cover produced by the December storms from melting. Most areas north of a line from Quincy to Champaign had a snow cover all month. Only one snowstorm occurred in January, one less than normal. This storm, which occurred on January 6-8, was widespread (Fig. 4). Snowfalls were greater than 4 inches over the northern two-thirds of the state with high values of 7 to 8 inches in northwestern Illinois.

February

February 2010 was a very cold and snowy month. Cold temperatures persisted through February, and the month had two major snowstorms, one more than normal. The storm on February 7-9 produced more than 12 inches of snow in Chicago, and the northern half of the state had 4 or more inches (Fig. 5). Eleven days later a deep low pressure center moved from Oklahoma across central Illinois, and it produced a second February storm on the 20th-21st (Fig. 5). This was the winter's final storm. It affected the northern half of the state with a peak of 8 inches in the Galesburg region. The February total snowfall at Chicago was 22.4 inches, the third largest on record. The highest daily temperature reached in Chicago during February was only 41 degrees, becoming one of only six years since 1890 when values did not reach 42 or higher.

Winter

The temperature and snowfall departures from normal during the winter are shown in table 1, illustrating the severity of conditions. The winter with temperatures well below normal, experienced a large number of days with snow cover on the ground. Chicago had 70 consecutive days with >1 inch snow on the ground, and this was the fourth largest number on record following behind 1978-79 (90 days), 1909-10 (81 days), and 1977-78

(72 days). Urbana, representative of central Illinois conditions, had 54 days with snow cover of 1 inch or more including the days during December 27-January 22; January 26-31, and February 6-26 periods.

Table 1. Departures from normal monthly and seasonal conditions during the winter of 2009-2010. Temperatures are degrees Fahrenheit and snowfall is in inches.

	Mean Temperature	Snowfall	Number of Storms
December	-1.0	+5.7	+2
January	-3.8	-0.7	-1
February	5.1	+5.2	+1
Winter	-3.3	+9.8	+2

The lack of mild daily temperatures during the winter is reflected in the fact that only 6 days had temperature above 40 degrees F at Chicago (23 is average), and Rockford had only 4 days with temperatures above 40, as compared to an average of 18 days. The average winter 2009-2010 snowfall across Illinois, which was 28.8 inches, ranked as the eighth largest in the past 125 years. The six major snowstorms was two more than average.

IMPACTS

The heavy snows, numerous storms, low temperatures statewide, and long-lasting snow cover in central and northern Illinois produced a myriad of physical, societal, and economic impacts in Illinois, some of a serious nature. These impacts included various damages to property, transportation problems, power outages, and costly efforts to deal with the weather problems. Anther problem included flooding that resulted from the melted snowfall. Residents of Illinois should find the information presented herein useful for future planning.

Property

The conditions led to many damages to property which included houses, farms, businesses, and vehicles. The three December storms caused $58 million in losses, The January snowstorm caused losses totaling $35 million, and the two February storms led to losses of $66 million. The winter total property losses in Illinois were $159 million, the ninth highest winter loss in Illinois since records began in 1949.

Environmental

Environmental impacts included extensive tree damage (heavy snow and high winds in northwestern Illinois) and flooding (precipitation much above normal). Flooding was a major physical impact in Illinois during and after the winter ended. River levels across Illinois during December were all well above normal stages, with flood stages occurring all along the Illinois River, on the Mississippi River from Grafton south to Chester, and on the Ohio River at Cairo. These high levels continued through January. Other rivers at or above flood stages in January included the Kaskaskia, Kankakee, Rock, Green, and

Mackinaw. In February flooding receded slightly on many streams. However, the Illinois River from Havana to Grafton remained above flood stage as did the Mississippi at Thebes, and the Ohio at Cairo.

Transportation

The snowstorms and frequent fogs limited visibilities, often leading to vehicle accidents. More than 6,500 accidents were reported in the winter as being weather related. Railroads in Illinois had many problems caused by the heavy snows and cold temperatures. Many trains were delayed , and two major derailments were caused by icing and blowing snow cover in northern Illinois in February (Railroads Illustrated, April 2010).

The storms, fogs, and high winds also curtailed commercial airline flights, and Chicago's O' Hare Airport had a large number of flight cancellations. O'Hare reported that 3 percent of all flights in December and 5 percent February were late due to bad weather. These late arrivals often clogged the airport and slowed outgoing flights.

Government

The wide temperature swings, coupled with moisture from the melting snow, created major pothole problems in streets and highways in many parts of the state. Damages to vehicles from hitting potholes were widespread. The pothole repairs in the five counties in northeastern Illinois involved 50 state crews and cost $2.3 million (Chicago Tribune, March 29). In Chicago they had to fill 230,000 potholes during the winter. The price of materials used in filling potholes had escalated rapidly since 2008, adding to the high costs. The statewide cost of pothole repairs was $48 million.

Snow removal (i.e., salt, fuel, overtime for workers) budgets for several Illinois communities were exceeded by mid February. Thousands of residents also had to pay private sector firms to remove snowfall from their clogged driveways. The huge pothole repairs and snow removal efforts, created major budget issues and problems for local governments and state agencies.

Retail Business

The numerous storms and heavy snow cover during late December through February curtailed retail shopping. Sales in February were only 65 percent of expected sales in Illinois during an already depressed nationwide economy (Chicago Tribune, April 4, 2010).

Agriculture

The numerous storms and heavy snows had a considerable effect on Illinois farmers. The 2009 growing season had been cool and wet and fall crop harvesting was greatly delayed. A third of the Illinois corn crop had to be harvested when possible in December 2009 and January 2010. The wet snowy conditions in the winter also limited normal efforts to perform tillage of farm fields. Furthermore, the flooding of streams and river eroded soils.

Human Health and Welfare

The prolonged cold conditions with continuous snow cover across the northern three-fourths of Illinois was frustrating and dangerous to many who needed to travel to work. Damages to homes and vehicles brought worries and fear to many. Deaths attributed to the winter weather conditions, mostly auto accidents, totaled 8.

SUMMARY

The three snowstorms in December 2009 were 2 more than normal; January had only one storm, one less than normal; but February had two snowstorms, one more than normal. The statewide snowfall totals for the winter were all well above normal. The statewide average was 28.8 inches which is 9.8 inches above normal. Snow totals ranged from a low of 8 inches at Cairo to over 50 inches in Chicago.

All three winter months had below normal temperatures, and the statewide average for the winter was 3.6 degrees F below normal. The heavy snowstorms in December, coupled with continuous below average temperatures, resulted in a snow cover that persisted from late December until the end of February. All aspects of the winter weather were far from normal.

Table 2. Losses and costs in millions of dollars, in Illinois associated with the winter 2009-2010 conditions.

Property damages	$159
Power losses and costs	118
Government costs	96
Transportation losses and costs	07
Retail losses	35
Environment	15
Total	$530

The numerous impacts resulting from the severe 2009-2010 winter conditions led to high losses and costs in several sectors. The winter's financial losses and costs are summarized in table 2. The greatest losses came to property. Losses and costs in the power use and production sector and in transportation were also large. The winter total in Illinois was $530 million.

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Figure 1. The pattern of total snowfall (inches) during December 2009-February 2010.

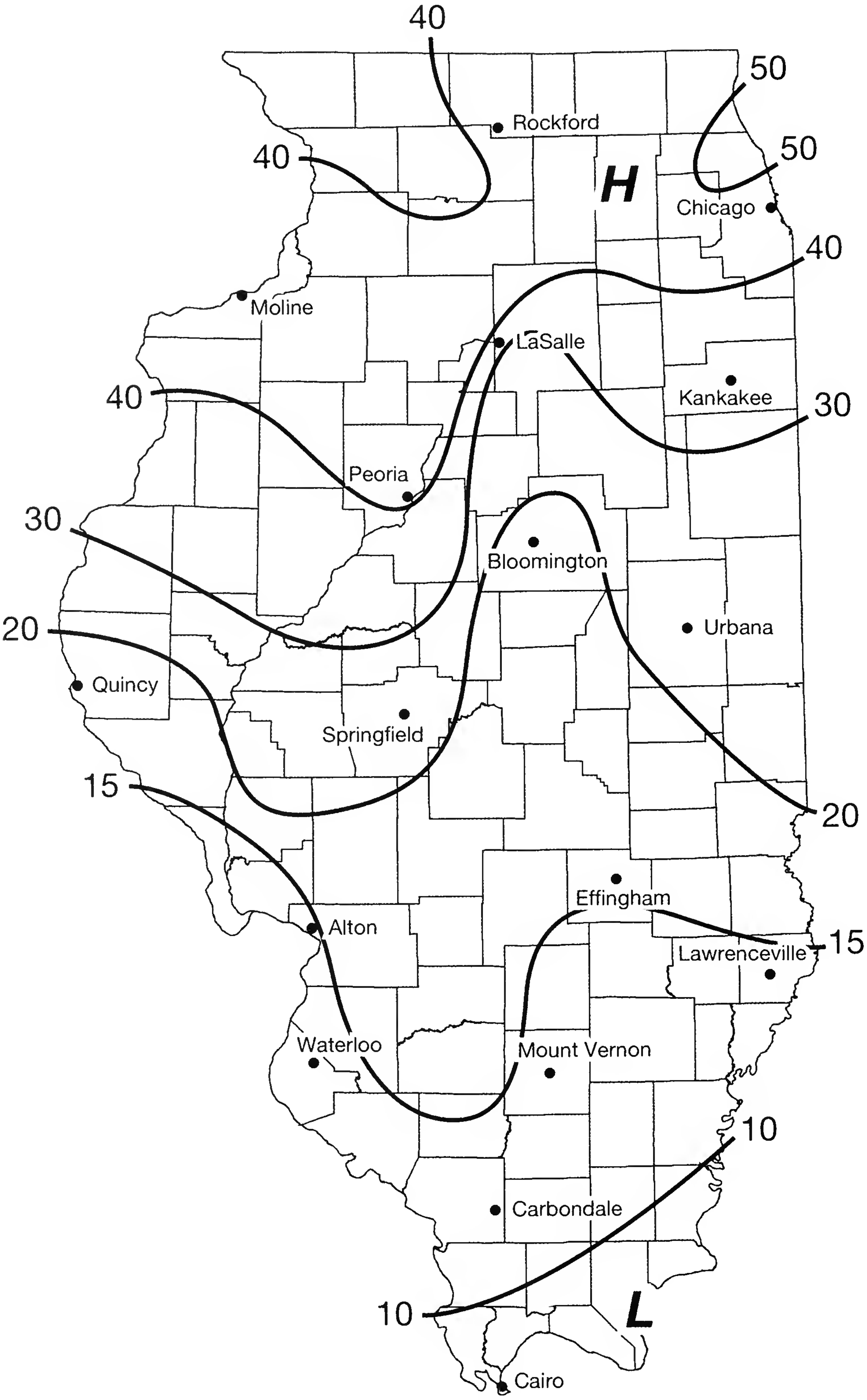


Figure 2. Patterns of snowfall (inches) for storms on December 7-9, 2009, and December 21-22, 2009.

