Physical and chemical limnology of four natural lakes located within the Indiana Dunes National Lakeshore, Northwestern Indiana.

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FLORISTIC INVESTIGATION OF CROOKED CREEK COMMUNITY JUAN SOLOMON PARK, INDIANAPOLIS, INDIANA

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ABSTRACT: The protection of plant resources in urban areas is a growing conservation concern. Inventory activities that document species presence and stewardship plans that protect and enhance these areas are needed. The results of a botanical inventory of the Crooked Creek Community Juan Solomon Park in Indianapolis, Indiana, are reported in this paper. The 46-acre park contains three distinct habitats, supporting a wide variety of plants. One hundred seventy-nine vascular plant species from 64 families were identified, including 53 (29.6%) non-native species that are naturalizing within the park. Despite its high percentage of alien species and urban setting, the park is an important natural area. The flora's coefficient of conservatism (*sensu* Swink and Wilhelm, 1994) was 54.1. Several exotic, invasive species (most notably garlic mustard, amur bush honeysuckle, and wintercreeper) pose potential future threats to the park's natural flora, and management efforts should be focused on their removal.

KEYWORDS: Coefficient of conservatism, floristics, Indiana, invasive exotics.

INTRODUCTION

Floristic investigations that document existing plant resources provide essential information for the sound stewardship of natural areas. Management recommendations based on inventory studies can help maintain natural areas through the protection of high-quality habitats and the control of invasive, exotic species. A botanical exploration of Crooked Creek Community Juan Solomon Park (a park run by the Indianapolis Parks Department) was carried out during the flowering season of 1996. The vascular plant species in the park were identified, and voucher specimens were collected. The major plant communities and habitats were also identified. The value of the park as a natural area was assessed using Swink and Wilhelm's (1994) coefficient of conservatism. Control recommendations were developed for potentially invasive species located in the park.

Crooked Creek Community Juan Solomon Park is located at the northwest corner of Grandview Drive and Fox Hill Road along Crooked Creek in Washington Township, Marion County, Indianapolis, Indiana (Lat. 39° 51′ N, Long. 86° 11′ W; Sec. 3, T16N, R3E, Indianapolis West Quadrangle). The park consists of 46 acres. Twenty-four acres were purchased by the city in 1975, and the land provides recreational and educational opportunities for many of the local residents. An additional 22 acres were purchased by the Crooked Creek Com-

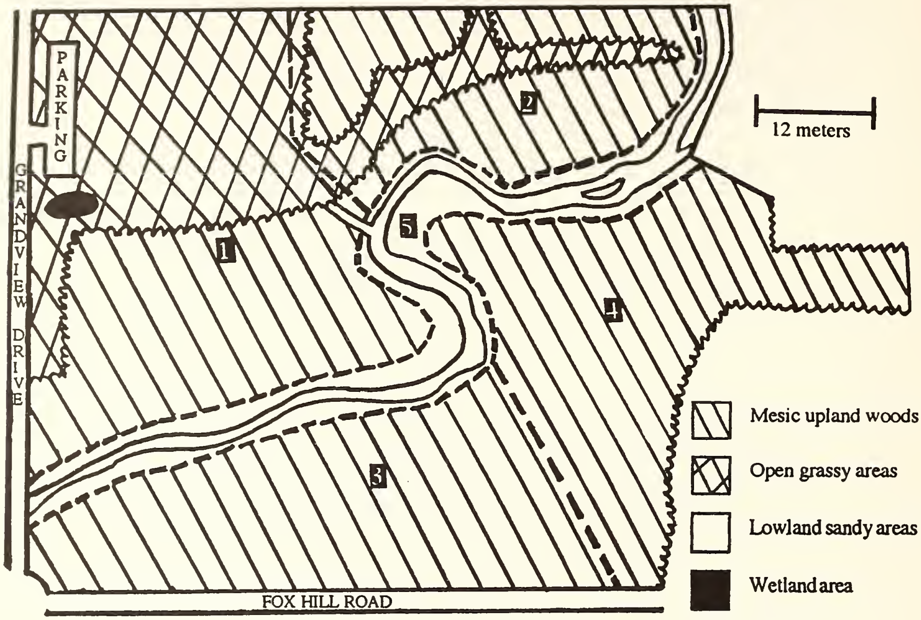

Figure 1. The major plant communities and habitats studied at the Crooked Creek Community Juan Solomon Park.

munity Council and donated to the city in September 1995. This area consists primarily of mesic upland woods. Crooked Creek, a fairly pristine creek, bisects the park into two roughly equal halves. Large sycamores and other hardwoods line the creek.

Although located in the most populous county in the State, Crooked Creek Community Juan Soloman Park is situated in a landscape of housing subdivisions and recently abandoned fields. The soils are mostly Genesee silt loams: deep, nearly level, well-drained soils formed in loamy alluvium (Sturm and Gilbert, 1978). Along the creek, small sand bars and sand spots were mapped within the soil. Indianapolis is located in the Tipton Till Plain Natural Region (*sensu* Homoya, *et al.*, 1985), a region of primarily undissected plain formerly covered by beech-maple-oak forest.

MATERIALS AND METHODS

To conduct the floristic survey, the park was divided into 5 sections according to geographical landscape (Figure 1). Each section was repeatedly visited to identify and collect as many different plants as possible. Specimens were collected over five months from April, 1996, to September, 1996, with the greatest emphasis during the months of June and July, the peak flowering season. The park was visited approximately 3 times a week during June and July and at least every two weeks during the remaining months.

Plant species were collected only if they were not considered rare, threatened, or endangered and if the sampling site had more than 20 individuals. Voucher specimens were deposited in the Friesner Herbarium (BUT) of Butler University, Indianapolis, Indiana. Photographic documentation is available for the majority of the species that could not be collected due to small sample size, inaccessability of the leaves from large trees, or the adverse effects of the plant on the collector (stinging nettle or poison ivy). Plants were identified using published reference manuals. The nomenclature follows Gleason and Cronquist (1991). The Indiana Department of Natural Resource's publication (1993) on Indiana's rare plants and animals was used to identify rare, threatened, or endangered plants. In addition, management recommendations for the control and identification of invasive exotics were developed.

The coefficient of conservatism (Swink and Wilhelm, 1994) was calculated for the flora to determine the park's quality as a natural area. Swink and Wilhelm (1994) determined C values by examining the fidelity of species to high quality habitats. For this calculation, native species were assigned quality index values (C), ranging from 0 for species that are not habitat specialists to 10 for species that are indicators of high-quality plant communities.

The coefficient of conservatism (I) was calculated using the equation

$$I = \bar{C}\sqrt{N}$$

where $\bar{C}$ represents the average quality index value of all the native species present, and N is the number of native species.

Based on site surveys in the Chicago area, Swink and Wilhelm (1994) rated sites with I values of less than 35 as not significant from a natural areas perspective, sites with I values from 35 to 50 as significant, and sites with I values greater than 50 as of paramount importance for conservation. The coefficient of conservatism is not based on the abundance or frequency of the native species, because these values can vary with the seasons or between years. In addition, exotic plant species are not used in the calculation. Swink and Wilhelm (1994) believe that a low coefficient of conservatism indicates the negative impact of non-native species; only the native species present are used to determine of the quality of the flora using their scheme. However, this system was developed for the Chicago area. Although all but two native species found in this study were given quality index values by Swink and Wilhelm, the habitat fidelity characteristics of the plants may be different in the park, which is located ca. 325 km south of Chicago. Efforts have been made to develop this methodology for other geographical regions, but no system is currently available for central Indiana (Herman, 1997; Ladd, in prep.).

RESULTS AND DISCUSSION

Based on repeated visits to the five survey sections of the park, three distinct habitats were identied: mesic upland woods, lowland sandy areas, and a small wetland. Each of these areas has a unique flora. The majority of the park is mesic upland woods, characterized by large, well-spaced trees, particularly

Quercus alba, *Acer saccharum*, and *Platanus occidentalis*, with very little vegetation on the forest floor. A similar remnant Tipton Till Plain forest was reported by Rothrock, *et al.* (1994) in Mounds State Park. In locations where sunlight breaks through the trees, a burst of understory growth, often comprised of *Cystopteris fragilis* and *Impatiens capensis*, occurs. This burst of growth occurs most frequently at the edge of the woods where the greatest abundance of herbaceous plants are found. Many areas of the woods host dramatic displays of spring ephemerals, such as *Erigenia bulbosa*, *Mertensia virginica*, *Erythronium americanum*, and *Sanguinaria canadensis*.

The lowland sandy areas are located primarily along Crooked Creek, which divides the park into two nearly equal halves. The substrate in this area varies from recent sand deposits to sandy loam and supports a very different plant community than the mesic upland woods. Such species as *Justicia americana* and *Polygonum hydropiperoides* were found in this area. Many of the plants in this habitat must be adapted to life in dry sand as well as in standing water due to the great fluctuations in the level of Crooked Creek throughout the growing season.

The wetland is located in direct sunlight near the parking lot and is inhabited by *Elocharis ovata*, *Mimulus ringus*, and *Rumex crispus*. The vegetation is prominent through July. After that time, the wetland dries up almost completely and is eventually mowed. During years of high rainfall, the area may remain wet throughout the summer.

A total of 2 fern and fern allies and 177 angiosperms have been identified at Crooked Creek Community Juan Soloman Park. Of the 179 taxa found, 126 are native to the Midwest. Because 29.6% of the species were alien, the entire park cannot be a pristine natural area. However, the majority of the exotic plants were primarily if not exclusively located near the highly disturbed roadside. Away from this area, the flora is largely native with the exception of a few exotic invasives, such as garlic mustard (*Alliaria petiolata*) and wintercreeper (*Euonymus fortunei*). One plant collected, the lesser celendine (*Ranunculus ficaria* subsp. *bulbifera*), is a State record. Lesser celendine is an exotic species that has likely escaped from horticulture.

When compared to other similar sites in the State of Indiana, Crooked Creek Community Juan Soloman Park has a large number of native species per acre. Crooked Creek has an average of 2.7 native plants per acre, compared to 2.0 for the Fall Creek Nature Preserve in Warren County (Tonkovich and Sargent, 1993) and 1.5 species per acre in Mounds State Park in Madison County (Rothrock, *et al.*, 1993).

The coefficient of conservatism (Swink and Wilhelm, 1994) was 54.1, indicating that Crooked Creek Community Juan Soloman Park is a high-quality natural area in spite of the large number of non-native species present. The quality index values (C) are given in the description that follows each species' name in the checklist. Because exotic species have the potential to decrease the plant diversity (Bratton, 1982), Crooked Creek Community Juan Soloman Park needs a management plan in order to retain its quality. The invasive exotics of great-

est concern in the park are garlic mustard (*Alliaria petiolata*), wintercreeper (*Euonymus fortunei*), and amur bush honeysuckle (*Lonicera maackii*).

Garlic mustard is most effectively controlled by pulling the immature plants, including their roots, from the ground and removing all pulled plants before seed-set (Nuzzo, *et al.*, 1991). This process is most effective before the species becomes fully established in high-density populations. Fortunately, although garlic mustard is present in many areas in the park, its numbers are low at any given site.

Wintercreeper is invading many areas of the mesic upland woods in the park both in the sun and shade. Eradication efforts should include cutting each vine by hand and spraying the plant with an herbicide that is non-toxic to aquatic organisms in the event that any runoff reaches Crooked Creek. Spraying should be done in the spring before the emergence of the spring ephemerals or during late autumn when most of the native plants are dormant (Hutchison, 1991). This practice must be continued in subsequent seasons to insure that all of the wintercreeper has been eliminated and that new invading individuals are not being introduced.

Amur bush honeysuckles can tolerate many different habitat types and moisture regimes, so they are easily established and spread. The honeysuckles inhibit the growth of native species through both shading and by releasing a growth-inhibiting chemical into the ground (Nyboer, 1991). To effectively eliminate amur bush honeysuckle, the plants should be cut and the stumps treated with herbicide (Nyboer, 1991). In addition, entire seedlings, including their roots, should be removed by hand-pulling when the soil is moist (Nyboer, 1991).

Management and control of invasive exotics is crucial to the maintenance of the high quality habitats currently present in the park. Follow-up studies will be needed to determine whether the control efforts have been effective. Furthermore, the small wetland area identified in this study should be protected during any additional development activity in the park.

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CHECKLIST OF VASCULAR PLANTS IN CROOKED CREEK COMMUNITY JUAN SOLOMAN PARK ARRANGED ALPHABETICALLY BY FAMILY*

DIVISION POLYPODIOPHYTA (Fern & Fern Allies)

Aspleniaceae — Spleenwort Family

Cystopteris fragilis (L.) Bernh. var. *fragilis*
Fragile fern; frequent near the border of Section 1 towards the soccer field; C = 10; CN = 81.

DIVISION EQUISETOPHYTA

Equisetaceae — Horsetail Family

Equisetum arvense L.
Common or field horsetail; occasional in sandy soil along the creek in Section 5; C = 0; CN = 168.