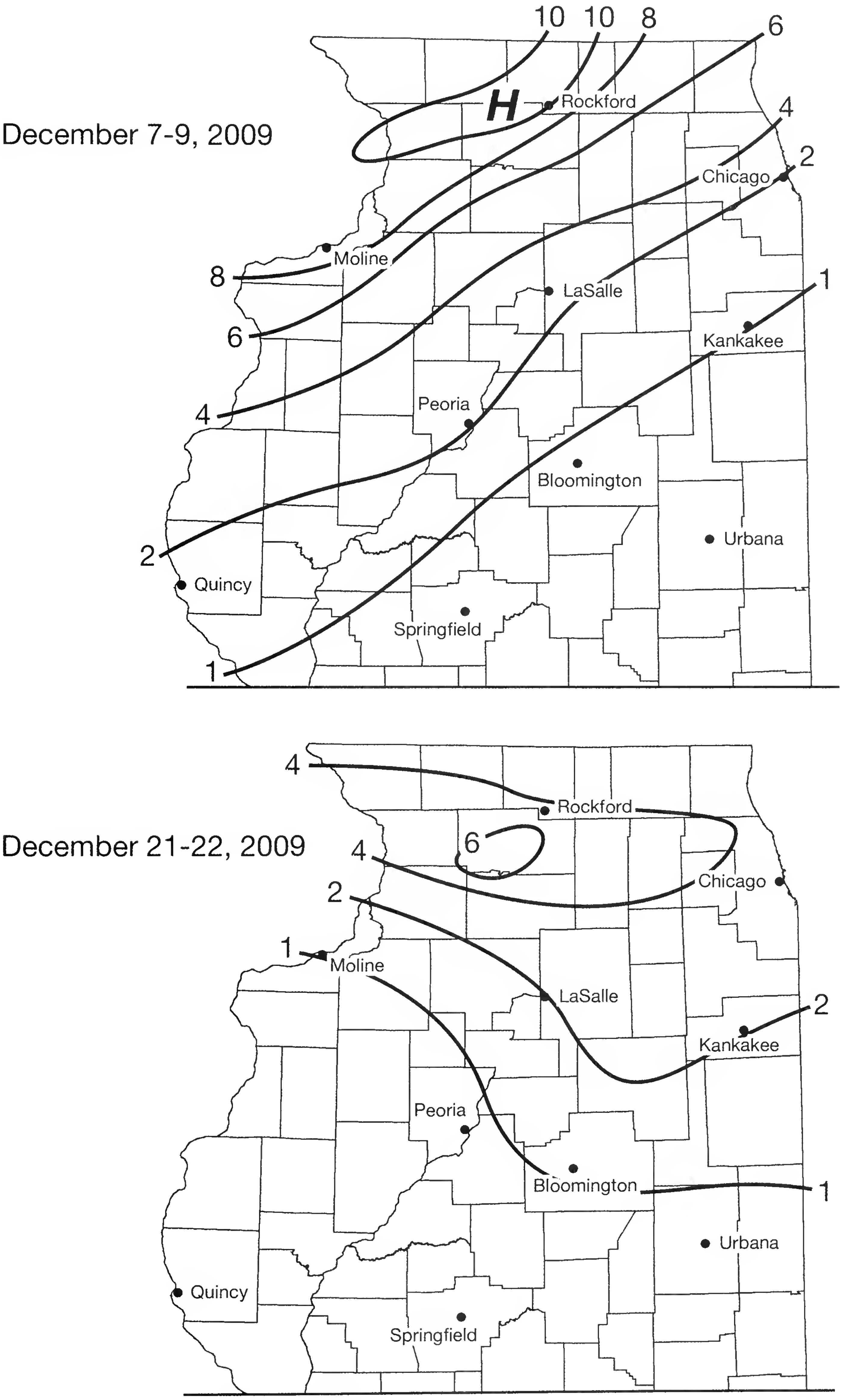


Figure 3. Pattern of snowfall (inches) from storm on December 25-26, 2009.

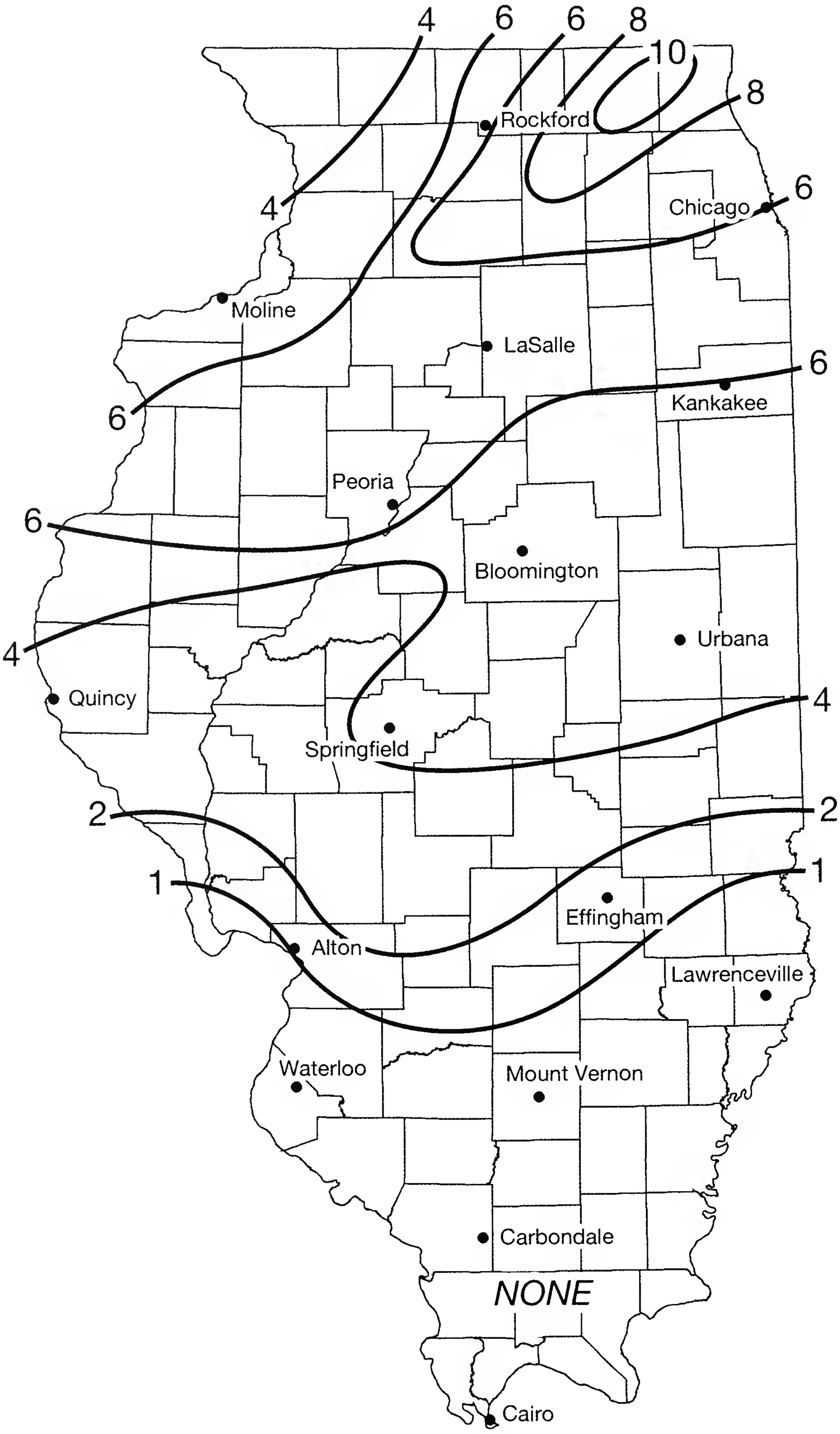


Figure 4. Pattern of snowfall (inches) forma storm on January 6-8, 2010.

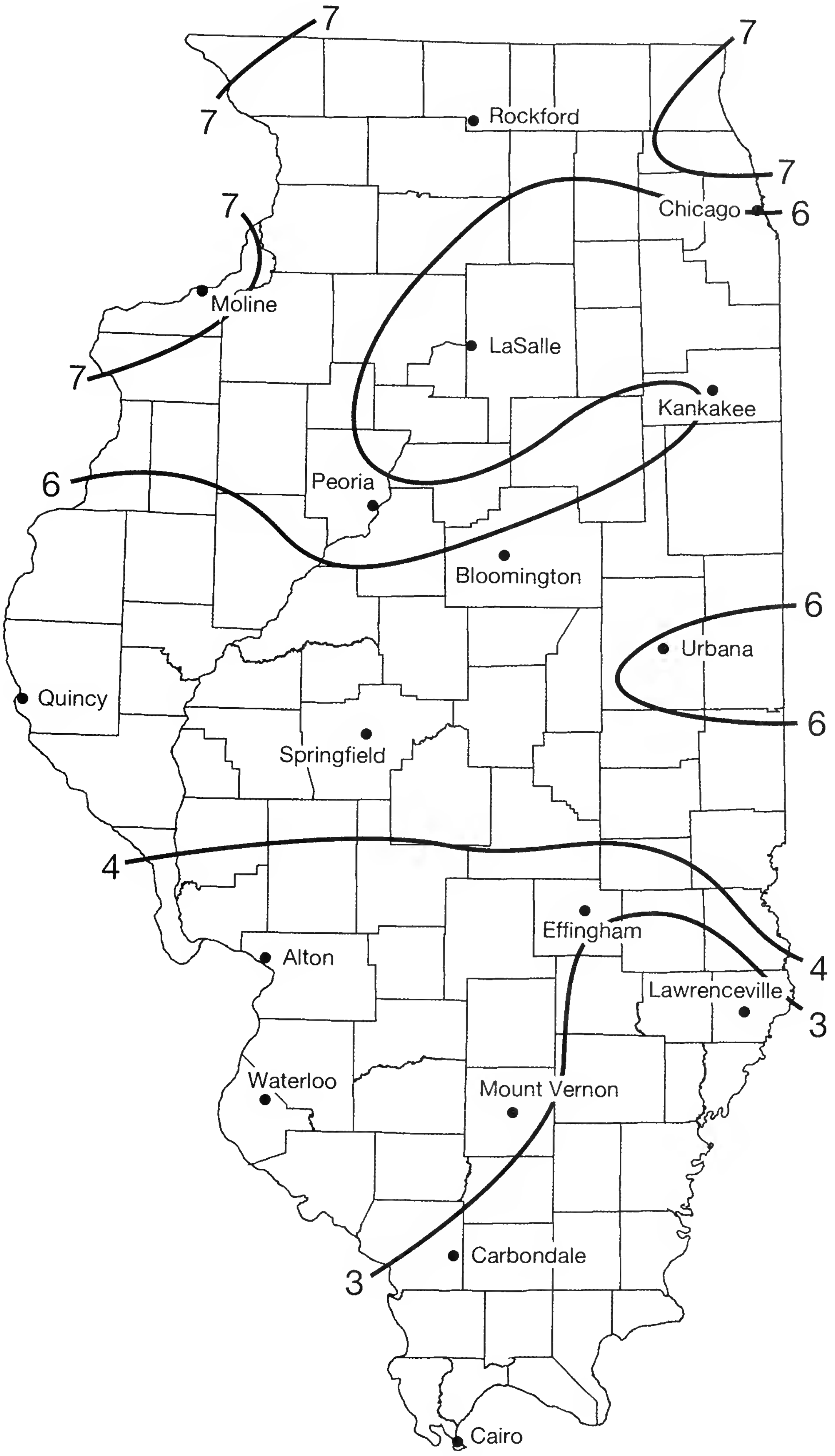
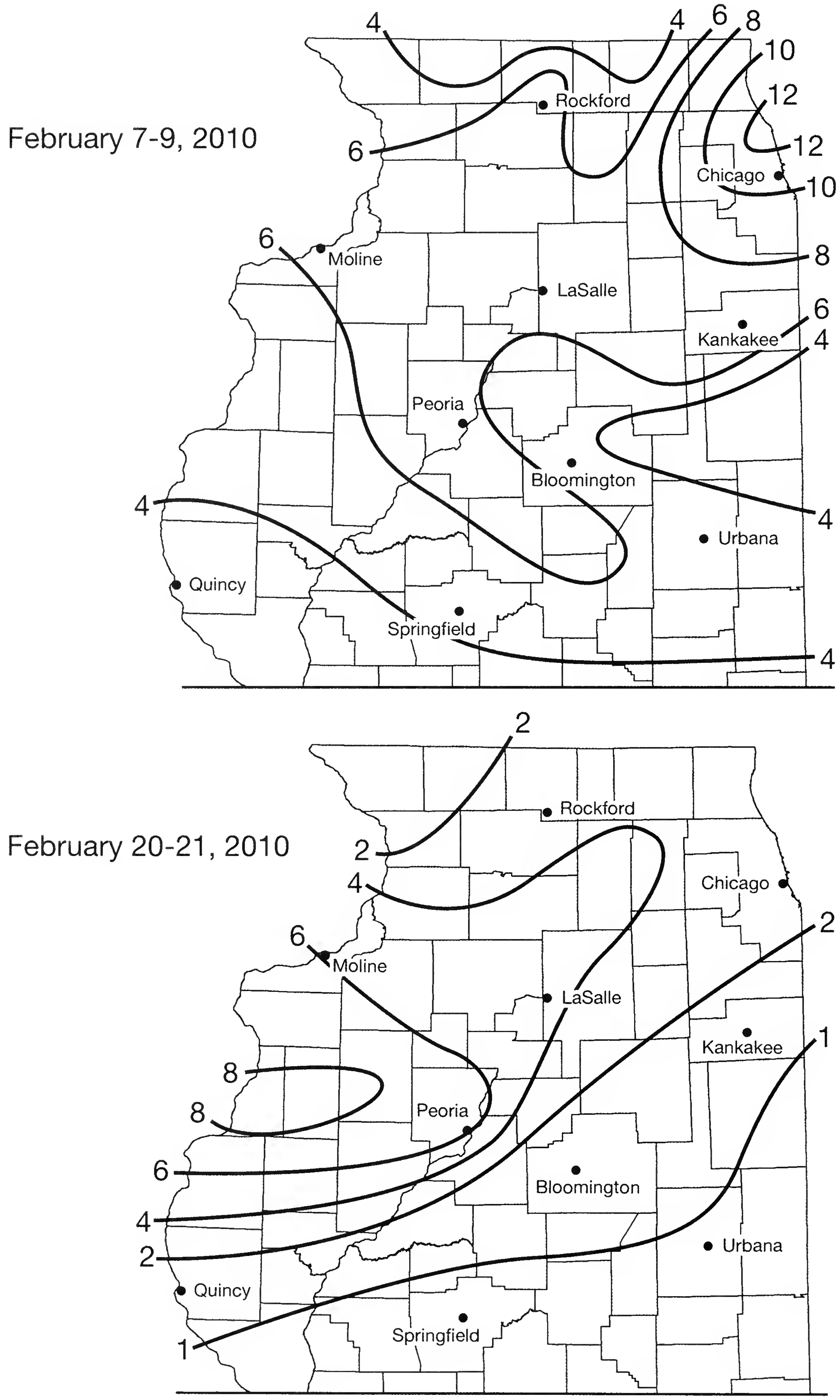


Figure 5. Patterns of snowfall (inches) for storms on February 7-9, 2010, and February 20-21, 2010.



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Use of a Right-of-Way by Breeding Birds in Lake County, Illinois

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ABSTRACT

Since 2007, there have been three objectives at the Lake County Research and Demonstration Area (LCRDA) in northeastern Illinois to: 1) compare commonly-used mechanical and herbicidal maintenance treatments on controlling target trees (trees capable of growing tall in wire zones and possibly causing a blackout, hereafter termed undesirable), 2) develop plant cover types that are resistant to tree invasion, and 3) determine the effectiveness of mechanical and herbicidal maintenance on vegetation and wildlife species of high public interest. The wire-border zone method of vegetation management was implemented on the right-of-way (ROW) on eight units of the Lake County Area, and four of the eight units (Gurnee Sites) were mowed in November 2009. The wire-border usually results in a tree-resistant forb-shrub-grass cover type in wire zones and a tall shrub cover type in border zones, thereby producing wildlife habitat diversity on the ROW.

INTRODUCTION

Transmission ROW are linear corridors that often traverse contiguous forests, thereby making these ROW extremely valuable for bird species requiring early successional habitats (Bramble et al.1992, Yahner et al. 2002). For instance, most nests found on the State Game Lands (SGL) 33 ROW in 1991-92 were those of early successional species, including field sparrow (*Spizella pusilla*), gray catbird (*Dumetella carolinensis*), eastern towhee (*Pipilo erythrophthalmus*), common yellowthroat (*Geothlypis trichas*), and indigo bunting (*Passerina cyanea*) (Bramble et al. 1994). My objective in the present study is to document 2-years (2008-09) of bird use of the LCRDA prior to maintenance in November 2009, with a particular focus on early successional bird species. Avifauna associated with the LCRDA has not been examined, to my knowledge.

STUDY AREA AND METHODS

The LCRDA is in Lake County, Illinois, just west and south of the town of Gurnee, 63 km north of Chicago, and 79 km south of Milwaukee. The LCRDA consists of a major span of ROW with several access points. Two sections of this ROW were selected tentatively in 2007 that accommodated eight treatment units, with each unit extending from 94-119 m long; the wire zone is about 46 m wide and each border zone is about 11 m wide. Sites selected for study depended on a measurement of undesirable tree density (e.g., trees that are can grow into the wire zone, thereby causing a blackout and invasive (including exotic species) or the presence of landscape features (e.g., residential areas, water bodies, and croplands were avoided). The LCRDA is about 2.41 km in length.

Undesirable tree species, e.g., green ash (*Fraxinus pennsylvanica*), are uncommon, and the invasive shrub, buckthorn (Rhamnus cathartica), an invasive species from Europe, is common throughout the ROW. A border zone, which ideally consists of desirable shrubs and trees, e.g., dogwoods (Cornus spp.) is virtually non-existent. Desirable trees and shrubs are those that are of benefit to wildlife as cover or food, provide aesthetic value to the ROW, and do not have the potential to grow tall enough to cause a power outage. The natural colonization of the border zones by desirable trees and shrubs will be encouraged via plant succession during the study. No shrubs or trees will be planted on the ROW.

I felt that it was critical to preliminarily assess the vegetation at the LCRDA in 2007 and again in depth in both 2008 and 2009, using techniques on SGL 33 RDA and Green Lane RDA in Pennsylvania (e.g., Yahner 2006). These techniques include a count of target (undesirable) trees at least 0.29 m in height. Trees were recorded within two permanent transect belts (each 19.56 m long x 1.96 m wide) in wire zones and within two corresponding permanent transect belts (each 9.78 m long x 1.96 m wide) that extended east and west within adjacent border zones of each unit. Only trees rooted in transect belts were counted, but those rooted outside the belt with foliage extending into the belt were not counted. I then calculated the total number of target trees/acre in each treatment unit and zone.

I noted the maximum height (to the nearest foot) of target trees in both wire and border zones of each unit in the vicinity of each transect belt (Yahner 2006). Cover types were determined within a 4.89-m radius plot placed in the center of each transect belt in wire and border zones, using the Braun-Blanquet Method for estimating abundance and sociability of major plants. From these estimates within each treatment unit, I calculated plant cover type(s) in each unit as forb, grass, shrub, tree, or a combination of these.

In June 2008, Lake County was designated a disaster county by the governor of Illinois because of excessive water in the area. This gives support for 2 years (2008-2009) of baseline information at the LCRDA.

The last year of ROW maintenance at the LCRDA was 2006, when it was maintained via herbicide. In a previous cycle (5 years earlier), it likely was treated via mowing (E. Cunningham, personal communication, 2007). The ROW consists of two rows of towers, with a 345 kV double-circuit tower to the west and a 138 kV double-circuit tower to the east. The 138- kV was built in 1958, and the 345-kV line was built in 1966. I monitored breeding bird populations for four consecutive mornings in both June 2008 and 2009, using a belt survey method (Yahner et al. 2002). Units were visited from dawn until about 11 am, varying order in which units were visited. All birds seen per unit, and their location in each unit (wire versus border) were noted during each survey. Care was made to monitor the location of each bird so not to count an individual bird twice. Birds flying entirely over the site were not counted. Because these results are based on a survey, I did not use statistics. Also, data were pooled in both years to increase sample size. With the exception of Red-winged Blackbirds, bird populations were similar between years.