DIVISION MAGNOLIOPHYTA

Acanthaceae — Acanthus Family

Justicia americana (L.) Vahl.
Water-willow; common on the sandy banks of the creek in direct sunlight; C = 6; CN = 94.

Ruellia strepens L.
Smooth ruellia; one isolated population in Section 2 under a dogwood across from the pavilion; C = 8; CN = 91.

Aceraceae — Maple Family

Acer negundo L.
Boxelder or ash-leaved maple; common throughout the park; C = 0; CN = 48.

Acer rubrum L.
Red maple; occasional throughout the mesic upland woods in all sections; C = 7; not collected.

Acer saccharum Marshall
Sugar maple; common throughout the park; C = 3; CN = 47.

* C = The quality index of Swink and Wilhelm (1994).
CN = Raelene Crandell's collection number. The Friesner Herbarium no longer assigns accession numbers.

Anacardiaceae — Sumac Family

Toxicodendron radicans (L.) Kuntze
Poison ivy; abundant throughout the park, often as a vine; C = 2; not collected.

Annonaceae — Custard Apple Family

Asimina triloba (L.) Duna
Pawpaw; frequent in the understory throughout all sections; C= 14; CN = 76.

Apiaceae — Carrot Family

Cryptotaenia canadensis (L.) DC.
Honewort; common throughout the mesic upland woods of Sections 1-4; C = 2; CN = 64.

Daucus carota L.
Wild carrot or Queen Anne's lace; one isolated population in Section 1 near Grandview Drive; CN = 119 (alien).

Erigenia bulbosa (Michx.) Nutt.
Harbinger of spring; common in Sections 1 and 2 in both the low wetland areas and mesic upland woods; C = 10.

Osmorhiza longistylis (Torr.) DC.
Sweet cicely; common throughout the park in moist soil and near the border of the woods; C = 3; CN = 49.

Sanicula marilandica L.
Black snakeroot; common throughout the park; C = 6; CN = 73.

Araceae — Arum Family

Arisaema triphyllum (L.) Schott
Jack in the pulpit; one isolated population in Section 3 under heavy tree cover; C = 4; not collected.

Aristolochiaceae — Birthwort Family

Asarum canadense L.
Wild ginger; abundant in large clumps in the mesic upland areas of Sections 1-4; C = 7; CN = 24.

Asclepiadaceae — Milkweed Family

Apocynum cannabinum L.
Indian hemp; occasional in the mesic upland woods of Sections 1 and 2; C = 4; CN = 104.

Asclepias incarnata L.
Swamp milkweed; occasional in sand and direct sunlight near the creek in Section 5; C = 4; CN = 137.

Asclepias syriaca L.
Common milkweed; occasional at the edge of the mesic upland woods in Sections 3 and 4; C = 0; CN = 114.

Asteraceae — Aster Family

Ambrosia artemisiifolia L.
Common ragweed; abundant throughout the park in all sections; C = 0; CN = 150.

Ambrosia trifida L.
Giant ragweed; occasional among *Ambrosia artemisiifolia* L. in all sections; C = 0; CN = 149.

Aster ericoides L.
Heath aster or squarrose white aster; common at the edge of the woods in Sections 1-4; C = 5; CN = 163.

Bidens cernua L.
Nodding bur-marigold; occasional in sandy soil along the stream in Sections 1, 2, and 5; C = 5; CN = 164.

Cirsium arvense (L.) Scop.
Canada thistle; abundant along the disturbed roadside in Sections 1, 3, and 4; CN = 110 (alien).

Erigeron annuus (L.) Pers.
Daisy fleabane; common in sparsely wooded areas and near the border of the woods; C = 0; CN = 31.

Eupatorium maculatum L.
Spotted joe-pye weed; occasional along the edge of the woods in Sections 1 and 2; C = 4; CN = 144.

Eupatorium perfoliatum L.
Boneset; occasional near the creek in sandy soil; C = 4; CN = 130.

Eupatorium rugosum Houtt.
White snakeroot; frequent in direct sunlight throughout all sections of the park; C = 4; CN = 151.

Helenium autumnale L.
Sneezeweed; occasional in sandy soil near the stream in Sections 1, 2, and 5; C= 5; CN = 167.

Helianthus divaricatus L.
Woodland sunflower; common at the edge of the woods in all sections and in sand near the creek; C = 5; CN = 166.

Heliopsis helianthoides (L.) Sweet.
False sunflower; rare in sand and direct sunlight near the creek in Section 5; C = 5; CN = 124.

Lactuca canadensis L.
Tall lettuce; frequent at the edge of the woods in partial sunlight; C = 2; not collected.

Lactuca floridana var. villosa (L.) Gaertner
Woodland or blue lettuce; abundant along the edge of the woods in partial sunlight; C = 5; CN = 134.

Lactuca serriola L.
Prickly lettuce; isolated population located along the disturbed roadside in Section 1; CN = 111 (alien).

Polymnia canadensis L.
Pale-flowered leaf-cup; abundant at the edge of the woods throughout all sections; C = 10; CN = 146.

Rudbeckia fulgida Ait.
Eastern coneflower; frequent at the edge of the woods in partial sunlight; C = 8; CN = 135.

Senecio jacobaea L.
Tansy-ragwort; rare, one plant in Section 2 at the edge of the woods; not collected (alien).

Silphium perfoliatum L.
Cup-plant; one population in Section 5 in sand and direct sunlight near the creek; C = 5; CN = 139.

Solidago canadensis L.
Common goldenrod; occasional throughout the park and near the creek in sunny areas; C = 1; CN = 164.

Sonchus oleraceus L.
Common sow-thistle; common along the roadside in Sections 3 and 4; CN = 131(alien).

Taraxacum officinale Weber *ex* Wiggers
Common dandelion; common in direct sunlight and open areas among grass; CN = 35 (alien).

Verbesina alternifolia (L.) Britton
Wingstem; common throughout the park in sunny areas; C = 5; CN = 147.

Balsaminiaceae — Jewel-Weed Family

Impatiens capensis Meerb.
Spotted touch-me-not; abundant in mesic upland areas among stinging nettle; C = 3; CN = 71.

Impatiens pallida Nutt.
Pale or yellow touch-me-not; occasional in mesic upland areas, not as abundant as *Impatiens capensis* Meerb.; C = 6; CN = 83.

Berberidaceae — Barberry Family

Podophyllum peltatum L.
May apple; frequent throughout all mesic upland areas, often occurring in large clumps; C = 4; CN = 21.

Betulaceae — Birch Family

Ostrya virginiana (Miller) K. Koch.
Hop-hornbeam or ironwood; occasional throughout the mesic upland woods of all sections; C = 5; not collected.

Boraginaceae — Borage Family

Mertensia virginica (L.) Pers.
Eastern bluebell; rare, in sandy soil near the creek in Section 2; C = 5; CN = 11.

Brassicaceae — Mustard Family

Alliaria petiolata (Bieb.) Cavara & Grande
Garlic-mustard; exotic invasive, abundant throughout all sections; CN = 19 (alien).

Barbarea vulgaris R. Br.
Yellow rocket; occasional in direct sunlight in Sections 1 and 2 among the mowed grass; CN = 97 (alien).

Cardamine concatenata (Michx.) O. Schwarz
Five-parted toothwort; common in the mesic upland areas of Sections 1-4 where the trees are sparse; C = 5; CN = 3.

Cardamine douglassi Britton
Purple cress; isolated population in the open wetland area of Section 1 near the parking lot; C = 7; CN = 70.

Hesperis matronalis L.
Dame's rocket; common throughout the mesic upland woods of Sections 1-4, particularily at the edges; CN = 30 (alien).

Lepidium virginicum L.
Poor-man's-pepper or pepper-grass; rare, one small, isolated population in the mesic upland woods of Section 1; CN = 86 (alien).

Caesalpiniaceae — Caesalpinia Family

Cercis canadensis L.
Redbud; occasional in mesic upland areas; C = 10; CN = 72.

Gleditsia triacanthos L.
Honey-locust; occasional throughout the park in all sections; C = 2; not collected.

Gymnocladus dioica (L.) K. Koch.
Kentucky coffee-tree; occasional in mesic upland areas; C = 8; not collected.

Campanulaceae — Bellflower Family

Campanula americana L.
American bellflower; one population in a small clearing in sandy soil; C = 3; CN = 126.

Lobelia siphilitica L.
Great lobelia; occasional in sand near the creek in Sections 1 and 2; C = 6; CN = 158.

Caprifoliaceae — Honeysuckle Family

Lonicera japonica Thunb.
Japanese honeysuckle; isolated population in Section 2 climbing on some trees and shrubs; CN = 77 (alien).

Lonicera maackii (Rupr.) Maxim.
Amur bush honeysuckle; common in Sections 1-4 along the edge of the woods; CN = 60 (alien).

Lonicera oblongifolia (Goldie) Hook
Swamp fly honeysuckle; occasional in mesic upland areas; C = 10; CN = 28.

Caryophyllaceae — Pink Family

Saponaria officinalis L.
Bouncing bet; one isolated population in sand and direct sunlight near the creek in Section 5; CN = 121 (alien).

Silene nivea (Nutt.) Otth.
White campion; common in sandy soil near the creek; C = 10; CN = 90.

Stellaria media (L.) Villars.
Common chickweed; common along the border of the woods in Sections 1 and 2; CN = 33 (alien).

Celastraceae — Bittersweet Family

Celastrus scandens L.
American bittersweet; occasional throughout the mesic upland woods of all sections; C = 4; not collected.

Euonymus atropurpureus Jacqs.
Wahoo; one shrub at the border of the woods in Section 2 that may have been planted for horticultural reasons; C = 8; CN = 78.

Euonymus fortunei (Turcz.) Hand.-Mazz.
Wintercreeper; exotic invasive throughout mesic upland woods of Sections 1-4; CN = 105 (alien).

Chenopodiaceae — Goosefoot Family

Chenopodium album L.
Lamb's quarters or pigweed; occasional along the disturbed road-side in Sections 3 and 4; CN = 132 (alien).

Clusiaceae — Mangosteen Family

Hypericum mutilum L.
Dwarf St. John's-wort; occasional near the creek in sandy soil and partial sunlight in Section 5; C = 8; CN = 118.

Commelinaceae — Spiderwort Family

Commelina communis L.
Common day-flower; occasional in sand near the creek in Section 5; CN = 136 (alien).

Tradescantia virginiana L.
Spiderwort; occasional in the mesic upland woods of Sections 1-4; C = 5; CN = 102.

Convolvulaceae — Morning-glory Family

Calystegia sepium (L.) R.Br.
Hedge-bindweed; locally abundant in Section 5 along the creek in sand and direct sunlight; C = 1; CN = 113.

Cornaceae — Dogwood Family

Cornus drummondii C.A. Meyer
Rough-leaved dogwood; occasional in Sections 1 and 2, most often near the border of the woods; C = 2; CN = 75.

Cucurbitaceae — Gourd Family

Sicyos angulatus L.
Bur-cucumber; occasional in Sections 1 and 2 climbing on small shrubs; C = 5; CN = 157.

Cyperaceae — Sedge Family

Carex amphibola Steudel
Sedge; common throughout the mesic upland woods of Sections 1-4; C = 10; CN = 58.

Carex davisii Schwein & Torr.
Sedge; occasional in sandy soil under heavy tree cover in Sections 1, 2, and 5; C = 7; CN = 87.

Carex grayi Carey
Sedge; occasional in moist, sandy soil; C = 7; CN = 127.

Carex shortiana Dewey
Sedge; one isolated population in sandy soil on the trail through Section 1; C = 10; CN = 89.

Elocharis ovata (Roth) Roemer & Schultes
Blunt spike-rush; locally abundant in the open wetland in Section 1 near the parking lot; C = 10; CN = 66.

Dipsacaceae — Teasel Family

Dipsacus sylvestris Huds.
Common teasel; abundant along the disturbed roadside in Sections 1, 3, and 4; CN = 112 (alien).

Fabaceae — Pea Family

Melilotus officinalis (L.) Pallas
Yellow sweet clover; one isolated population in Section 4 near Fox Hill Road; CN = 99 (alien).

Robinia pseudoacacia L.
Black locust; common throughout the mesic upland woods; CN = 42.

Trifolium dubium Sibth.
Little hop-clover; frequent in direct sunlight in the open grassy areas of Sections 1 and 2; CN = 37 (alien).

Trifolium repens L.
White clover; abundant in direct sunlight in the open grassy areas of Sections 1 and 2; CN = 36 (alien).

Fagaceae — Beech Family

Fagus grandifolia Ehrh.
American beech; frequent throughout the park; C = 5; CN = 122.

Quercus alba L.
White oak; occasional throughout the mesic upland woods of all sections; C = 5; not collected.

Quercus muhlenbergii Engelm.
Yellow oak; common in the mesic upland woods of Sections 1-4; C = 8; CN = 84.

Quercus palustris Muenchh.
Pin-oak; occasional throughout the mesic upland woods of all sections; C = 8; not collected; likely planted.

Quercus rubra L.
Red oak; the edge of the woods near the pavilion; not as common as the other oaks; C = 7; CN = 84.