RESULTS AND DISCUSSION

A total of 20 bird species was observed on the LCRDA in June 2008 and 2009 during breeding surveys. Of these 20 species, seven species were common in both years combined (observed at least once per day) (Table 1). Based on all 20 species, 10 (50%) are considered early successional species by many authorities. Common species found in both seasons were Red-winged Blackbirds (scientific names are in Table 1), Song Sparrows, Common Grackles, and Northern Cardinals. High numbers of Red-winged Blackbirds in June 2008 were expected because this species prefers wetlands and water. These habitats were abundant throughout the LCRDA vicinity, and this species nests in colonies. Song Sparrows and other early successional species were found on the LCRDA because several units contained high densities of woody shrubs.

In June 2008, which had an extremely wet spring, abundances of birds were somewhat higher than in June 2009. Densities in June 2008 attest to the need to conduct field studies for at least 2 years. Border zones usually were used more often than wire zones by birds in both years. For example, in June 2009, only 36% of the bird observations were in wire zones at the Gurnee sites. Exceptions in June 2008 were Red-winged Blackbirds, which probably nested or foraged in wet wire zones, American Goldfinches, which foraged in wire zones, and Eastern Kingbirds (*Tyrannus tyrannus*), which used the towers as perches and possibly as nest sites as at the Green Lane Research and Demonstration Area (RDA) (Yahner et al. 2002). In summary, based on 2 years of observations at the LCRDA, avifauna during the breeding season is abundant and diverse. The LCRDA is very important to early successional species, e.g., Song Sparrow, particularly in a ROW that traverses habitat unlike that of the LCRDA. I found that most species at the LCRDA are early successional species, as is true of two sites in Pennsylvania (Bramble et al. 1992, Yahner et al. 2002). Of these two sites, one site mainly traverses contiguous forest (SGL 33 RDA) and the other site is amid residential areas (Green Lane RDA).

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Table 1. Average number of individuals of a bird species seen per day of seven common species (those in which at least one individual was noted/day) and average number of common species seen per ha per zone (no./ha per zone [wire vs. border] in eight units at the Lake County Research and Demonstration Area near Gurnee, Illinois, in June 2008 and 2009 combined. Total area sampled at the LCRDA = 5.09 ha.

		No./Day/ha/Zone	
Species	Avg. No./Day	Wire	Border
Red-winged Blackbird (*Agelaius phoeniceus*)	9.0 (44.0)	0.27 (0.96)	1.13 (3.51)
American Goldfinch (*Spinus tristis*)	3.5 (5.5)	0.03 (0.12)	0.68 (0.17)
Gray Catbird (*Dumetella carolinensis*)	3.0 (3.5)	0.03 (0.03)	0.57 (0.28)
Song sparrow (*Melospiza melodia*)	3.0 (11.0)	1.47 (0.10)	0.11 (0.91)
Common Grackle (*Quiscalus quiscula*)	2.5 (8.0)	0.00 (0.10)	0.57 (0.57)
Northern Cardinal (*Cardinalis cardinalis*)	2.0 (6.0)	0.08 (0.12)	0.34 (0.51)
Yellow Warbler (*Dendroica petechia*)	1.0 (5.5)	0.06 (0.09)	0.00 (0.98)
Total (all 20 species)	34.0 (104.5)		

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Wild Turkeys Cause Little Damage to Row Crops in Illinois

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ABSTRACT

Similar to much of the agricultural Midwest, Eastern wild turkey (*Meleagris gallopavo silvestris*) populations have increased considerably in Illinois, making them more visible to landowners and occasionally being blamed for crop damage. We studied food habits of turkeys and wildlife damage to row crops to assess whether turkeys were causing damage to corn and soybeans in Illinois. Crops and gizzards were collected from 118 hunter-harvested turkeys during spring 2002. Corn and/or soybeans were found in >30% of samples, but these crops were consumed as waste grain and no young plants were detected. We sampled newly planted corn and soybean fields for wildlife damage during spring 2002 in areas where turkeys were present. Of 11,150 corn plants inspected, only 0.4% were damaged, and only 1 damaged plant was attributable to avian sources. Of 53,918 soybean plants sampled, 4.7% were damaged by wildlife, and none were attributable to turkeys. We sampled damage to 8,944 ears of corn during fall 2002; only 1.7% of ears were damaged, and none by turkeys. Similar to other studies in the agricultural Midwest, we found turkeys caused no definitive damage to row crops in Illinois.

Key words: food habits, human-wildlife conflict, *Meleagris gallopavo*, wild turkey

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INTRODUCTION

Wild turkey populations have been restored and enhanced through introductions and re-introductions in 49 states within the last 40 years, and nationwide populations are estimated to exceed 5 million birds with the Midwest having the highest densities (Kurzejeski et al., 1987, Miller et al., 2000, Tapley et al., 2001). Agricultural habitats are distributed throughout most of the Eastern wild turkey's (*Meleagris gallopavo silvestris*) distributional range. In the agriculturally-dominated Midwest, it has become clear to wildlife managers that agricultural habitats are actively used by turkeys (Porter, 1977, Craven, 1989, Gabrey et al., 1993, Miller et al., 2000, Swanson et al., 2001). Since turkeys are relatively large, gregarious, and feed during the day, they are readily observed in agricultural areas. This increased abundance and greater visibility of turkeys has led to concern among farmers, and wildlife managers as to the degree of agricultural damage caused by turkeys. Studying food habits of turkeys and crop damage simultaneously could prove useful in dispelling myths and changing how this species is perceived by concerned farmers. Therefore, several Midwestern states have studied turkeys in agricultural landscapes and investigated the perceived or real agricultural damage turkeys cause (Craven, 1989, Gabrey et al., 1993, Paisley et al., 1996, Swanson et al., 2001).

The Illinois Department of Natural Resources (IDNR) has received increasing numbers of complaints from landowners blaming turkeys for crop damage (P. Shelton, IDNR, personal communication) which prompted our study of turkey damage to crops in Illinois. Specifically, we quantified (1) food habits of turkeys during spring, and (2) summer crop damage attributable to turkeys. Our goal was to provide wildlife managers with information regarding how much turkeys actually damage crops in Illinois.

MATERIALS AND METHODS

Study Areas

The study area for the food habits objective included the 96 of 102 Illinois counties open to the 2002 spring turkey hunting season. The predominant land cover type in Illinois is row crop agriculture; about 54% of the land cover is row crops and 11% is forest (Foster et al., 1997). Forest cover at the county level ranges from 40-60% in the unglaciated Shawnee Hills region in extreme southern Illinois to <5% in the intensively farmed east-central portion of the state (Luman et al., 1996).

The study area for the crop damage objective was a 1,082-ha area of private land located in Jackson County, in southern Illinois, constructed from radiotelemetry locations of turkeys in a concurrent study (Greene, 2003). Land cover on the southern Illinois study area was 49% deciduous forest; dominated by white oak (*Quercus alba*), black oak (*Q. rubra*), and hickories (*Carya* spp.); 37% cropland (26% in row crops, primarily corn and soybeans); and 6% rural grasslands (Luman et al., 1996). The remaining 8% cover was transportation (i.e., roads and railroads), urban areas, and streams.

Food Habits

Turkey crops were collected from hunters during the 2002 Illinois spring turkey season (8 Apr-16 May). A request for hunter assistance in crop and gizzard collections was included in all 2002 spring turkey season permit packets issued by the IDNR, and a toll-free telephone number was established for successful hunters to contact the Cooperative Wildlife Research Laboratory (CWRL) at Southern Illinois University Carbondale. An automated request for hunter cooperation was also added to the IDNR's telephone check-in system for successful hunters mid-way through the hunting season. Successful hunters were asked to save and freeze the crop and gizzard from their harvested turkey and then contact the CWRL to receive a postage-paid envelope and packing materials.

Crop and gizzard samples were placed in a freezer until all samples were received. Contents were analyzed using methods described by Martin et al. (1946) and Swanson et al. (1974); these methods are the standard for studies of turkey food habits (Paisley et al., 1996, Swanson et al., 2001). Crops were separated from gizzards and total volume of crop contents was measured using water displacement in a graduated cylinder. Contents were then separated by like types, and volume of each food type was measured as above. Food items <1 cc were recorded as trace and only included in the frequency of occurrence data. Gizzard contents were inspected and any identifiable food items not found in the respective crop were included in the frequency of occurrence data.

Row Crop Damage

Four corn and 4 soybean fields in the Jackson County study area were sampled to estimate damage caused by wildlife during 5 June-26 July 2002. A systematic sampling design was chosen to ensure total field coverage and to reduce biases associated with sampling fields with different land cover types and proportions along their respective borders. First, a baseline was established at the longest field axis and parallel to the rows. Then, an initial transect was randomly located along the baseline and a total of 10 equidistant perpendicular transects were located along the baseline extending to the field edges. The number of plots required for each transect was determined by the formula:

Number of plots/transect = (transect length/sum of all transects) × field area

An initial plot location was randomly located along each transect and the required number of plots were located perpendicular to and equidistant along transects. Plot length began at the transect and successive plots extended in opposite directions. Plots were 10 m × 2-rows-wide for corn and 10 m x 3-rows-wide for soybeans.

We recorded the following data along crop transects: total number of plants, number of plants grazed or otherwise damaged by wildlife, and wildlife species responsible for damage. The latter was determined using a combination of wildlife sign and criteria described by Dolbeer (1980) and the Ohio Department of Natural Resources (2001); turkey damage was identified as an "avian source" of damage. We assessed the nature of damage done to specific plants, and when possible, identified tracks and droppings of wildlife species coincident with damage occurrence. For example, avian sources of damage were generally indicated by digging and scratching of the seed bed, and deer damage appeared as ragged leaf edges following browsing. Plants grazed or damaged were marked and their fate recorded. Fields were sampled once/week for 4 weeks, beginning 1 week post-emergence.

The 4 corn fields were sampled during spring-summer 2002 and 1 additional field was sampled for wildlife damage in September 2002. Soybeans were not sampled in the fall because they were not considered a primary turkey food source (Korschgen, 1967). Transects and plots were established using the same methods as aforementioned. Total number of ears/plot, number of ears damaged, and wildlife species responsible were recorded.

RESULTS

Food Habits

We collected 118 food habit samples from hunters; 102 consisted of the crop and gizzard and 16 consisted of the gizzard only. Forty-one food items (33 plant, 8 animal) were identified (Table 1). Corn ranked first in frequency of occurrence, aggregate volume, and aggregate percent. Soybeans ranked fifth in frequency of occurrence and sixth in aggregate volume and aggregate percent. All agricultural food items were waste, and no emergent agricultural plants were found. Corn accounted for 42.9% of the total volume (29.7% frequency of occurrence), and soybeans 2.7% of total volume (12.7% frequency of occurrence). Wheat was found only in trace amounts (<1% frequency of occurrence).

Plant to animal ratios based on aggregate volume and aggregate percent were 37.0:1, and 17.0:1, respectively.

Row Crop Damage

We sampled 53,918 soybean plants in the spring, of which only 2,515 (4.7%) were damaged. Only 2 sources of damage were identified: white-tailed deer (*Odocoileus virginianus*) and woodchuck (*Marmota monax*). Avian sources caused no damage to soybean plants. A total of 11,150 corn plants was sampled, of which, only 50 (0.4%) were damaged. Insects damaged the most plants (n = 31), followed by deer (n=18) and birds (n=1).

We examined 8,944 corn ears for damage in the fall; 153 (1.7%) were damaged. European corn borer damage and stalk rot were combined as they were sometimes impossible to discern and accounted for 58.8% of all damage. Avian sources, deer, and raccoon (*Procyon lotor*) accounted for 26.1%, 12.4%, and 2.6% of all damage, respectively.

DISCUSSION

Turkeys did not cause any definitive damage to row crops in Illinois. However, turkey use of waste grains, especially corn, as a food source in agricultural landscapes has been documented by several researchers (Lancia and Klimstra, 1978, Porter, 1980, Payer and Craven, 1995, Paisley et al., 1996) and our results indicate that turkeys use waste grains extensively in Illinois. In spring, agricultural crops constituted >45% (42.9% corn) of the foods found in crop and gizzard samples. Because no unweathered seeds or seedlings of any agricultural crops were observed in any of the spring samples, agricultural food items were only waste from the previous harvest. These results are generally unsurprising given the abundance of waste grain in Illinois cropfields (Warner et al., 1989).

Most turkey food habits studies depict soybeans as a rarely used food item, if they are even mentioned at all (Korschgen, 1967, Hurst, 1992, Payer and Craven, 1995). In contrast, we found soybeans accounted for 3% (12.7% frequency of occurrence) of the total food volume in spring. However, these food habits studies were conducted before populations proliferated in agricultural regions and this may be the reason soybeans are rarely mentioned in the literature as a turkey food item.

Turkeys have been documented to consume hundreds of different plant and animal species throughout the year (Mosby and Handley, 1943), and we found 41 different food items used by turkeys in this study. The diversity of food items available to turkeys between highly agricultural areas and those areas considered ideal turkey habitat (i.e., a 1:1 mix of open land to forested land; Kurzejeski and Lewis, 1990) are probably very different. However, the fact that turkeys very are adaptable, opportunistic feeders, and now thrive in areas once considered less than optimal (i.e., agricultural areas), suggests that managing habitat for food production may be less important than managing for needs such as nesting, brood rearing, and roosting refugia (Hurst, 1992). The exception would be the northern limit of turkey range, where turkey populations can be expanded with programs that supplement natural food availability. In northern turkey populations, turkeys can sustain themselves on agricultural crops such as corn food plots during periods of persistent deep snow that limits natural food availability (Haroldson, 1996, Porter et al., 1980).

Crop damage by wildlife is a major concern for landowners and farmers, and has been studied at multiple scales and using various techniques (Paisley et al., 1996). In the top 10 corn-producing states, wildlife were estimated to reduce yield by 1.7 bushels/ha, and yield lost in Illinois alone was 0.9 bushel/ha (Wywialowski, 1996). Other studies (Gabrey et al., 1993, Payer and Craven, 1995, Paisley et al., 1996) have addressed the issue of turkey damage to crops and have generally concluded that turkey damage was minimal, especially to emergent crops. Although turkeys caused no definitive crop damage in our study, several other sources contributed to crop loss. As in our study, Clarke and Young (1986) reported insects caused the most damage to seedling corn in Iowa. Avian damage occurred less frequently in Illinois compared to other studies (Hiesterberg, 1983). However, bird damage, especially by blackbirds, is not evenly distributed and is influenced by a variety of factors (Bollinger and Caslick, 1985), making direct comparisons between regions difficult. Deer and raccoons also caused damage to crops in Illinois, as reported by other studies (Gabrey et al., 1993, Swanson et al., 2001).

CONCLUSIONS

Turkeys have been labeled as diet generalists by wildlife biologists, and this is supported by our study and numerous other food habits studies. Conducting more food habits studies and compiling lists of what turkeys eat will probably not change this fact or reveal much novel information. However, food habits studies in combination with more specific questions may add to the knowledge base of turkey ecology. For example, what foods are critical to a pre-laying hen and how might this affect reproductive success and hence turkey numbers?

Most studies of turkey damage have concluded that it is minimal or nonexistent (Gabrey et al., 1993, Swanson et al., 2001). Further turkey damage studies at current population levels are unlikely to reveal contrasting results. However, if more land is converted to agricultural (row crops) land use, especially given increased interest in ethanol production in the Midwest and Illinois (Bies, 2006), reliance on agricultural foods may increase. Perhaps then the issue of turkey damage will need to be revisited.

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Table 1. Percent frequency (%F), aggregate volume (AV), and aggregate percent (AP) of food items found in crops and gizzards of 118 wild turkeys harvested in Illinois during the spring 2002 hunting season.

Food item	%F	AV	AP
Plant foods			
Corn, *Zea mays*	29.7	42.9	44.8
Grass leaves, Graminae	17.8	2.6	1.8
Hackberry, *Celtis laevigata*	16.9	trace	trace
Dandelion, *Taraxacum officinale*	14.4	4.3	4.5
Soybeans, *Max glycine*	12.7	2.7	3.7
Unclassified grass seed	11.0	14.6	4.1
Buttercup, *Ranunculus* spp.	9.3	6.2	11.4
Undetermined plants and debris	9.3	trace	trace
Clover, *Trifolium* spp.	6.8	15.8	5.5
Kentucky coffee, *Gymnocladus dioca*	3.4	trace	trace
Yellow harlequin, *Corydalis flavula*	3.4	1.3	2.2
Fescue, *Festuca arundinacea*	3.4	trace	trace
Rattlesnake fern, *Botrychium virginianum*	2.5	trace	trace
Chickweed, *Stellaria media*	2.5	trace	trace
Crabgrass, *Digitaria sanguinalis*	2.5	0.6	1.4
Sedges, *Carex* spp.	2.5	trace	trace
Ragweed, *Ambrosia artemisiifolia*	1.7	trace	trace
Unidentified legume, Legumaceae	1.7	0.3	0.4
Jack-in-the-pulpit, *Arisaema atrorubens*	0.8	trace	trace
Osage orange, *Maclura pomifera*	0.8	trace	trace
Green dragon, *A. dracontium*	0.8	trace	trace
Violet, *Viola* spp.	0.8	trace	trace
Acorn, *Quercus* spp.	0.8	trace	trace
Sedge seed, *Carex* spp.	0.8	trace	trace
Clover, *Meliotus* spp.	0.8	trace	trace
Wheat, *Triticum aestivus*	0.8	trace	trace
Poison ivy, *Rhus radicans*	0.8	trace	trace
Persimmon, *Diospyros virginiana*	0.8	trace	trace
Wild strawberry, *Duchesnea indica*	0.8	trace	trace
Raspberry, *Rubus* spp.	0.8	trace	trace
Foxtail, *Setaria faberii*	0.8	0.6	2.7
Daisy fleabane, *Erigeron annuus*	0.8	trace	trace
Buckwheat, *Fagopyrum sagitattum*	0.8	trace	trace
Animal foods			
Beetle, Coleoptera	5.1	1.0	1.8
Stinkbug, Pentatomidae	5.9	0.2	0.1
Assasin bug, Reduviidae	3.4	trace	trace
Earthworm, Annelida	0.8	trace	trace
Snail, Gastropoda	0.8	trace	trace
Grasshopper, Orthoptera	0.8	trace	trace
Caterpiller, Lepidoptera	0.8	trace	trace
Unidentified insects	0.8	trace	trace

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Scavenging Rates Highest at Windowed Compared to Windowless Sites at Millikin University in Decatur, Illinois

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ABSTRACT

The number of bird-window collisions is estimated to be between 100 million-1 billion per year. One reason for the wide estimate in the number of collisions is that scavengers tend to find carcasses before they are found. We examined whether bird-window collisions influence foraging patterns by comparing scavenging rates at windowed sites compared to windowless walls. The study was conducted at Millikin University in Decatur, Illinois from Fall 2007 to Fall 2008. Six, 40-day trials were conducted in which 20 grams of chicken breast was placed at 16 sites (8 windowed and 8 windowless sites), and the status of the chicken was monitored every 12 hours. Scavenging rates were faster at windowed sites 0 m from windows compared to windowed sites 10 m from windows and locations 0 and 10 m from windowless walls. Scavenging rates also varied by season with faster rates in the spring and summer months compared to the fall and winter. While scavenging rates were faster at windowed sites 0 m from windows, seasonal scavenging patterns did not correspond with the seasonal distribution of bird-window collisions. Thus, faster scavenging rates in the spring and summer are most likely a result of an increase in the number and kinds of scavengers present.

INTRODUCTION

On average, 1-10 birds die in bird-window collisions per building per year (Klem 1990). Bird-window collisions occur because birds do not recognize glass as a barrier reflecting habitat or birds attempt to fly through two parallel panes of clear glass (Klem 1989). The large range in the estimated number of collisions may partially be a result of a lack of reliable estimates of search efficiency and scavenging rates (e.g., Osborn et al. 2000). Bird-window collisions can be difficult to detect as the coloration of bird carcasses is often cryptic. Scavengers may take carcasses before they can be discovered. Scavengers may remove 10-50% of carcasses after one day (Kostecke et al. 2001).

While the average number of bird-window collisions is 1-10 birds per building per year (Klem 1990), the frequency of collisions is not equally distributed throughout the year. At Millikin University in Decatur, Illinois, 69% of bird-window collisions occur during three months (May, September, and October), corresponding with the peak of spring and fall bird migration (Horn unpubl. data). Moreover, common fatalities at windows, such as warblers and doves, range from 20 – 130 grams and are large prey items relative to other available food sources. Thus, for scavengers whose home range contains a high density of windowed structures, it may be energetically rewarding to forage closer to buildings during peak bird migration to take advantage of a seasonal influx of larger prey items.

We examined whether scavenger foraging patterns were influenced by bird-window collisions. Specifically, we determined whether the scavenging rate was different at windowed sites compared to non-windowed sites (e.g., Klem et al. 2004). We also examined how scavenging rates changed by season. We predicted that windowed sites would have faster scavenging rates because scavengers may find more profitable prey in the form of carcasses from bird-window collisions.