Quercus velutina Lam.
Black oak; occasional throughout the mesic upland woods of all sections; C = 6; not collected.

Fumariaceae — Fumitory Family

Dicentra cucullaria (L.) Bernh.
Dutchman's breeches; frequent throughout the mesic upland woods of Sections 1-4; C = 6; CN = 2.

Grossulariaceae — Gooseberry Family

Hydrangea paniculata Siebold
Hydrangea; occasional in Section 5 in sandy soil and partial sunlight; CN = 129 (alien).

Hydrophylaceae — Waterleaf Family

Hydrophyllum appendiculatum Michx.
Biennial waterleaf; occasional in sandy soil and throughout the mesic upland woods of Sections 1-4; C = 8; CN = 26.

Iridaceae — Iris Family

Sisyrinchium angustifolium Miller
Blue-eyed grass; one isolated population in Section 1 at the edge of the woods near Grandview Drive; C = 10; CN = 34.

Juglandaceae — Walnut Family

Carya cordiformis (Wangenh.) K. Koch.
Bitternut hickory; occasional throughout the mesic upland woods of all sections; C = 7; not collected.

Carya ovata (Miller) K. Koch.
Shagbark hickory; occasional in the mesic upland woods; C = 5; not collected.

Lamiaceae — Mint Family

Glechoma hederacea L.
Gill-over-the-ground; abundant throughout all sections; CN = 8 (alien).

Lamium amplexicaule L.
Henbit; common in direct sunlight and at the edge of the woods in Sections 1 and 2; CN = 14 (alien).

Leonurus cardiaca L.
Motherwort; common near the edge of the woods near Fox Hill Road in Sections 3 and 4; CN = 101 (alien).

Mentha arvensis L.
Field mint; occasional in sandy soil near the creek; C = 5; CN = 138.

Prunella vulgaris L.
Self-heal; occasional at the edge of the woods in Sections 1 and 2; CN = 98 (alien).

Stachys tenuifolia Willd.
Smooth hedge-nettle; occasional to frequent at the edge of the woods in Sections 1 and 2; C = 8; CN = 148.

Teucrium canadense L.
Germander; occasional in Section 1 at the edge of the woods; C = 3; CN = 120.

Liliaceae — Lily Family

Allium tricoccum Aiton
Ramps, wild leek; one small isolated population under heavy tree cover along the trail through Section 1; C = 7; CN = 93.

Allium vineale L.
Field-garlic; common throughout the park in partial to direct sunlight, especially near its borders; CN = 59 (alien).

Camassia scilloides (Raf.) Cory
Wild hyacinth; occasional in sandy soil in Sections 1 and 2; C = 6; CN = 10.

Erythronium americanum Ker-Gawl.
Yellow trout lily; common in the heavily shaded areas of the mesic upland woods of Sections 1-4; C = 8; CN = 5.

Hemerocallis fulva (L.) L.
Day-lily; common along the disturbed roadside in Sections 3 and 4 near Fox Hill Road; CN = 103 (alien).

Narcissus pseudo-narcissus L.
Daffodil; two isolated plants in sandy soil near the creek; not collected (alien).

Ornithogalum umbellatum L.
Star of Bethlehem; rare, two isolated populations in Sections 1 and 3; not collected (alien).

Polygonatum biflorum (Walter) Elliott
Soloman's seal; abundant in sandy soil and throughout the mesic upland woods of all sections; C = 3; CN = 32.

Trillium recurvatum Beck
Red trillium; common in the heavily shaded areas of the mesic upland woods of Sections 1-4; C = 5; CN = 18.

Moraceae — Mulberry Family

Morus alba L.
White mulberry; frequent throughout all sections; CN = 51 (alien).

Oleaceae — Olive Family

Fraxinus americana L.
White ash; common throughout the mesic upland woods of Sections 1-4; C = 5; CN = 50.

Fraxinus pennsylvanica Marshall
Green ash; occasional along the creek in Section 5 and rare throughout the mesic upland woods of Sections 1-4; C = 5; not collected.

Onagraceae — Evening Primrose Family

Circaea lutetiana L.
Enchanter's nightshade; abundant in Sections 1 and 2; C = 1; CN = 82.

Oenothera biennis L.
Common evening-primrose; rare along the disturbed roadside in Sections 1 and 3; C = 0; not collected.

Oxalidaceae — Wood Sorrel Family

Oxalis grandis Small
Yellow wood-sorrel; abundant in direct sunlight in the open grassy areas of Sections 1 and 2; CN = 38 (alien).

Papaveraceae — Poppy Family

Sanguinaria canadensis L.
Bloodroot; common throughout the mesic upland woods of Sections 1-4; C = 6; CN = 1.

Stylophorum diphyllum (Michx.) Nutt.
Celandine-poppy; one isolated population in Section 2 across from the playground in a sparsely wooded area; C = 10; CN = 27.

Phytolaccaceae — Pokeweed Family

Phytolacca americana L.
Pokeweed; two isolated populations in Sections 1 and 4; C = 1; CN = 115.

Plantaginaceae — Plantain Family

Plantago lanceolata L.
English plantain; common near the disturbed roadside in Sections 3 and 4; CN = 85, 160 (alien).

Plantago major L.
Common plantain; common in the open areas of Sections 1 and 2 among the mowed grass; CN = 106 (alien).

Platanaceae — Plane-Tree Family

Platanus occidentalis L.
Sycamore; common throughout all sections; C = 6; not collected.

Poaceae — Grass Family

Dactylis glomerata L.
Orchard grass; common throughout all sections; CN = 57 (alien).

Eleusine indica (L.) Gaertn.
Yard grass; common throughout the park in the open, disturbed areas of all sections; CN = 140 (alien).

Elymus riparius Wieg.
Streambank wild rye; common throughout the mesic upland woods of Sections 1-4; C = 5; CN = 107.

Elymus villosus Muhl.
Downy wild rye; common in sandy soil in Sections 1, 2, and 5; C = 5; CN = 65 (alien).

Elytrigia repens (L.) Nevski.
Quack-grass; common in the open areas of Sections 1 and 2; CN = 62 (alien).

Festuca rubra L.
Red fescue; frequent throughout all sections of the park; CN = 56 (alien).

Phalaris arundinacea L.
Reed canary grass; frequent at the edge of the creek in sandy soil in Sections 1, 2, and 5; CN = 88 (alien).

Phleum pratense L.
Timothy; common throughout the mesic upland woods of Sections 1-4; CN = 108 (alien).

Poa pratensis L.
Kentucky bluegrass; frequent throughout all sections of the park; CN = 61 (alien).

Setaria glauca (L.) P. Beauv.
Yellow foxtail grass; frequent near the edge of Fox Hill Road and in other disturbed areas in Sections 1, 3, and 4; CN = 159, 161(alien).

Polemoniaceae — Phlox Family

Phlox divaricata L.
Common phlox; occasional in sandy soil in Sections 1 and 2; C = 5; CN = 13.

Phlox paniculata L.
Summer phlox; occasional in sandy soil along the creek; CN = 143.

Polygonaceae — Buckwheat Family

Polygonum amphibium L.
Water smartweed; occasional in sand near the creek in Sections 1, 2, and 5 among *Polygonum lapathifolium* L.; C = 4; CN = 154.

Polygonum hydropiperoides Michx.
False water-pepper; occasional in moist sand and often standing water near the creek in Section 5; C = 7; CN = 128.

Polygonum lapathifolium L.
Pale smartweed; occasional in sand near creek in Sections 1, 2, and 5; C = 0; CN = 155.

Polygonum pensylvanicum L.
Smartweed; common in disturbed areas near the roadside and near the border of the woods in Sections 1-4; C = 0; CN = 68.

Polygonum persicaria L.
Lady's thumb; common along Fox Hill Road in Sections 3 and 4; CN = 141 (alien).

Polygonum scandens L.
False buckwheat; occasional in all sections of the park climbing on small shrubs; C = 1; CN = 152.

Polygonum virginianum L.
Virginia knotweed or jumpseed; occasional throughout the park in partial sunlight; C = 2; CN = 156.

Rumex crispus L.
Curly dock; common in the open wetland in Section 1 and in the mesic upland woods of Sections 1-4; CN = 67 (alien).

Pontederiaceae — Water-Hyacinth Family

Pontederia cordata L.
Pickerel-weed; one plant found in the creek along the edge of the trail in Section 1; C = 10; not collected.

Portulaceae — Purslane Family

Claytonia virginica L.
Spring-beauty; frequent in direct sunlight and at the edge of the woods in Sections 1-4; C = 2; CN = 4.

Portulaca oleracea L.
Common purslane; common growing out of the cracks in the asphalt near the edge of the parking lot in Section 1; CN = 142 (alien).

Primulaceae — Primrose Family

Lysimachia ciliata L.
Fringed loosestrife; common in Sections 1 and 2 in partial to direct sunlight; C = 4; CN = 79.

Ranunculaceae — Buttercup Family

Anemonella thalictroides (L.) Spach.
Rue anemone; common throughout Sections 1 and 2; C = 7; CN = 17.

Ranunculus abortivus L.
Small-flowered crowfoot; common in sandy soil and the mesic upland woods of Sections 1-4; C = 0; CN = 20.

Ranunculus ficaria L. subsp. *bulbifera* Lambionon
Lesser celandine; one isolated population in sandy soil in Section 2; CN = 7 (alien).

Rosaceae — Rose Family

Agrimonia gryposepala Wallr.
Common agrimony; occasional at the edge of the woods in partial sunlight in Section 2; C = 2; CN = 145.

Crataegus sp. L.
Hawthorn; common in the mesic upland woods; C = 4; not collected.

Geum canadense Jacq.
White avens; only a couple dozen plants along the edge of the woods in Sections 1 and 2; C = 1; CN = 80.

Prunus serotina Ehrh.
Wild black cherry; common throughout the mesic upland woods of Sections 1-5; C = 1; CN = 43.

Rosa carolina L.
Pasture rose; one isolated population in Section 4 near Fox Hill Road.; C = 5; CN = 100.

Rosa multiflora Thunb.
Multiflora rose; one shrub in Section 2 at the edge of the woods that may have been planted for horticultural reasons; CN = 39 (alien).

Rubus allegheniensis T.C. Porter
Common blackberry; one shrub in Section 2 at the edge of the woods that may have been planted for horticultural reasons; C = 3; CN = 40.

Rubiaceae — Madder Family

Gallium aparine L.
Cleavers; abundant in all mesic upland areas where myrtle is not abundant; C = 1; CN = 23.

Salicaceae — Willow Family

Populus deltoides Marshall
Common cottonwood; occasional in the mesic upland areas; C = 2; CN = 52.

Salix babylonica L.
Weeping willow; one tree in Section 3 near the bridge on Grandview Drive; C = 53 (alien).

Salix nigra Marshall
Black willow; occasional throughout the mesic upland woods of Sections 3 and 4; C = 4; not collected.

Scrophulariaceae — Figwort Family

Mimulus ringens L.
Monkey-flower; common in direct sunlight in Section 1 among the mowed grass and in the wetland; C = 6; CN = 96.

Verbascum thapsus L.
Common mullein; occasional along the roadside in Sections 3 and 4; CN = 123 (alien).

Veronica arvensis L.
Corn speedwell; common in Sections 1 and 2 in direct sunlight among the grass; often occurs with *Lamium amplexicaule* L.; CN = 15 (alien).

Veronica peregrina L.
Purslane speedwell; common in Sections 1 and 2 in direct sunlight among the grass; C = 0; CN = 29.

Simaroubaceae — Quassia Family

Ailanthus altissima (Miller) Swingle
Tree of heaven; only one isolated population in Section 1, but common in Sections 3-4; CN = 95 (alien).

Solanaceae — Nightshade Family

Solanum carolinense L.
Horse-nettle; occasional to rare in Sections 1 and 4 near the edge of the woods; CN = 109 (alien).

Solanum dulcamara L.
Bittersweet; common in Sections 1-3 in partial to direct sunlight; CN = 54 (alien).

Tiliaceae — Linden Family

Tilia americana L.
Basswood or American linden; occasional throughout the park; C = 5; not collected.

Ulmaceae — Elm Family

Celtis occidentalis L.
Northern hackberry; common throughout the park; C = 3; not collected.

Ulmus rubra Muhl.
Red or slippery elm; common throughout the mesic upland woods of Sections 1-5; C = 4; CN = 46.

Urticaceae — Nettle Family

Pilea pumila (L.) Gray
Clearweed; common along the edge of the woods in direct sunlight in Sections 1 and 2; C = 5; CN = 153.

Urtica dioica L.
Stinging nettle; abundant in the mesic upland woods and throughout all sections, especially among jewelweed; not collected (alien).

Verbenaceae — Vervain Family

Phryma leptostachya L.
Lopseed; common at the border of the mesic upland woods in Sections 1 and 2; C = 4; CN = 92.

Verbena urticifolia L.
White vervain; occasional at the border of the mesic upland woods in Sections 1 and 2; C = 5; CN = 116.