METHODS

The study was conducted on the Millikin University campus in Decatur, Illinois from Fall 2007-Fall 2008. During the study, six, 40-day trials were performed. The six trials were conducted Oct. 9–Nov. 17, 2007 (Fall 2007), Feb. 3-Mar. 14, 2008 (Winter 2008), Mar. 27-May 7 (Spring 2008), May 20-June 30 (Summer 1 2008), July 13-Aug. 23 (Summer 2 2008), and Sept. 3-Oct. 15 (Fall 2008). During each trial, we used 8 windowed sites and 8 non-windowed sites. The sites were located at 9 academic buildings with similar architecture and levels of human activity, and each building had 1 or 2 sites. The area occupied by the buildings fit within the home range of most mammalian scavengers.

At each of the 16 sites, 20 grams of uncooked chicken was placed in one of two locations: 0 m from the building or 10 m from the building. Twenty grams of chicken was selected to approximate the weight of a migrating warbler. Most bird carcasses are found within 1 m of a window (Horn pers. obs.). Thus, scavengers should not be searching for carcasses 10 m from windows. Each day, chicken was placed at 4 of 32 locations, and its fate was monitored every 12 hours for 48 hours after which it was removed. During each 12-hour check, if the chicken was no longer present or was at least 50% missing, it was considered to be scavenged. Over an eight-day period, all 32 locations had chicken, and over a 40-day period, each location had chicken five times. The order of chicken placement was random, and was the same each trial.

95% confidence intervals of the number of hours until chicken was scavenged were calculated for windowed sites 0 and 10 m from buildings and windowless walls 0 and 10 m from buildings for each season and for all seasons combined. In addition, confidence intervals were calculated for all locations combined for each season. Non-overlapping confidence intervals were considered statistically significant.

RESULTS

We found that scavenging rates were faster at windowed sites 0 m from buildings compared to windowed sites 10 m from buildings and windowless walls (Fig. 1). The mean scavenging rates were 34.4 hours at locations 0 m from windows, 39.5 hours 10 m from windows, 37.9 hours 0 m from windowless walls, and 38.5 hours 10 m from windowless walls. Scavenging rates differed by season with scavenging rates fastest in spring and summer, and slowest in fall and winter (Fig. 2). Scavenging rates ranged from 32.5 hours in late Summer 2008 to 45.3 hours in Fall 2008. Differences in seasonal scavenging rates resulted in two general patterns. In the fall and winter months, we observed faster scavenging rates at windowed sites 0 m from buildings compared to windowless walls (Fig. 3), whereas in spring and summer, there were no differences in scavenging rates among locations (Fig. 4).

DISCUSSION

In general, scavengers removed chicken from windowed sites 0 m from buildings at a faster rate than windowed sites 10 m from buildings and non-windowed locations. Thus, scavengers may be actively searching along windowed walls for carcasses. Klem et al. (2004) found that bait at windowed sites was removed while bait at windowless walls was not. In addition, they found that scavengers returned to locations where food was previously found.

We found that scavenging rates were faster in the warmer months compared to the colder months. This relationship has varied among studies. DeVault and Rhodes (2002) found that vertebrate scavenging was faster as air temperature increased, while DeVault et al. (2004) found slower scavenging rates by vertebrates during warmer periods. DeVault et al. (2004) suggested that the discrepancy in results between these two studies was due to seasonal temperature differences.

Seasonal changes in scavenging rates may be a result of changes in the abundance and composition of scavengers. The domestic cat (*Felis catus*), eastern fox squirrel (*Sciurus niger*), and insects were among the scavengers observed between Fall 2007-Fall 2008 at Millikin University. The domestic cat was spotted on several occasions. Nutter et al. (2004) found there were more pregnant cats in March-May. An increased number of cats in the spring and summer months may have resulted in faster scavenging rates. In addition, arthropods and bacteria are more abundant and decompose carcasses more quickly in the summer months (DeVault et al. 2004).

While scavenging rates were faster 0 m from windows, scavenging rates did not correspond with peak times for bird-window collisions. Bird-window collisions at Millikin University are most likely to occur during spring and fall migration (Horn unpubl. data), while differences in scavenging rates between windowed and windowless sites are most likely to be detected in fall and winter. This suggests that faster scavenging rates in spring and summer are more likely a result of an increased number of scavengers (DeVault et al. 2004). The greater number of scavengers may search larger areas during warmer months, and in turn, reduce the influence the presence of windows has on scavenging rates.

While groundskeepers were informed of our bird-window collision studies, it is possible that some chicken was removed by groundskeepers. However, given the location of the chicken, it was more likely that chicken was taken from locations 10 m from buildings (which would be near sidewalks and parking lots) compared to 0 m from buildings (which were grassed). Thus, any effect that groundskeepers had would make it more difficult to detect the differences we observed. Future studies should examine the composition of scavengers on the Millikin University campus and the role of domesticated (e.g., dogs and cats) versus wild animals on scavenging rates.

ACKNOWLEDGMENTS

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Figure 1. Cumulative results of scavenging rates comparing windowed sites and windowless walls at locations 0 and 10 m from buildings. Scavenging rates were faster at windowed sites 0 m from the building compared to the other three locations.

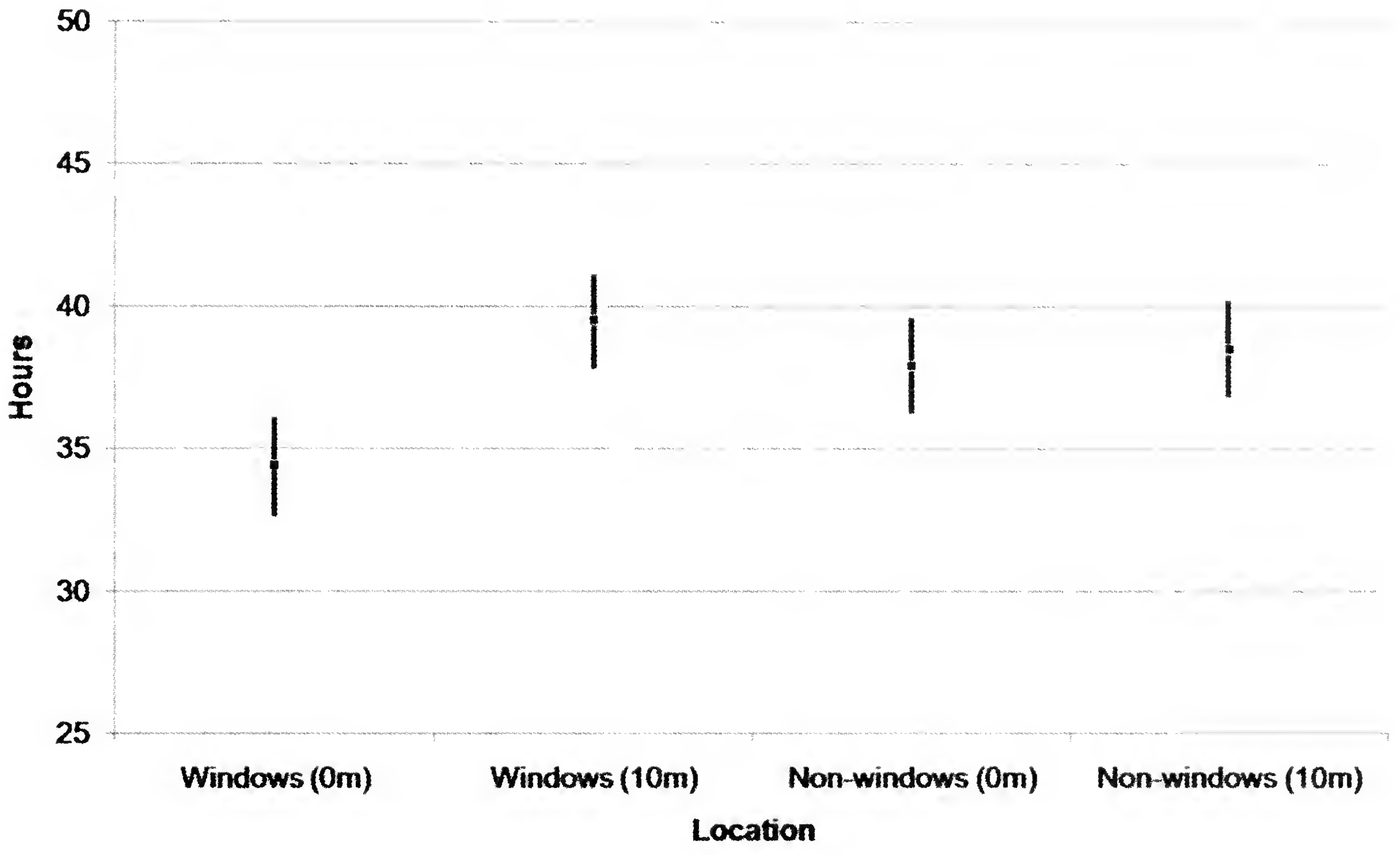


Figure 2. Cumulative results of scavenging rates by season. Scavenging rates were generally faster in the spring and summer months compared to the fall and winter months.