Violaceae — Violet Family

Viola cucullata Aiton.
Blue marsh-violet; abundant throughout all sections; C = 9; CN = 6.

Viola pubescens Aiton.
Yellow forest violet; common throughout Sections 1-4; C = 5; CN = 16.

Viola striata Aiton.
Cream or pale violet; abundant throughout Sections 1-4; C = 6; CN = 12.

Vitaceae — Grape Family

Parthenocissus quinquefolia (L.) Planchon
Virginia-creeper; abundant in all sections; C = 2; CN = 49.

Vitis vulpina L.
Winter grape; abundant in all sections and common climbing on small shrubs; C = 9; CN = 125.

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THE LICHEN FLORA OF HOOSIER PRAIRIE STATE NATURE PRESERVE

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ABSTRACT: Twenty-nine species of lichens are reported from Hoosier Prairie State Nature Preserve in Lake County, Indiana. Thirteen are of the crustose growth form, thirteen are foliose, and three are fruticose. An annotated species list with information on the habitats and distribution for each species is provided. The results of this study indicate that lichenized fungi are relatively uncommon at this nature preserve.

KEYWORDS: Arenicolous, corticolous, crustose, foliose, fruticose, lichen, lignicolous, saxicolous.

INTRODUCTION

The Hoosier Prairie State Nature Preserve is located about 43 km (27 miles) southeast of downtown Chicago in Lake County, Indiana (Figure 1). This 177 hectare (439 acre) State Nature Preserve, which is located in the Northwestern Morainal Natural Region (Homoya, *et al.*, 1985), is owned and managed by the Indiana Department of Natural Resources. The prairie developed on beach sand lying over lake bottom clay after Lake Michigan water levels receded from this area about 9,000 years ago.

The topography is nearly level, with the elevation averaging 189 m (620 feet). Soils are generally sandy and predominantly of the Brems, Maumee, and Watseka Series (Persinger, 1972). For northwestern Indiana, the average January temperature ranges from a high of -1° C (30° F) to a low of -9°C (16° F), and the average July temperature, from a high of 28° C (83° F) to a low of 17° C (63° F). An average of 91 cm (36″) of precipitation falls per year (Bair, 1992).

Several natural communities are found at Hoosier Prairie. Dry savannas occur on sand rises and are dominated by *Quercus alba* L. and *Q. velutina* Lam. Mesic sand prairie openings lie between the rises and swales and are dominated by *Populus deltoides* Marshall, *P. tremuloides* Michx., and *Salix interior* Rowlee. Wet prairies, sedge meadows, and marshes are scattered throughout the preserve in depressions and flats.

Management of the prairie includes brush cutting and prescribed burning. Other human influences include concrete curbing in a gravel parking lot, wood rail fencing, a mowed hiking trail, and a few piles of concrete rubble. The surrounding land is approximately 75% residential and 25% industrial.

Hoosier Prairie is within the boundaries of Calkins' (1896) flora, but none of the 125 species he reported were cited specifically from Lake County, Indiana. Wetmore (1986) reported 62 species of lichens from the Indiana Dunes National Lakeshore, but he did not include any from nearby Hoosier Prairie.

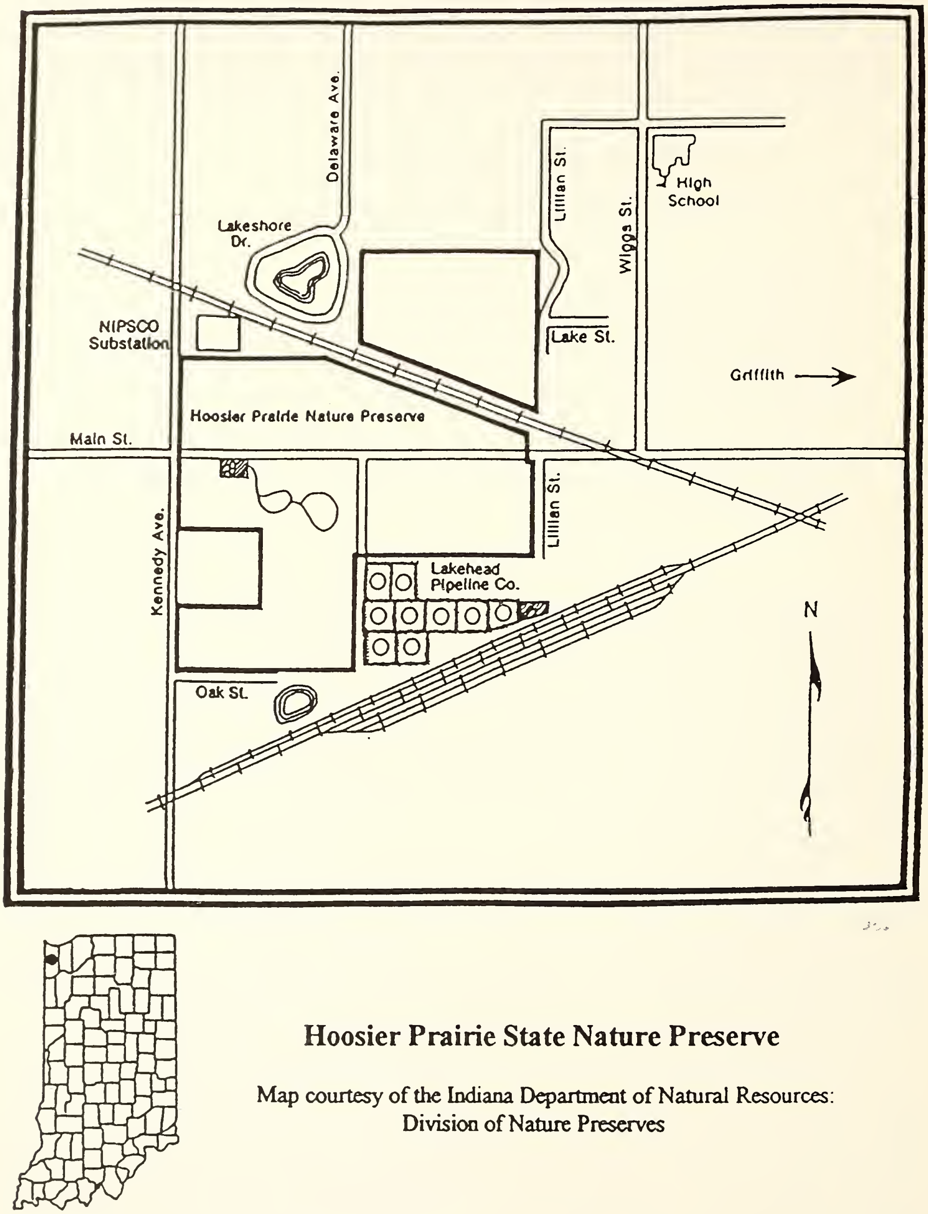

Figure 1. Hoosier Prairie Nature Preserve.

Since no lichenological studies were conducted in Hoosier Prairie, the purpose of this study was to provide information on the habitats and distribution of the lichen flora there.

MATERIALS AND METHODS

Between August 1991 and April 1997, six trips were made to Hoosier Prairie to collect voucher specimens and information on the habitats of these lichens.

Spot tests for chemical substances were made on the collected specimens using sodium hypochlorite and potassium hydroxide. Thin-layer chromatography (Culberson, 1972) was used to verify secondary-product chemistry of the *Cladoniae*. Specimens were identified using keys by Brodo (1988), Hale (1979), and Wilhelm (1995). A set of voucher specimens has been deposited in the herbariums at the Indiana Dunes National Lakeshore, Porter, Indiana, and at the Morton Arboretum, Lisle, Illinois.

RESULTS AND DISCUSSION

Twenty-nine species of lichenized fungi in 19 genera are reported from Hoosier Prairie State Nature Preserve (see Checklist). Thirteen species are of the crustose growth form, thirteen are foliose, and three are fruticose. Two species were common, three were frequent, ten were occasional, and fourteen were rare. The most common lichens were *Candelaria concolor* and *Physcia millegrana*. These two species are ubiquitous throughout northwestern Indiana.

Nearly 62% of the flora was generally found on corticolous substrates (*Quercus*, *Populus*, and *Salix* spp.), 17% was lignicolous (on a wooden fence around the parking lot and on decorticate logs), 14% was saxicolous (on concrete curbing and rubble), and 7% was arenicolous (on sandy soil).

Only 11 of the 125 species reported by Calkins were found at Hoosier Prairie. Of the 62 species reported by Wetmore, only 17 were found. The study areas of both Calkins and Wetmore were much larger than Hoosier Prairie and probably had more habitats and subtrates available for lichen colonization. Eleven species of lichens were found that were not included in Calkins' and Wetmore's studies. At least 6 of those species were found on substrates that were brought in for construction of the parking lot (concrete and wood) and were not found in a natural setting.

The effect prescribed burning is having on the Hoosier Prairie lichen flora is not known, and no attempt was made to determine this. However, Wetmore (1981) mentions that frequent burning reduces lichen abundance, which may account for their low numbers here.

ACKNOWLEDGMENTS

The author would like to thank Dr. Gerould Wilhelm and Linda Masters, both of Conservation Design Forum, Inc., Elmhurst, Illinois, for doing the thin-layer chromatography on the *Cladoniae* and for their help and assistance in the identification and verification of specimens. Also, thanks to Tom Post, Regional Ecologist with the Indiana Department of Natural Resources, and John A. Bacone, Director of the Indiana Division of Natural Resources, for permission to do this study at an Indiana State Nature Preserve and to two anonymous reviewers for their comments and suggestions. Finally, thanks to volunteer Deb Petro for initially suggesting a lichen study at Hoosier Prairie and for showing me around the Nature Preserve.

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CHECKLIST OF THE LICHENS OF HOOSIER PRAIRIE STATE NATURE PRESERVE

The following is an annotated list of the lichenized fungi collected at Hoosier Prairie. Their arrangement is alphabetical by genus and then species. Presence, along with a brief description of habitat, is followed by the growth form and substrate(s), which are listed in brackets. The collection number is given in parentheses. All collections were made by the author. Nomenclature and authority follow Esslinger and Egan (1995). Lichens reported by Wetmore (1986) are indicated by a "W."

Amandinea Choisy *ex* Scheid. & H. Mayrh.

Amandinea punctata (Hoffm.) Coppins & Scheid. Rare; on a weathered wood rail fence (196). [CRUSTOSE / LIGNICOLOUS]. W.

Anisomeridium (Müll. Arg.) Choisy

Anisomeridium nyssigenum (Ellis & Everh.) R.C. Harris. Rare; on the lower trunk of *Quercus alba* in a shaded mesic woodland (1371). The conidial state of this lichen, which has been called *Sarcinulella banksiae* Sutton & Alcorn, is represented here. [CRUSTOSE / CORTICOLOUS].

Arthonia Ach.

Arthonia caesia (Flotow) Körber. Occasional; on the trunks of *Populus tremuloides* and *Quercus velutina* (201). [CRUSTOSE / CORTICOLOUS]. W.

Caloplaca Th. Fr.

Caloplaca feracissima H. Magn. Rare; on weathered concrete curbing (250). [CRUSTOSE /SAXICOLOUS]. W.

Caloplaca holocarpa (Hoffm. ex Ach.) M. Wade. Occasional; on a weathered wood rail fence and a decorticate log (350). [CRUSTOSE / LIGNICOLOUS].

Caloplaca microphyllina (Tuck.) Hasse. Rare; on a weathered wood rail fence (193). [CRUSTOSE / LIGNICOLOUS].

Candelaria A. Massal.

Candelaria concolor (Dickson) Stein. Common; on the lower branches of *Populus deltoides* and *Quercus velutina* (206). [FOLIOSE / CORTICOLOUS]. W.

Candelaria concolor var. *effusa* (Tuck.) G. Merr & Burnham. Occasional; on the trunks of *Populus deltoides* and *Quercus velutina* (813). [FOLIOSE / CORTICOLOUS].

Candelariella Müll. Arg.

Candelariella reflexa (Nyl.) Lettau. Occasional; on a weathered wood rail fence and lower branches of *Quercus velutina* (1368). [CRUSTOSE / CORTICOLOUS - LIGNICOLOUS].

Cladonia P. Browne

Cladonia peziziformis (With.) J.R. Laundon. Rare; on sandy soil along a mowed hiking trail (214). [FRUTICOSE / ARENICOLOUS]. W.

Cladonia polycarpoides Nyl. Rare; on sandy soil in a wet depression with *Drosera intermedia* (346). [FRUTICOSE / ARENICOLOUS]. W.

Cladonia ramulosa (With.) J.R. Laundon. Occasional; at the base of *Quercus velutina* (1372). [FRUTICOSE / CORTICOLOUS]. W.

Cyphelium Ach.

Cyphelium tigillare (Ach.) Ach. Rare; on a weathered wood rail fence (1494). [CRUSTOSE /LIGNICOLOUS].

Endocarpon Hedwig

Endocarpon pusillum Hedwig. Rare; on concrete rubble (812). [CRUSTOSE / SAXICOLOUS]. W.