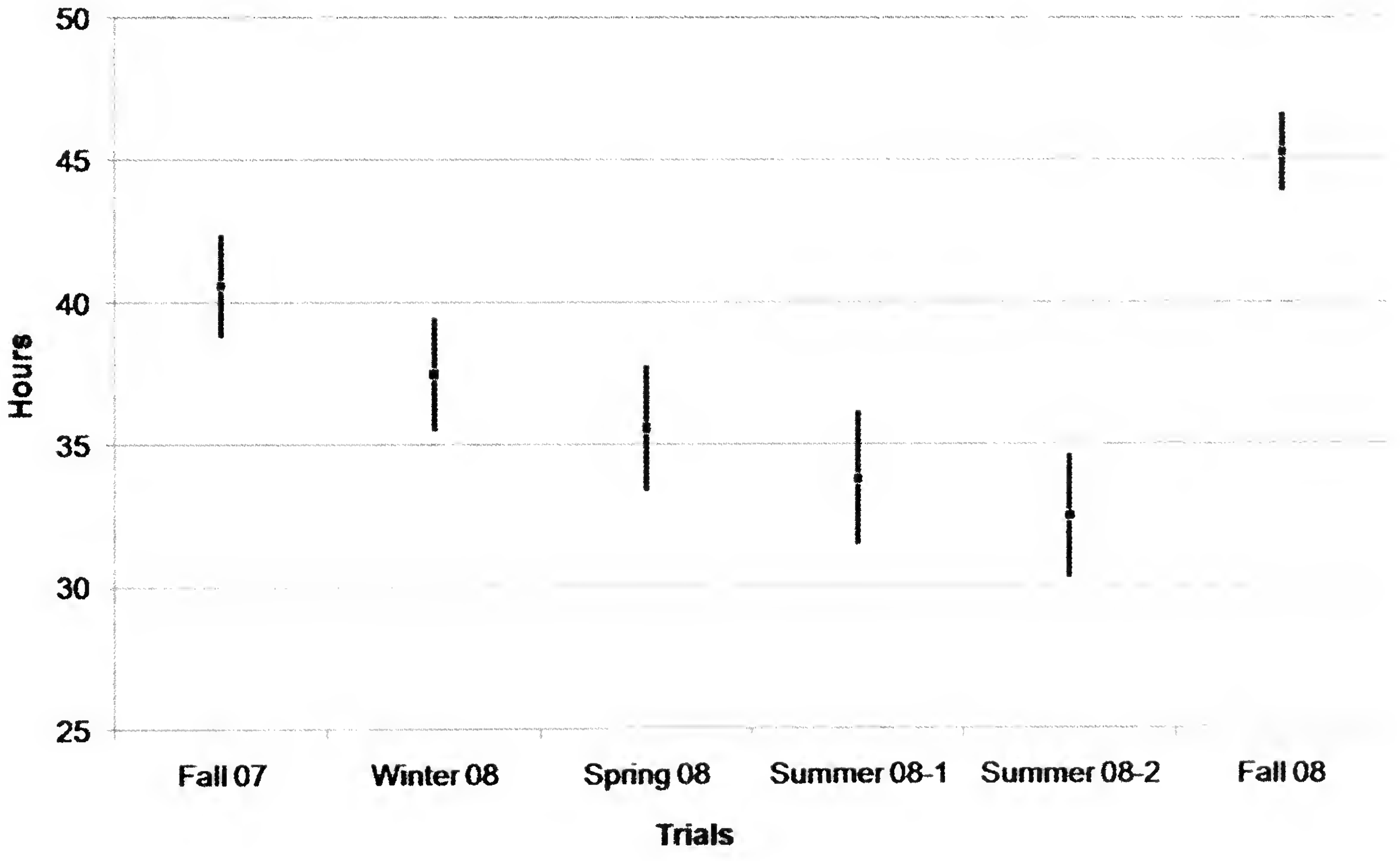


Figure 3. In Fall 2007 and Winter 2008 (shown), scavenging rates were faster at windowed sites 0 m from the building compared to locations 0 and 10 m from windowless walls.

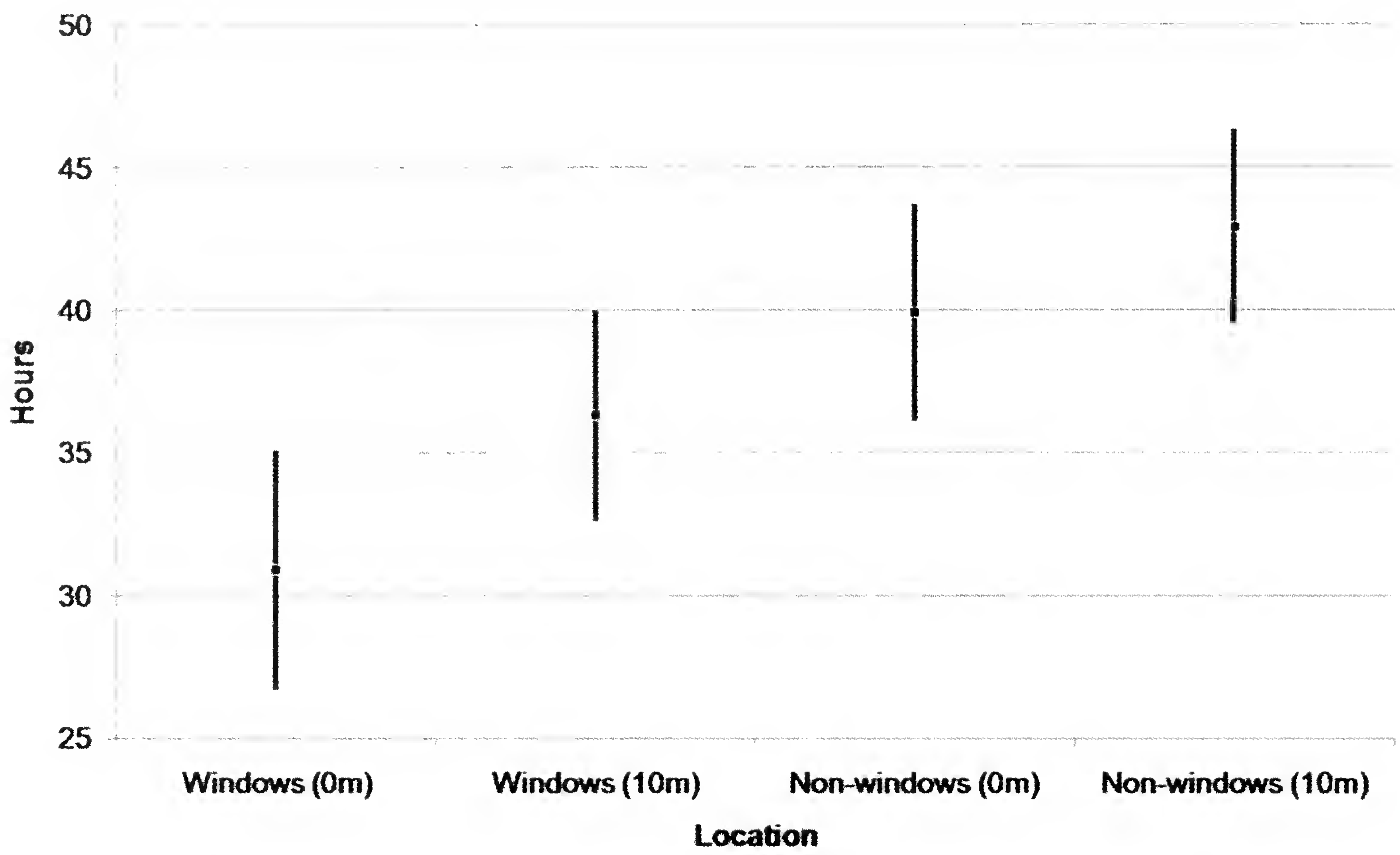
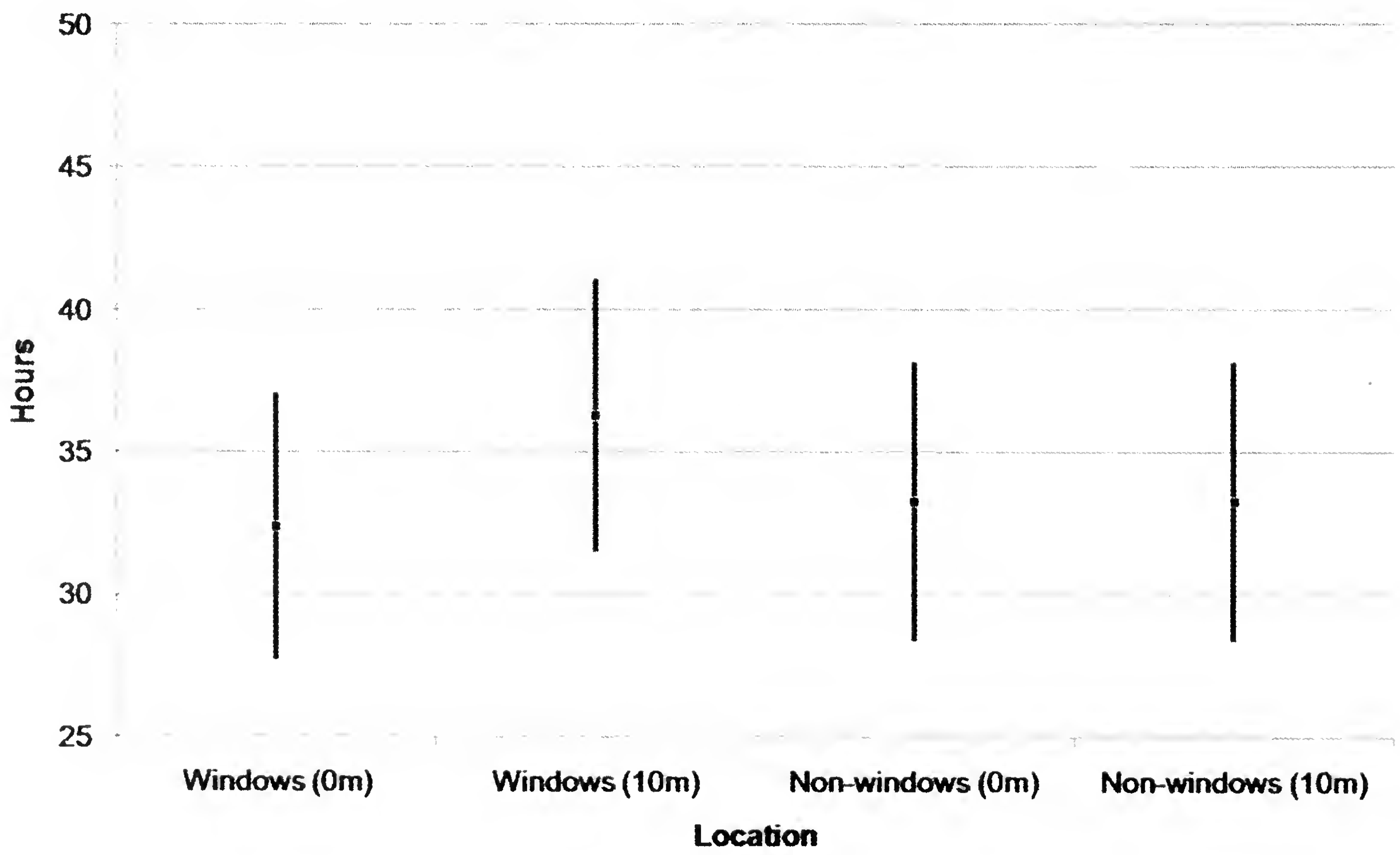


Figure 4. In Spring and Summer 2008 (May 20-June 30 shown), no differences in scavenging rates were found between windowed and windowless-wall sites.



BOOK REVIEW 2010 - #3

Vanderpoorten, A. and B. Goffinet. Introduction to Bryophytes. 2009. viii + 303 pages (+ 16 pages unnumbered); figures; tables; black and white photographs; colored photographs (plates); line drawings; glossary; references; index. Cambridge University Press, New York, New York. ISBN: 978-0-521-70073-3 (Soft Cover) and ISBN: 978-0-521-87712-1 (Hard Cover); Prices: $45.00 and $110.00, respectively. Available from Cambridge University Press, 32 Avenue of the Americas, New York, NY 10013.