Flavopunctelia (Krog) Hale

Flavopunctelia flaventior (Stirton) Hale. Rare; on the lower trunk of *Quercus rubra* (205-A). [FOLIOSE / CORTICOLOUS].

Hyperphyscia Müll. Arg.

Hyperphyscia adglutinata (Flörke) H. Mayrh. & Poelt. Occasional; on a decorticate oak log and on the lower branches of *Quercus velutina* (1318, 1370) and *Salix interior* (1373). [FOLIOSE / CORTICOLOUS - LIGNICOLOUS].

Lecanora Ach.

Lecanora dispersa (Pers.) Sommerf. Rare; on weathered concrete curbing (253). [CRUSTOSE /SAXICOLOUS]. W.

Lecanora strobilina (Sprengel) Kieffer. Rare; on the lower trunk of *Quercus alba* (1495). [CRUSTOSE / CORTICOLOUS].

Lecanora symmicta (Ach.) Ach. Frequent; on the lower trunks of *Quercus velutina* (202) and *Salix interior* and on a weathered wood rail fence (192). [CRUSTOSE /CORTICOLOUS-LIGNICOLOUS].

Melanelia Essl.

Melanelia subaurifera (Nyl.) Essl. Rare; on the lower branches of *Salix interior* (1496). [FOLIOSE / CORTICOLOUS].

Parmelia Ach.

Parmelia sulcata Taylor. Frequent; on the lower branches of *Populus tremuloides* (224), *Quercus velutina*, and *Salix interior* (207). [FOLIOSE / CORTICOLOUS]. W.

Phaeophyscia Moberg

Phaeophyscia pusilloides (Zahlbr.) Essl. Occasional; at the base of *Quercus velutina* (815) [FOLIOSE / CORTICOLOUS]. W.

Phaeophyscia rubropulchra (Degel.) Essl. Occasional; at the bases of *Populus deltoides* (210) and *Salix interior* (1369). [FOLIOSE / CORTICOLOUS]. W.

Physcia (Schreber) Michaux

Physcia adscendens (Fr.) H. Olivier. Occasional; on the lower trunk of *Populus deltoides* (211). [FOLIOSE / CORTICOLOUS]. W.

Physcia millegrana Degel. Common; on the trunks and lower branches of *Populus deltoides*, *Quercus velutina* (198), and *Salix interior* (213). [FOLIOSE / CORTICOLOUS]. W.

Physcia stellaris (L.) Nyl. Frequent; on the trunks and lower branches of *Populus deltoides* and *Quercus velutina* (209). [FOLIOSE / CORTICOLOUS]. W.

Punctelia Krog

Punctelia rudecta (Ach.) Krog. Rare; on the trunk of *Quercus rubra* (205). [FOLIOSE /CORTICOLOUS]. W.

Thelidium Massal.

Thelidium microcarpum (Leight.) A.L. Sm. Rare; on concrete rubble (344). [CRUSTOSE /SAXICOLOUS].

Xanthoria (Fr.) Th. Fr.

Xanthoria fallax (Hepp) Arnold. Occasional; on the lower branches of *Quercus velutina* (814) and on a wood rail fence (251). [FOLIOSE / CORTICOLOUS - LIGNICOLOUS]. W.

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GENETIC EVIDENCE FOR TWO POTASSIUM TRANSPORT SYSTEMS IN THE GREEN ALGA, *CHLAMYDOMONAS REINHARDTII*

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ABSTRACT: The genetic evidence for two independent potassium transport systems in *Chlamydomonas reinhardtii* is presented. The first system was previously described and is encoded by the *TRK* genes. The second, described here, is encoded by the HKR gene.

KEYWORDS: *Chlamydomonas reinhardtii*, potassium transport, transport mutants.

INTRODUCTION

Potassium is the major monovalent cation in plant and algal cells, where it plays an important role in several cellular processes, such as osmoregulation, protein synthesis, and charge balance (Leigh and Wyn-Jones, 1984). Because of the essential role potassium plays in these processes, its concentration within the cytoplasm and various other cell compartments is highly regulated. This control is achieved through the regulation of potassium transport across the membrane barriers of various compartments. For example, the cytoplasmic potassium concentration is maintained at a fairly constant level of approximately 150 mM even though plants grow successfully in media with potassium concentrations ranging from 10 μM to 10 mM. A higher plant's ability to respond to a range of external potassium concentrations is achieved by two kinetically distinct transport systems. The first, a high-affinity system, exhibits typical Michaelis-Menten kinetics and reaches saturation in the micromolar range; the second, a low-affinity system, operates in the millimolar range and is often said to be non-saturable (Kochian and Lucas, 1982). In a recent study of potassium transport in the green alga *Chlamydomonas reinhardtii,* Malhotra and Glass (1995) reported kinetic data that support the existence of two potassium transport systems, a saturable, high-affinity system (HATS) and a non-saturable, low-affinity system (LATS).

In recent years, much progress in our understanding of the nature of potassium transporters has been made through a variety of kinetic and electrophysiological analyses (*e.g.,* Kochian and Lucas, 1982; Maathius and Sanders, 1994). Insight into the structure of transporters has been enhanced greatly with the cloning of plant potassium channel genes (Anderson, *et al.,* 1992; Sentenac, *et al.,* 1992). This progress notwithstanding, gaps remain in our understanding.

One approach to the study of potassium transport that has not been explored fully is the isolation and characterization of potassium transport defective clones. This approach, employing *Chlamydomonas* as a model system, was first outlined by Polley and Doctor (1985), who isolated and conducted a preliminary characterization of three potassium transport defective clones. Subsequently, additional mutant clones have been isolated and characterized, and the presence of at least three unlinked genes (*trk*) that encode the high affinity transport system has been demonstrated (Polley, in review). In work reported here, genetic evidence for a second potassium transport system is presented. Isolation of mutant transport alleles should make possible the identification of additional components of the potassium transport system and the future cloning of genes involved in transport and its regulation.

MATERIALS AND METHODS

Strains. The mutant clone DP2 (*trk2-1 act1 mt-*) was derived as a recombinant from a cross between the potassium transport defective clone KDP5 (*trk2-1 mt+*) and CC1680 (*act1 ac80 mt-*). KDP5 was isolated after UV-mutagenesis of wild-type strain 137c (Polley, in review). Both the wild-type and mutant strain CC1680 were obtained from the *Chlamydomonas* Genetics Center. Mutant clone 10KDP1 was isolated after UV-mutagenesis of clone DP2.

Media and Growth Conditions. Cells were grown axenically at 25° C under continuous illumination either in aerated liquid cultures or on medium solidified with agar. Medium 0K0N is a modification of tris-acetate-phosphate medium (TAP medium) that possesses only trace amounts of potassium or sodium (Polley and Doctor, 1985). The potassium requirement of mutant clones was determined by measuring the rate of growth in 0K0N supplemented with different concentrations of KCl. Growth was monitored by following absorbance (light scattering) at 560 nm. Absorbance is directly proportional to cell number, and the same correlation between cell number and absorbance exists for cells grown in media of different potassium concentrations.

Mutagenesis and Genetic Analysis. Four milliliters of DP2 cells grown to a density of approximately 5 x 10^6 cells/ml were placed in a 4.5 cm Falcon petri dish and exposed to UV-irradiation for 90 sec in a Strategene UV Crosslinker. After exposure, cells were grown overnight in the dark to fix the mutation. The cells were then plated on 10K0N (0K0N medium supplemented with 10 mM KCl). Approximately 5-10% of the cells survive UV irradiation. Survivors were screened by replica-plating to 1K0N (0K0N supplemented with 1 mM KCl). Mating and tetrad analysis were done as described by Harris (1989).

RESULTS AND DISCUSSION

Approximately 1,000 DP2 clones that survived UV-mutagenesis were screened for their ability to grow on 1K0N. Of these, 5 failed to grow, and they were designated as putative *h*igh *K^+* *r*equiring (*hkr*) mutants. One of these, clone 10KDP1, was selected for further study. The concentration of potassium required

Table 1. Growth rate of wild-type and mutant clones (growth rate constants, k, where $A_t = A_0e^{kt}$, are the averages of three experiments ± standard error).

Growth Rate Constant (k x 10^{-2})					
		KCl (mM)			
Strain	Alleles	10	5	1	0.1
137c	*TRK2-1 HKR*	ND*	7.5±0.5	7.7±0.9	7.9±1.0
DP2	*trk2-1 HKR*	8.0±0.3	ND	7.0±0.1	0.6±0.9
10KDP1	*trk2-1 hkr*	7.0±0.3	5.2±0.6	0.0±0.0	ND

* ND = not done.

for growth and the specificity of the requirement were determined by measuring the rate of growth in liquid media supplemented with different concentrations of KCl (Table 1). Growth was monitored by measuring absorbance (see methods); readings were taken every 3-5 hours during exponential growth of the culture. The growth rate constant, k, is based on 6 time points. The reported values in Table 1 are the averages of three experiments. As the data clearly show, *trk2-1* cells require KCl concentrations greater than 0.1 mM to achieve a wild-type growth rate; *trk2-1 hkr* cells require concentrations greater than 1 mM. In both cases, NaCl cannot substitute for KCl (Polley and Doctor, 1985, and data not shown).

The *trk2-1* allele maps to linkage group II and is linked to the *act1* allele (PD > NPD, Table 2, Tetrad Analysis; Polley, in review). The mutant clone 10KDP1 was crossed to wild type (*trk2-1 hkr act1 mt-* x *TRK2-1 HKR ACT1 mt+*), and tetrad analysis was performed in order to map the genetic lesion, *hkr*, relative to the *trk2-1* and *act1* alleles. The possible genotypes resulting from this cross and their respective phenotypes and tetrads are shown in Table 2 (Genotypes and Phenotypes). The phenotypes are defined as low KCl when cells achieve wild-type growth rate on 0.1 mM KCl, as intermediate KCl when cells require 1 mM KCl, and as high KCl when cells require 10 mM KCl in order to grow at wild-type rates. Of the four genotypes listed, only the phenotype of the recombinant *TRK2-1 hkr* could not be predicted *a priori.* The wild-type *TRK2-1* allele was assumed to be epistatic to *hkr,* and, therefore, the phenotype of *TRK2-1 hkr* would be low KCl. That this assumption is correct is supported by the observation that only three classes of tetrads, as defined by the phenotypic ratios of tetrad products, were obtained (Table 2, Tetrads and Phenotypes). Based on the criteria PD = NPD and NPD/T > 0.25 (Perkins, 1953), the tetrad data (Table 2, Tetrad Analysis) show that the *hkr* gene is unlinked to *trk2-1.*

While the *hkr* lesion in 10KDP1 might actually be a mutation in one of the other two, unlinked *TRK* genes, this possibility seems unlikely for two reasons. First, genetic recombinants harboring two mutant *TRK* alleles (*trk1 trk2-1, trk1 trk3,* or *trk2-1 trk3*) do not exhibit growth rates different from cells with just one mutant *TRK* allele (Polley, in review). This finding suggests that the *TRK* gene

Table 2. Genetic analysis of clone 10KDP1.

Genotypes and Phenotypes

Genotype	Phenotype
TRK2-1 HKR	Low KCl
trk2-1 hkr	High KCl
trk2-1 HKR	Intermediate KCl
TRK2-1 hkr	Low KCl

Tetrads and Phenotypes

Tetrads	Phenotypic Ratios
Parental Ditype	2 High : 2 Low
Nonparental Ditype	2 Inter. : 2 Low
Tetratype	2 Inter. : 1 Low : 1 High

Tetrad Analysis

Cross	*trk2-1 act1*	*trk2-1 hkr*
KDP5 x CC1680	16:0:12*	
10KDP1 x CC125	16:0: 5	8:5:8

* PD:NPD:T.

products interact functionally; *i.e.,* if one mutant polypeptide disrupts function of a multimeric protein complex, a second mutant polypeptide would not have a noticeable effect because the complex is already disabled. The *hkr* allele in a *trk2-1* background, however, does increase the potassium requirement for growth. The *hkr* allele must, therefore, affect the function or regulation of some other potassium transport system.

Second, and consistent with the above interpretation, is the observation that *TRK2-1* is epistatic to *hkr*. If the *TRK* genes encode for a potassium transport system that is able to transport potassium from media with low concentrations (0.1 mM) of potassium, and if the *HKR* gene encodes for a transport system that is effective only in media with intermediate levels (1.0 mM) of potassium, then one would expect *trk hkr* cells to require high concentrations (10 mM) of potassium to grow. By similar reasoning, one would also expect cells with a functional TRK system not to need an HKR system; *i.e., TRK2-1 hkr* cells will grow on low levels of potassium.

In summary, the above genetic data support the conclusion that two distinct transport systems exist: the TRK system which operates at low levels of potassium and the HKR system which operates at higher levels of potassium. Future work will involve a kinetic analysis of potassium transport by 10KDP1, mapping the *hkr* mutant allele, and determining if *hkr* in a *trk1* or *trk3* background also require, as would be expected, high concentrations of potassium.