Introduction to Bryophytes (IB) is a noteworthy, up to date, text on the biology, from an evolutionary perspective, of liverworts, hornworts, and mosses. A wide range of topics are explored among ten chapters including, but not limited to, morphology, geography, ecology, physiology, and conservation. Coverages of the topics are enhanced by effective figures and photographs. In addition, selected topics are discussed in special boxed off areas. As the authors intended, the book's contents focus on recent advances in the study of bryophytes. This is evident by the large number of mostly primary literature citations of nearly 500. Of these, about 87% were published from 1990 to some in 2009. Although the book's coverage assimilates selected materials from the more comprehensive tome Bryophyte Biology edited by Goffinet and Shaw (Cited in IB), Introduction to Bryophytes can stand alone and is suitable for beginning students of bryology with an introductory background in botany. Because the book's contents center mostly on relatively recent literature, we will, from time to time, mention older monographs not cited by the authors to assist new students to bryology who might seek additional information, historical perspectives, and different points of views on related bryological topics.

In chapter one, "Evolutionary significance of bryophytes," the authors build a firm comparative morphological case regarding bryophytes as embryophytes along with the other terrestrial plants, the vascular plants. The vascular plants (tracheophytes) of our biosphere are the ferns and fern allies (pteridophytes), the non-flowering seed plants (gymnosperms), and the flowering seed plants (angiosperms). Also, bryophytes and vascular plants are members of the same kingdom, Kingdom Plantae. In addition to the commonality of the life histories among bryophytes and vascular plants; the bryophytes have distinct morphological features that are noteworthy; we will mention two. First, when one sees a liverwort, hornwort, or moss in the field or elsewhere, the observed specimen, with only a very few exceptions, represents the gametophyte (1n) phase of the organism's heteromorphic alternation of phases (or generations). The gametophyte phase of bryophytes is the conspicuous and dominant photosynthetic phase and the gamete producing phase. Secondly, the sporophyte (2n) phase of bryophytes remains attached to its gametophyte parent throughout its development to maturity and often past spore release. In contrast, among the vascular plants the sporophyte (2n) phase is the dominant and major photosynthetic phase; whereas the gametophyte (1n) phase is generally inconspicuous.

Furthermore, in considering the comparative morphological features of bryophytes and vascular plants, the authors explore the evolutionary status of liverworts, hornworts, and mosses among the terrestrial plants with an eye on their ancestral origin and transition from an aquatic environment to an aerial land environment. Different phylogenetic hypotheses among extant lineages of terrestrial plants are considered fairly. The hypotheses are based on evidence from comparative morphological and anatomical studies of extant and extinct plant specimens as well as from the analyses of deoxyribonucleic acid sequences of extant plant specimens. Apparently, one of the currently favored hypotheses concerning the evolutionary status of the bryophytes is that "... hornworts share a common ancestor with tracheophytes, mosses form a sister group to this combined lineage, and liverworts mark the transition to land, ..." (Chp. 1, p. 15). With respect to evolutionary considerations, Smith (1955, Fig. 82, pp. 131-134) has an intriguing discussion and line drawing relating to "... an anthocerotean origin of pteridophytes." Also, for further exploratory reading on the life histories of bryophytes (and vascular plants) beginning students should consider the following introductory textbooks: Bold, Alexopoulos, and Delevoryas, 1980; Doyle, 1970; Parihar, 1965; Richardson, 1981; Schofield, 1985; Simpson, 2006; Smith, 1955; and Watson, 1964.

Recognizing that bryophytes have a global distribution and are primary producers in almost all terrestrial ecosystems, including fresh water ecosystems; chapter two, "Ecological significance of bryophytes," covers a range of topics concerning their functional and compositional roles in terrestrial plant communities. Aboveground biomasses for bryophytes compared to vascular plants (+ lichens) vary from small values in temperate deciduous forest communities to major values in *Sphagnum* peat lands and often in arctic tundra communities (Fig. 2.3, p. 29). Hence, in some plant communities, particularly in polar regions, bryophytes are the major primary producers. In addition to Longton's (1988) monograph on the life of polar bryophytes and lichens, investigations on the ecology of arctic bryophytes are reported in topical chapters of the Canadian and United States International Biological Progamme – Tundra Biome volumes edited by Bliss (1977) and Tieszen (1978), respectively. Furthermore, chapter two includes an interesting discussion on *Sphagnum* peat lands and to quote a noteworthy point mentioned on page 29 – "There is more carbon stored in *Sphagnum* and *Sphagnum* litter than any other genus of plants, vascular or non-vascular." Thankfully, the authors indicate what consequences are likely if the carbon dioxide fixed in *Sphagnum* peat lands should be released into the atmosphere by decomposition owing to global warming. Moreover, the chapter covers productivity, mineral nutrient cycling, succession, soil formation, and other topics. In addition to chapter two, selected ecological aspects of bryophytes are treated in chapters seven and eight.

Within the hierarchy of plant classification, many contemporary taxonomists segregate the bryophytes into three divisions (phyla). The next three chapters (3, 4, & 5) provide an overview of each division; that is, the "Liverworts" (Marchantiophyta), "Mosses" (Bryophyta), and "Hornworts" (Anthocerotophyta), respectively. Each chapter starts with an introductory statement about the division. Subsequently, the largest portion of each chapter provides a substantial morphological coverage of its respective division. These treatments are complemented by numerous line drawings, photographs, and photomicrographs. Each chapter ends with a pointed discussion on "Classification and macroevolution" with a focus on phylogeny and summaries on "Biogeography and ecology" for its respective division. For a historical perspective, Bold and coauthors (1980) employed the division names Hepatophyta, Anthocerotophyta, and Bryophyta for the liverworts, hornworts, and mosses, respectively. Other authors placed all three groups of bryophytes into a single division, the Bryophyta, and ranked the liverworts, hornworts, and mosses in classes. For example, Parihar (1965) employed the class names Hepaticopsida, Anthoceropsida, and Bryopsida, respectively. Whereas, the class names Hepaticae, Anthoceratae, and Musci were employed by Smith (1955) and Schofield (1985), respectively.

Among bryophyte taxa, many species have a broad global distribution (cosmopolitan); probably some species occur on all continents. On the other hand, numerous species are limited to a particular phyto-geographical region (disjunct) but also occur elsewhere even on other continents. And still other species are known to occur only in a particular region (endemic), perhaps only in a particular type of habitat. The authors treat these aspects of the "Biogeography" of bryophytes in chapter six in reference to their taxonomic diversity, origin, and evolution in relation to distribution patterns with interpretations in reference to plate tectonics and long-distance dispersal. Here discussions on disjunct and endemic species are especially noteworthy. As a point of academic interest, new students might note that the "Biogeography" of bryophytes is in the arena of floristic plant geography. An overview of this approach to phytogeography is clearly discussed by Daubenmire (1978).

Chapter seven, "Ecology," concerns the terrestrial distribution and adaptive evolution of bryophytes in relation to environmental factors. There are three major sections in chapter seven. The first section, "Global ecology," is directed towards interpretations of climatic changes ascertained from the distribution of macrofossils of *Sphagnum* and *Racomitrium langenosum* in peat profiles. The second section, "Landscape ecology," calls attention to a case study of the liverwort *Calypogeia fissa* in discontinuous forest habitats within an agricultural landscape located in Belgium. A positive relationship between species richness and forest cover indicated that species distributions of forest bryophytes are controlled by the overstory. Section three, "Population ecology," treats the concepts of the ecological niche and interactions of taxa with an emphasis on selected epiphytic communities. However, some terrestrial bryophyte communities are discussed with respect to competitive exclusion. The final portion of this section provides insights on how particular features of life histories of bryophyte species might enhance their survival. For example, fugitive and pioneer species tend to be more reproductive in spore and/or gemmae production than later seral species. In general, chapter seven can be considered in the arena of ecologic plant geography as discussed by Daubenmire (1978). Also in this area, we recommend the related review chapters, written by experts and brought together in the volume Bryophyte Ecology edited by Smith (1982).

Extant bryophytes have adapted to a range of abiotic and biotic factors of their environments (habitats). Some bryophyte species appear to have relatively narrow ecological ranges (ecological amplitudes) whereas other species have broad ecological ranges. Chapter eight, "Physiological ecology," explores the adaptive features of bryophytes to abiotic environmental factors especially water, light, mineral nutrition, and temperature. Here, we will mention some aspects concerning the water and temperature factors. Water relations are discussed in some detail with a focus on desiccation tolerance (very low cellular water content) of the gametophytes. Desiccation tolerance is a recognized physiological feature of most bryophytes and is most likely a feature that contributed to their adaptation to terrestrial habitats. Temperature affects all metabolic processes, but is commonly evaluated from measurements of photosynthetic, respiratory, and growth rates. Hence, among bryophyte species there are ranges of metabolic responses to the three carnal temperatures: minimum, optimum, and maximum (Daubenmire, 1974). Generally, bryophytes have a capacity to endure freezing temperatures and it is unlikely that they require or exist continuously in their natural habitats at their optimal temperatures; therefore their maximal temperatures are likely to be the critical factor in habitat selection, provided other environment factors are suitable. Chapter eight can be considered a subdiscipline of ecology referred to as autecology. Daubenmire's (1974) textbook is an excellent introduction to the subject, and there are chapters on the autecology of bryophytes in Smith's (1982) tome mentioned previously. Furthermore, students of bryology need to appreciate that many bryophytes are not the only organisms that can survive extreme cellular water losses and low temperatures. A recent fascinating book by Wharton (2002) discusses numerous organisms that deal with extreme environments. Also, new students to bryology need to explore Dyer and Duckett's (1984) multi-authored volume containing ecologically related reviews and Glime's (Cited in IB) progressing treatise on a broad range of ecological topics.

"Bryophytes in a changing world" (Chp. 9) concerns the effects of pollutants on bryophyte communities and physiological features of bryophytes with respect to acidification and eutrophication of water resources. In addition, the chapter covers the use of bryophyte taxa as references for bio-monitoring. And a brief discussion on adaption to a changing environment is included. In the book's final chapter (Chp. 10) "Conservation biology" the authors point out that bryophytes are often overlooked in land conservation, biological diversity, and restoration projects. On the other hand, it now appears that bryophytes and other cryptogams are now recognized as significant components of plant communities. With this in mind, the authors provide an overview of methods for assessing the status of bryophyte taxa in plant communities in reference to their endangered survival, and needs for conservation and restoration.

In closing, we recommend Introduction to Bryophytes to all students of bryology, new and advanced. Also, college and university libraries need to add this monograph to their botanical collections.

Reviewers: James R. Rastorfer, Department of Biological Sciences, Chicago State University, and the Department of Botany, The Field Museum, Chicago, IL and Judith B. Rastorfer, Park Forest, IL

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