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IMPACT OF WHITE-TAILED DEER ON FOREST COMMUNITIES WITHIN BROWN COUNTY STATE PARK, INDIANA

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ABSTRACT: The white-tailed deer (*Odocoileus virginianus*) is an herbivorous species that can significantly influence the structure of forest communities wherever it occurs in excessive numbers. This species has a propensity to increase beyond the carrying capacity of its habitat when predation pressure is reduced. The influence of white-tailed deer on the plant communities within Indiana's State Parks, which have been closed to hunting by man for several decades, are explored in this paper. During 1993 and 1994, sites (stratified by physiographic position) were sampled within Brown County State Park and adjacent State and National Forests (open to public hunting). A reduction in the percentage cover of the ground flora and the mature height of some specific plant species inside Brown County State Park as compared to external sites subjected to hunting pressure was noted. In addition, the recruitment of many woody species into larger size classes was reduced significantly within Brown County State Park. The current forest structure within Brown County State Park indicates that this reduction in recruitment has been occurring for many years. The reduction in recruitment, along with the damage documented within the herbaceous layer, suggests that the sustainability and structure of the forests within the park may ultimately be affected unless deer numbers are controlled and the forest understory is allowed to recover.

KEYWORDS: *Adiantum pedatum*, Brown County State Park, Indiana, percentage cover, plant communities, species richness, white-tailed deer.

INTRODUCTION

White-tailed deer, along with large predators, had been eliminated from Indiana by 1900 (Mumford and Whitaker, 1982). In 1934, the Federal Aid to Wildlife Restoration (Pittman-Robertson Act) provided funds for the reintroduction of white-tailed deer into southern Indiana (Mumford and Whitaker, 1982). These introduced deer benefitted from a landscape of second-growth forests, openings, and farmlands that had been created by logging, clearing, and agriculture (Smith, 1991).

By 1948, the Pittman-Robertson project reported an overabundance of deer and deer-induced damage to agricultural and native plant communities, leading to the first modern hunt within 17 Indiana counties in 1951 (Mumford and Whitaker, 1982). State Parks in Indiana were closed to hunting and have remained so until recently. Restricted hunting has allowed the white-tailed deer populations in some State Parks to expand beyond the capacity of their habitat to support them.

Deer have a selective foraging strategy when food resources are abundant, but they change to a more generalist strategy as resources are depleted (Brown and Doucet, 1991; Strole and Anderson, 1992; Kohlman and Risenhoover, 1994). Selective foraging by a generalist species is a learned behavior which maximizes nutrient intake but is subject to constraints at low levels of food availability (Westoby, 1974). Deer are known to select a species according to its chemical composition, and intake has been found to be constrained by forage toxicity (McArthur, *et al.*, 1993). These foraging strategies often lead to browse species preference. Several studies show that deer select certain herbaceous and woody species over others (Korschgen, 1962; Nixon, *et al.*, 1970; McCaffery, *et al.,* 1974). This foraging strategy is termed the "optimization model," and the model implies that the grazing pressure on a species within a plant community may increase as that species becomes rarer (Westoby, 1974).

Foraging strategies have been found to be sensitive to changes in plant availability (Kohlman and Risenhoover, 1994). Deer avoid nonpreferred browse species even when more preferred species become depleted. Deer search for and consume preferred forage until it becomes rare before switching to an apparently less desired species (Gillingham and Bunnell, 1989). Deer density may also affect food selection. Preferred foods, such as acorns, were found to be utilized more quickly by a larger deer population (McCullough, 1985; Kohlman and Risenhoover, 1994). Therefore, at higher population levels, deer could significantly alter plant communities by extirpating the more preferred species.

Evidence of intensive browsing by white-tailed deer in forest plant communities has been documented (Marquis, 1974; Alverson, *et al.*, 1988; Strole and Anderson, 1992; Balgooyen and Waller, 1995) and found to negatively effect the regeneration of some tree species by reducing their recruitment and survival (Marquis, 1974; Strole and Anderson, 1992). This effect on regeneration has been studied in the eastern hemlock (*Tsuga canadensis*) forests of northeastern Wisconsin, where, in areas that are heavily browsed, sugar maple (*Acer saccharum*) rapidly replaces hemlock (Anderson and Loucks, 1979). However, Anderson and Loucks (1979) also found that once browsing pressure was relieved, the hemlock recovered. Their finding suggests that a species subject to intensive browsing may recover if the pressure is reduced. In addition, the amount of browsing pressure on certain preferred forage species could be used as an indicator of deer abundance within an area (Korschgen, 1962).

In 1993, a committee was established by the Indiana Department of Natural Resources to develop alternative solutions for managing the excessive popu-

lation of white-tailed deer within Brown County State Park, Indiana. The committee concluded that the deer were seriously damaging understory vegetation and recommended a limited hunt within the park boundaries. This hunt occurred in December 1993. The committee also initiated a study to investigate the effects of overbrowsing on understory vegetation (Brown County State Park Deer Study Committee, 1993). The forest communities within Brown County State Park, Yellowwood State Forest, and Hoosier National Forest (the latter two are both open to hunting) were sampled in 1993 by James Van Kley (a Ph.D. student at Purdue University) to determine the impact of white-tailed deer on the vegetation. Preliminary measurements of the structure of the plant community and the browse damage within Brown County State Park indicated that the deer were browsing heavily on selected herbaceous and woody species and significantly reducing the percentage cover, species richness, and mature heights of the ground flora species. This study also found a difference between the southwestern corner and the main body of Brown County State Park, with the southwestern corner showing less damage (Parker and Van Kley, 1993). Parker and Van Kley (1993) theorized that because the southwestern corner was bordered by Yellowwood State Forest and Hoosier National Forest, the deer in the southwestern corner of Brown County State Park experienced more hunting pressure than those within the main body of the park.

Permanent study areas were not established by Van Kley to observe trends in browse damage. Therefore, the current study was initiated in the spring of 1994 to determine the structure and composition of the plant communities following the removal of 392 deer in December 1993. Permanent plots were established to monitor changes in the plant communities in response to long-term change in deer populations.

STUDY AREAS

Brown County State Park, located in south-central Indiana, was first opened in 1929 and is Indiana's largest State Park at 6,358 hectares. The park is located within the Brown County Hills Section of the Highland Rim Natural Region (Homoya, *et al.*, 1985). This area is defined by acid silt loam soils with a small amount of loess and characteristic topographic features such as deeply dissected uplands, steep slopes, and narrow hollows (Homoya, *et al.*, 1985; Van Kley and Parker, 1993). Uplands are dominated by oak-hickory forest (Homoya, *et al.*, 1985); common plants on the upper slopes are chestnut oak (*Quercus prinus*), common greenbrier (*Smilax rotundifolia*), low growing shrubs, and sedges (in particular, painted sedge (*Carex picta*)). The ravines contain mesic species (Homoya, *et al.*, 1985) such as beech (*Fagus grandifolia*), red oak (*Quercus rubra*), sugar maple (*Acer saccharum*), and white ash (*Fraxinus americana*). Control areas were selected within Yellowwood State Forest and the Pleasant Run Unit of the Hoosier National Forest, which border the southwestern section of Brown County State Park. Both the State and National Forests are open to annual deer harvest.

METHODS

Twenty sites within Brown County State Park and ten control sites in Yellowwood State Forest/Hoosier National Forest were randomly selected to establish permanent study plots. The 20 sites in the park were divided into eight sites in the southwestern corner, where less browsing was observed (Parker and Van Kley, 1993), and 12 in the main body of the park. The Ecological Classification System developed for the Pleasant Run Unit of Hoosier National Forest was used to determine similar physiographical units inside and outside the park (Van Kley and Parker, 1993). Sites were limited to closed-canopy, relatively mature forests and divided into four ecological landtypes: mesic northerly or northeasterly slopes, dry southerly or southwesterly slopes, mesic bottomlands, and dry ridges. One or a combination of these landtypes were sampled at each site; a total of 19 landtypes were sampled in Yellowwood State Forest/Hoosier National Forest, 16 within the southwestern corner of Brown County State Park, and 27 in the main body of Brown County State Park. All the sites were sampled within two months of each other to avoid site-to-site variation.

The following vegetative variables were measured using a series of nested plots at each sample location: the percentage cover of the ground flora, the species richness of the ground flora, and the stem density and species richness of the woody species within four size classes (1 = < 50 cm in height; 2 = 50 to 200 cm in height; 3 = > 200 cm in height and < 2.5 cm dbh; and 4 = > 200 cm in height and > 2.5 cm dbh). The mature heights of six herbaceous species were also recorded.

The percentage cover of the ground flora was measured using a ten-meter line transect running parallel to the contour of the slope in each landtype measured at a site. The length of overlap (cm) for the ground flora, including both herbaceous and woody class 1, was recorded and used to calculate the percentage cover for each species.

To record the number of stems and woody species in classes 1 and 2, a one meter by ten meter belt transect was established using the ten-meter line transect as its lower edge. The dbh of woody species in classes 3 and 4 was recorded within a 100 m^2 circular plot, the center of which was the start of the line transect.

Ground flora richness in each landtype was determined by recording all the herbaceous species found within the belt transect and circular plot. The species present within the circular plot were determined by walking concentric circles from the outer edge to the center.

Six species were chosen to test for differences in mature plant height within Yellowwood State Forest/Hoosier National Forest, the southwestern corner of Brown County State Park, and the main body of Brown County State Park. The chosen species showed dramatic differences in mean mature height in heavily browsed areas relative to less impacted ones (Parker and Van Kley, 1993). The species measured were: maidenhair fern (*Adiantum pedatum*), Jack-in-the-pulpit (*Arisaema triphyllum*), wild licorice (*Galium circaezans*), sweet cicely

(*Osmorhiza claytonii*), Christmas fern (*Polystichum acrostichoides*), and common greenbrier (*Smilax rotundifolia*). To determine mature height, the forbs were measured along the stem to the node with the highest leaf or whorl of leaves. For Christmas fern, the length of the longest frond was measured. Three to five plants of each species were measured within each belt transect and their heights were averaged to determine the mean height of the species. The percentage cover was also calculated for these species.

One-way analysis of variance was used to compare the means for vegetation variables among the sites within Yellowwood State Forest/Hoosier National Forest, the southwestern corner of Brown County State Park, and the main body of Brown County State Park. For tests of mature height and percentage cover of the individual species, only the landtypes in which the species were known to be common were used. These included mesic slopes and bottomlands for maidenhair fern, Jack-in-the-pulpit, wild licorice, sweet cicely, and Christmas fern. All sites were used for common greenbrier. An alpha level of $P < 0.10$ was used to delineate significant differences in the vegetation variables among the three sample areas.

RESULTS

The average number of species was not significantly different in the three areas (Table 1). However, on average, more species were found in all landtypes in Yellowwood State Forest/Hoosier National Forest and the southwestern corner of Brown County State Park than in the main body of the park. The percentage cover of the ground flora was significantly reduced in the main body of the park compared to both its southwestern corner and the areas outside the park. The coverage of the ground flora averaged only 14.4% per sample site in all landtypes within the main body of Brown County State Park as compared to 27.8% in the park's southwestern corner and 21.7% in Yellowwood State Forest/Hoosier National Forest. The greatest difference in percentage cover of the ground flora was found on mesic and bottomland sites. Coverage within the main body of Brown County State Park was 50% less than inYellowwood State Forest/Hoosier National Forest.

Specific species exhibited differences in their percentage cover within the park when compared to the control areas (Table 2). Maidenhair fern and sweet cicely both exhibited a significantly lower percentage cover inside the southwestern corner and in the main body of the park when compared to Yellowwood State Forest/Hoosier National Forest. Sweet cicely did not intersect the transect within the park's southwestern corner at any sites and only overlapped the transect at 0.3% of the sites in the main body of the park as compared to 1.5% in Yellowwood State Forest/Hoosier National Forest. Christmas fern showed a significantly higher percentage cover in Yellowwood State Forest/Hoosier National Forest and the southwestern corner of the Brown County State Park relative to the main body of the park, where it averaged 0.9% per sample site. Common greenbrier had a significantly higher percentage cover in Yellowwood State For-

Table 1. Mean ground flora richness measured within a 10 m^2 belt transect and a 100 m^2 circular plot, and the percentage cover of the ground flora measured on a 10 m line transect observed at sample locations outside Brown County State Park, in the southwestern corner of Brown County State Park, and in the main body of Brown County State Park during 1994. Row means with different letters are significantly different ($P < 0.10$).

Variable Sampled at Each Ecological Landtype	Yellowwood State and Hoosier National Forests	Southwestern Corner of Brown County State Park	Main Body of Brown County State Park
All Sites (n = 62)			
Ground flora richness	21.5 a	22.1 a	19.8 a
Percentage cover of ground flora	21.7 a	27.8 a	14.4 b
Mesic Bottomlands (n = 15)			
Ground flora richness	32.0 a	30.1 a	28.9 a
Percentage cover of ground flora	33.7 a	40.9 a	14.5 b
Mesic Slopes (n = 22)			
Ground flora richness	24.6 a	24.2 a	21.5 a
Percentage cover of ground flora	18.0 a	22.0 a	8.0 b
Dry Slopes (n = 15)			
Ground flora richness	13.6 a	14.0 a	12.8 a
Percentage cover of ground flora	22.3 a	34.9 a	23.1 a
Dry Ridges (n = 10)			
Ground flora richness	7.5 a	15.3 a	13.0 a
Percentage cover of ground flora	11.2 a	14.7 a	12.2 a

est/Hoosier National Forest than in either area of the park. The percentage cover of greenbrier was significantly greater in the southwestern corner relative to the main body of Brown County State Park. Jack-in-the-pulpit and wild licorice displayed no significant differences in coverage among the three areas.

The mean heights of the mature plants for the six selected species were also compared (Table 2). Jack-in-the-pulpit and common greenbrier were found to be significantly taller in Yellowwood State Forest/Hoosier National Forest than in both the southwestern corner and main body of Brown County State Park. Maidenhair fern and Christmas fern were significantly shorter in the main body of Brown County State Park when compared to the southwestern corner of the park and Yellowwood State Forest/Hoosier National Forest. Both Jack-in-the-pulpit and maidenhair fern were approximately 10 cm taller within Yellowwood State Forest/Hoosier National Forest than in both the southwestern corner and the main body of the park. Common greenbrier averaged 45 cm taller in Yellowwood State Forest/Hoosier National Forest when compared to both

Table 2. The mean percentage cover and mean height for selected species observed within a 10 m^2 belt transect at sample locations outside Brown County State Park, in the southwestern corner of Brown County State Park, and in the main body of Brown County State Park during 1994. The values used are from landtypes where the species was common. Row means for heights and percentage cover of the ground flora with different letters are significantly different ($P < 0.10$).

Critical Species and Variable Tested	Yellowwood State and Hoosier National Forests	Southwestern Corner of Brown County State Park	Main Body of Brown County State Park
Adiantum pedatum[1]			
Percentage cover	2.3 a	0.4 b	0.1 b
Height (cm)	31.1 a	32.2 a	22.0 b
Arisaema triphyllum[1]			
Percentage cover	0.9 a	0.9 a	1.2 a
Height (cm)	22.3 a	12.9 b	12.0 b
Galium circaezans[1]			
Percentage cover	0.1 a	0.07 a	0.08 a
Height (cm)	15.4 a	15.0 a	14.6 a
Osmorhiza claytonii[1]			
Percentage cover	1.5 a	0 b	0.3 b
Height (cm)	35.2 a	24.0 ab	11.2 b
Polystichum acrostichoides[1]			
Percentage cover	4.7 a	2.8 a	0.9 b
Height (cm)	51.5 a	41.9 a	26.5 b
Smilax rotundifolia[2]			
Percentage cover	4.9 a	3.1 b	2.1 c
Height (cm)	141.1 a	95.9 b	93.1 b

[1] Mesic slopes and bottomlands.
[2] All sites.

areas within Brown County State Park. Sweet cicely was significantly taller in Yellowwood State Forest/Hoosier National Forest than in the main body of the park, averaging 35.2 cm within Yellowwood State Forest/Hoosier National Forest and 11.2 cm within the main body of Brown County State Park. Wild licorice displayed no significant difference in mean height among the three sampling areas.

Overall, the number for woody stems (class 1) was significantly greater in the southwestern corner of Brown County State Park relative to Yellowwood State Forest/Hoosier National Forest and the main body of the park (Table 3). The greatest difference occurred on mesic slopes and dry ridges where the num-

Table 3. The number of stems for woody species and the species richness within four size classes recorded at sample sites outside of Brown County State Park, in the southwestern corner of Brown County State Park, and in the main body of Brown County State Park during 1994. Row means with different letters are significantly different ($P < 0.10$). Size class 1 = stems < 50 cm in height, size class 2 = stems 50 to 200 cm in height, size class 3 = stems > 200 cm in height and < 2.5 cm dbh, and size class 4 = stems > 200 cm in height and > 2.5 cm dbh. The density of size classes 1 and 2 are per 10 m^2 plot and for size classes 3 and 4 are per hectare.

Critical Species and Variable Tested	Yellowwood State and Hoosier National Forests	Southwestern Corner of Brown County State Park	Main Body of Brown County State Park
All Sites			
Size class 1			
Density	39.6 a	67.6 b	39.4 a
Species richness	8.4 a	8.8 a	6.1 b
Size class 2			
Density	1.3 a	0.6 ab	0.2 b
Species richness	0.8 a	0.5 a	0.04 b
Size class 3			
Density	405 a	94 b	159 b
Species richness	1.8 a	0.7 b	1.0 b
Size class 4			
Density	932 a	831 a	833 a
Mesic Bottomlands			
Size class 1			
Density	47.0 a	45.3 a	48.0
Species richness	8.5 a	10.0 a	5.9 b
Size class 2			
Density	1.0 a	0.3 a	0.6 a
Species richness	1.0 a	0.2 b	0.14 b
Size class 3			
Density	200 a	75 a	143 a
Species richness	1.0 a	0.8 a	0.9 a
Size class 4			
Density	700 a	750 a	671 a
Mesic Slopes			
Size class 1			
Density	38.9 a	90.0 b	30.3 a
Species richness	8.1 a	7.3 a	5.5 a
Size class 2			
Density	2.0 a	0.8 ab	0 b
Species richness	1.0 a	0.6 a	0 b
Size class 3			
Density	450 a	150 b	175 b
Species richness	2.4 a	0.8 b	1.1 b
Size class 4			
Density	875 a	833 a	838 a

Table 3 (Continued)

Critical Species and Variable Tested	Yellowwood State and Hoosier National Forests	Southwestern Corner of Brown County State Park	Main Body of Brown County State Park
Dry Ridges			
Size class 1			
Density	18.0 a	73.3 b	25.0 a
Species richness	6.0 a	9.0 b	5.6 a
Dry Slopes			
Size class 1			
Density	43.4 a	46.7 a	51.6 a
Species richness	9.8 a	9.7 a	7.3 a
Dry Slopes and Ridges			
Size class 2			
Density	0.7 a	0.7 a	0 b
Species richness	0.6 a	0.5 a	0 b
Size class 3			
Density	471 a	50 b	142 c
Species richness	1.7 a	0.5 b	0.9 b
Size class 4			
Density	1128 a	883 a	925 a

ber of stems in the southwestern corner of the park averaged 90.0 and 73.3, respectively. Dry slopes and mesic bottomlands did not exhibit any significant differences among the three areas.

The number of species observed in the one meter by ten meter belt transect was significantly higher for all landtypes in Yellowwood State Forest/Hoosier National Forest and the southwestern corner of Brown County State Park than in the main body of the park. The difference was most evident in the mesic bottomland sites in Brown County State Park which averaged 5.9 species per sample site compared to 8.5 in Yellowwood State Forest/Hoosier National Forest and 10.0 in the southwestern corner of the park. The other landtypes did not show any significant differences with the exception of dry ridges, where a significantly higher number of species was observed in the southwestern corner of Brown County State Park than in either Yellowwood State Forest/Hoosier National Forest or the main body of the park.

The overall number of stems for all woody species (class 2) per sample site for all landtypes was significantly higher in Yellowwood State Forest/Hoosier National Forest when compared to the main body of the park (Table 3). Sites averaged 1,300 stems per hectare in Yellowwood State Forest/Hoosier National Forest as compared to 200 stems per hectare inside the main body of the park. Mesic slopes as well as dry slopes and ridges also exhibited this pattern; however, significant differences were not observed for these landtypes in the southwestern corner of Brown County State Park relative to either Yellowwood

State Forest/Hoosier National Forest or the main body of the park. Mesic bottomlands did not show any significant differences among the three areas. The number of woody species in size class 2 was also significantly higher in Yellowwood State Forest/Hoosier National Forest and the southwestern corner of Brown County State Park than in the main body of the park, where papaw (*Asimina triloba*) was the only species found on transects (Table 3).

The number of woody stems (class 3) per hectare was significantly reduced on all sites except mesic bottomlands within the park when compared to Yellowwood State Forest/Hoosier National Forest (Table 3). Species richness for this size class followed the same pattern (Table 3). Significantly more species per sample site were found within Yellowwood State Forest/Hoosier National Forest, which averaged 1.8 species per sample site, than in the southwestern corner (0.7) or the main body (1.0) of the park.

The number of woody species (class 4) per hectare was not significantly different inside Brown County State Park when compared to Yellowwood State Forest/Hoosier National Forest (Table 3). The number of stems averaged 932 per hectare for all landtypes within Yellowwood State Forest/Hoosier National Forest as compared to 831 in the southwestern corner and 833 in the main body of the park, respectively. This pattern was observed for all the different landtypes.

The same vegetation variables were also measured in 1993 within Brown County State Park and Yellowwood State Forest/Hoosier National Forest by Van Kley, and the means of these variables show similar trends between the two years (Table 4). For example, the average number of ground flora species per site found outside the park in 1994 was similar to the number found in 1993 (21.5 in 1994 and 23.3 in 1993). However, the number of species found per site in the southwestern corner and main body of Brown County State Park was higher in 1994. Percentage cover of the ground flora was similar in both years within the main body of Brown County State Park, averaging 14.4% in 1994 and 14.7% in 1993. However, Yellowwood State Forest/Hoosier National Forest exhibited a slightly lower percentage cover, and the southwestern corner of Brown County State Park exhibited a higher percentage cover in 1994. The southwestern corner of Brown County State Park also exhibited an increase in the number of seedlings in 1994. In contrast, sapling numbers stayed constant between the two sampling seasons.

DISCUSSION

Excessive browsing within Brown County State Park has resulted in reduced numbers and sizes for some plant species, a conclusion consistent with those of Alverson, *et al.* (1988) and Balgooyen and Waller (1995). These researchers found that white-tailed deer could directly and indirectly affect the abundance and structure of many herbaceous species, thereby influencing forest composition. Likewise, Balgooyen and Waller (1995) indicated that many herbaceous species, especially preferred browse species, were jeopardized by high deer den-

Table 4. The mean species richness and percentage cover of the ground flora as well as the mean density of woody stems in size classes 1 and 2 recorded at sample sites outside Brown County State Park, in the southwestern corner of Brown County State Park, and in the main body of Brown County State Park during 1993 (Parker and Van Kley, 1993). Row means with different letters are significantly different ($P < 0.10$). Size class 1 = stems < 50 cm in height, and size class 2 = stems 50 to 200 cm in height.

Critical Species and Variable Tested	Yellowwood State and Hoosier National Forests	Southwestern Corner of Brown County State Park	Main Body of Brown County State Park
All Sites			
Ground flora richness	23.3 a	16.6 b	14.7 b
Percentage cover of ground flora	34.1 a	18.6 b	14.6 b
Woody size class 1	33.3 a	23.7 b	13.9 c
Woody size class 2	3.9 a	0.5 b	0.4 b
Mesic Bottomlands			
Ground flora richness	34.8 a	22.4 b	20.8 b
Percentage cover of ground flora	39.0 a	28.3 a	13.1 b
Woody size class 1	47.2 a	13.2 b	8.8 b
Woody size class 2	5.0 a	0.6 b	0.5 b
Mesic Slopes			
Ground flora richness	30.3 a	21.3 b	17.1 b
Percentage cover of ground flora	32.4 a	10.9 b	8.0 b
Woody size class 1	35.8 a	16.9 b	11.5 b
Woody size class 2	4.0 a	0.1 b	0.5 b
Dry Slopes			
Ground flora richness	14.0 a	12.1 ab	9.9 b
Percentage cover of ground flora	29.2 a	23.6 a	21.2 a
Woody size class 1	25.6 ab	33.9 a	16.8 b
Woody size class 2	4.6 a	0.8 b	0.2 b

sities. The significant reduction in both percentage ground cover and the size of several herbaceous species within Brown County State Park when compared to Yellowwood State Forest/Hoosier National Forest indicates that the deer population had exceeded the carrying capacity of their habitat within the park.

The southwestern corner of Brown County State Park was less affected by deer browsing than the main body of the park in both 1993 and 1994. The shared boundary with Yellowwood State Forest/Hoosier National Forest might have allowed increased hunting pressure in the southwestern corner of the park.

No consistent significant difference for woody stem density (class 1) was found between the park and the State and National Forests. However, the higher number of woody stems (class 2) outside the park when compared to both areas within the park suggests that the trees are successfully reproducing, but repeated browsing prevents seedlings from growing into the larger size classes.

Marquis (1974) found that browsing by white-tailed deer on the Allegheny Plateau in Pennsylvania prevented stems from growing beyond the seedling stage. His conclusions agree with those of Frelich and Lorimer (1985) and Anderson and Katz (1993), who both concluded that browsing by white-tailed deer was severely affecting the reproduction and recruitment of eastern hemlock into larger size classes.

The large number of plant species still found within Brown County State Park in 1993 and 1994 indicates a potential for recovery of the plant communities if deer populations are maintained at lower levels. Other researchers have also suggested that controlling deer numbers can effectively decrease browse damage (Anderson and Loucks, 1979; Frelich and Lorimer, 1985; Alverson, *et al.*, 1988; Anderson and Katz, 1993). Anderson and Loucks (1979) suggest that wildlife should be maintained at a level that would not be detrimental to important tree species. They also suggest that in areas where wildlife is having a detrimental effect, hunting regulations should be relaxed to prevent changes in tree species composition. Significant improvement in the understory could occur within a few years if deer numbers were maintained at lower levels (Anderson and Loucks, 1979). However, a significant period of time will be needed before the forest can completely recover. Anderson and Katz (1993) suggest that the time needed for recovery after release from browsing pressure is directly proportional to the time the forest was subjected to this pressure.

The limited removal of 392 deer (17 deer per square mile or 2.590 km^2) from the park in 1993 may have been responsible for the slight improvement in the condition of the understory vegetation. An increase in the number of plant species found per site occurred within the park in 1994. However, this increase in species number might be the result of deer reduction or annual variation. Before concrete conclusions can be reached about the specific damage caused by deer, more data needs to be collected during subsequent growing seasons. Continued studies of the understory vegetation could show not only differences in the degree of impact due to white-tailed deer browsing but also variation in the vegetation due to annual variability and the timing of sampling within the growing season.

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PHYSICAL AND CHEMICAL LIMNOLOGY OF FOUR NATURAL LAKES LOCATED WITHIN THE INDIANA DUNES NATIONAL LAKESHORE, NORTHWESTERN INDIANA

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ABSTRACT: Four lakes located in the Indiana Dunes National Lakeshore in northwestern Indiana were evaluated for their physical and chemical limnology. The morphometric characteristics for each lake were measured as were chemical variables, including pH, conductivity and major ions, and nutrients. The study lakes were shallow depressions (z_m = 1.17-3 m; $\bar{z}$ = 0.8-2.51) with steep slopes. Their shallow depths enabled dissolved oxygen to be distributed throughout the entire water column; thus, these lacustrine wetlands never stratify. The pH in these lakes was neutral to slightly alkaline (range = 7.20-10.02), while their conductivity ranged from 40 to 1339 μS/cm. The amount of total dissolved solids ranged from 48.6 to 67.0 mg/L. The oxidation-reduction potential showed a stepwise progression in values ranging from -60 to 475 mv, and more than 90% of the measurements were in an oxidized state. The presence of an oxidized microzone above the sediment interface with the water column prevents metals and nutrients from autochthonous recycling. Total nitrogen levels were similar to those in mesoeutrophic lakes in northeastern and north-central Indiana, while total phosphorus ($\bar{x}$ = 0.121 mg/L) was an order of magnitude higher than in most of the lakes in north-central ($\bar{x}$ = 0.025 mg/L) and northeastern ($\bar{x}$ = 0.052 mg/L) Indiana.

KEYWORDS: Bathymetry, conductivity and major ions, nutrients, pH, trophic status.

INTRODUCTION

Most regional studies of the chemical and physical limnology of glacial lakes have been carried out in Minnesota, Wisconsin, and Michigan (Heiskary, *et al.*,1987; Omernik and Gallant, 1988). Glacial lake limnology along the dunes and nearshore of Lake Michigan has been devoted mainly to the recognition of environmental indicators and the identification of the aquatic biota (Simon, *et al.*,1989; Simon and Moy, 1997; Simon and Stewart, in press). Little attention has been given to the physical and chemical attributes of riverine and depressional wetlands in northwestern Indiana.

The greatest concentration of depressional wetlands in Indiana exists within the Indiana Dunes National Lakeshore (Beaty, *et al.*, 1994). Knowledge of the

status and condition of these palustrine and lacustrine wetlands is limited. Many have never been surveyed. The collection of baseline data is necessary for determining patterns in lake trophic status and for analyzing the physical attributes of other natural systems in northwestern Indiana. The morphologic features of these lakes were determined by climatic and edaphic factors that affect the chemical dynamics of the lake, which, in turn, shapes the biota within these ecosystems.

Early investigations of the physical and chemical environment in the natural lakes of Indiana concentrated on the glacial lakes of northeastern Indiana. Classic studies of lake morphometrics in Indiana include the State Geological Survey report on northern lakes (Blatchley and Ashley, 1901), the physical and biological studies of Lake Maxinkuckee (Evermann and Clark, 1920), and numerous lake studies conducted by the Indiana Lakes and Stream Survey (Scott, *et al.,* 1928, 1938; Scott, 1931; Wohlschlag, 1950; Gerking, 1950; Ricker, 1955; Eberly, 1959; Mueller, 1964). The National Eutrophication Survey conducted by the U.S. Environmental Protection Agency in cooperation with the Indiana Department of Environmental Management (formerly a part of the Indiana State Board of Health) during the mid-1970s evaluated 27 lakes in Indiana (numerous individual reports published by U.S. Environmental Protection Agency, 1976). These studies provided data on the chemical and physical characteristics of northern Indiana lakes and discussed their trophic status. The westernmost lake surveyed during that study was Bass Lake in Starke County.

Our objective was to describe the chemical and physical characteristics of four natural palustrine and lacustrine wetlands in northwestern Indiana. While many aspects of their biota can be determined without a knowledge of the physical and chemical characteristics of these lakes, many of the indices of productivity cannot be used without these data. This survey was designed to collect data on the physical and chemical characteristics of four typical palustrine and lacustrine depressional wetlands in the Indiana Dunes National Lakeshore. In addition to discussing the chemical and limnological characteristics of these lakes, our findings will be compared with data from other natural lakes in northern Indiana that were collected during the National Lake Eutrophication Survey.

MATERIALS AND METHODS

Description of the Study Area. The nearshore of Lake Michigan includes a variety of depressional wetlands, such as pannes, ponds, and lakes (Figure 1). Several distinct dune beach complexes were formed during the Pleistocene and Holocene Epochs when Lake Michigan was at higher levels than today (Leverett and Taylor, 1915; Bretz, 1951; Hansel, *et al.*, 1985). The area is part of a province referred to by various scientists as the Calumet Lacustrine Plain (Schneider, 1966), the Central Corn Belt Plain Ecoregion (Omernik and Gallant, 1988), or the Lake Michigan Border Section of the Northwestern Morainal Natural Region (Homoya, *et al.*, 1985). This region is a mosaic of natural and human-impacted areas, including the Indiana Dunes National Lakeshore, the Indiana

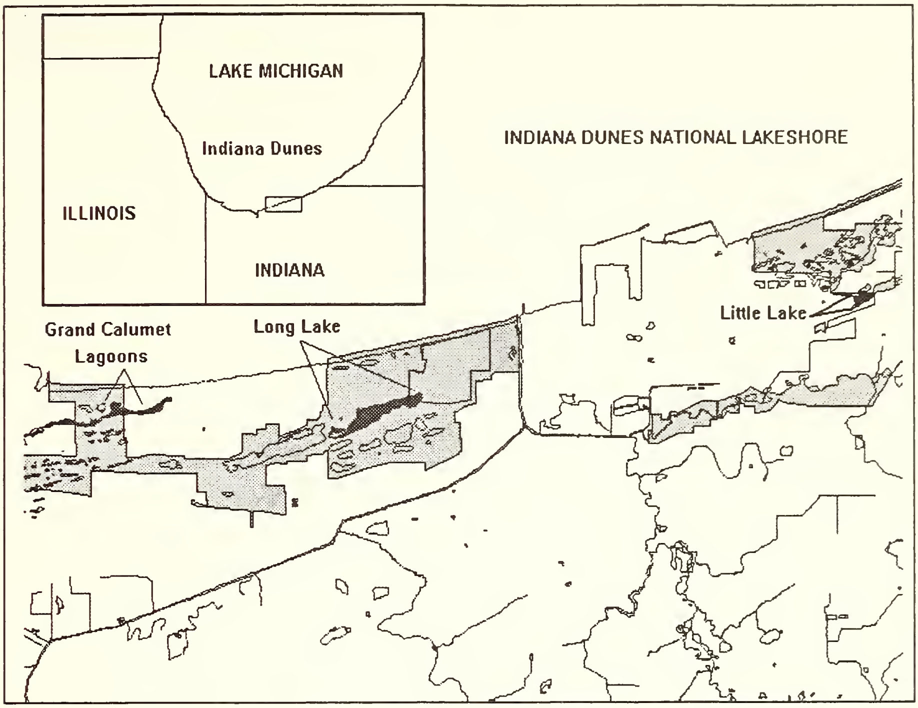

Figure 1. A map of northwestern Indiana showing the location of the four lacustrine wetlands studied.

Dunes State Park, and the Clark and Pine Natural Area. To the west lies one of the most industrialized steel and petrochemical areas in the United States (Moore and Trusty, 1977; Simon, *et al.*, 1989). The four depressional wetlands discussed in this paper are found in the Indiana Dunes National Lakeshore.

Regional Climate and Hydrology. The prevailing climate in northwestern Indiana is temperate continental modified by Lake Michigan so that the climate can take on semi-marine characteristics. The mean annual temperature is 10° C. Average annual precipitation at Gary (the largest nearby city) is about 907.5 mm; normal seasonal precipitation averages 145 mm in the winter, 252.5 mm in the spring, 285 mm in the summer, and 225 mm in the fall (National Oceanic and Atmospheric Administration, 1982). Total monthly rainfall is more variable during warm months that during cold months. The total annual precipitation between 1951-1980 ranged from about 575 mm to nearly 1250 mm. Annual snowfall varies due to the lake effect. Annual average snowfall is 875 mm at Gary with the predominant snow season from November to March. Due to the proximity of the study wetlands to Lake Michigan, early frosts and unusually late spring frosts may be delayed by 2-3 weeks. The coldest month (January) has an average normal monthly temperature of -5.1° C; the average normal monthly temperature during the warmest month (July) is 22.9° C (Beaty, *et al.*, 1994).

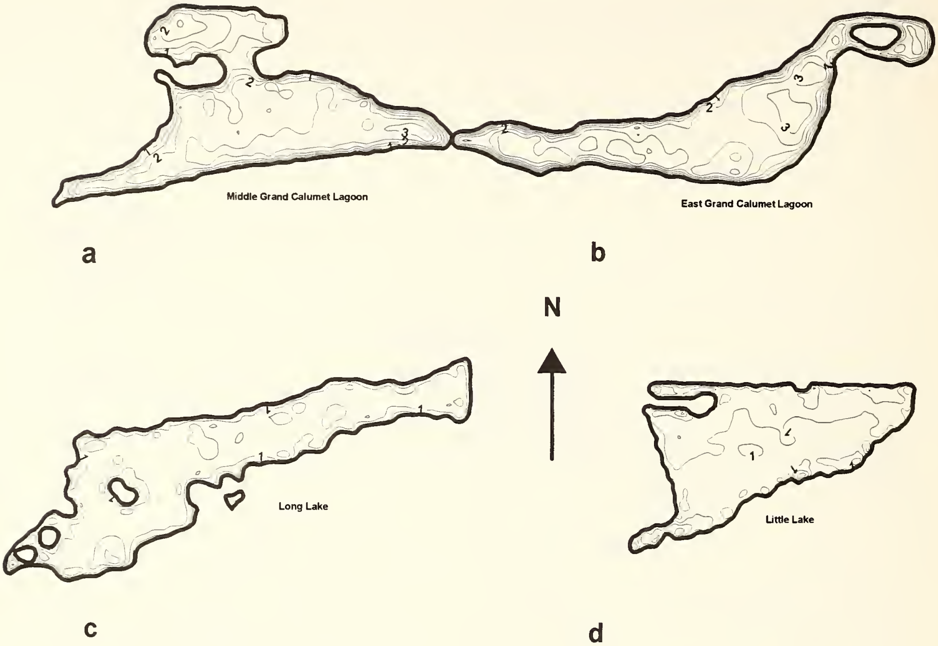

Figure 2. Bathymetric contour maps of the four study lakes: a = Middle Grand Calumet Lagoon; b = East Grand Calumet Lagoon; c = Long Lake; and d = Little Lake. The depth contour line intervals are 0.5 m.

The ponds of West Beach and Miller Woods comprise the last remnant, depressional wetlands in northwestern Indiana along the Lake Michigan dunes in the Indiana Dunes National Lakeshore. These ponds are remnants of geological Lake Chicago that were created by the lowering of lake levels and the shifting of sand dunes (Moore and Trusty, 1977). Long Lake is a large, dunal pond located southeast of Miller Woods in the West Beach Segment. The Grand Calumet Lagoons are riverine wetlands derived from the Grand Calumet River. The Lagoons are the former mouth of the river. They are separated from the river by a covered culvert on adjacent industrial property. The Lagoons are divided into three segments of relatively equal area—the East, Middle, and West Lagoons. This study was confined to the Middle and East Lagoons, the "least disturbed" ponds in the Indiana Dunes National Lakeshore and the City of Gary's Marquette Park. Little Lake is a former portion of Cowles Bog that was separated from the bog by a levee built for an electric utility substation.

Bathymetry, Morphometry, and Chemical Limnology. The bathymetric contour maps of the four lakes (Figure 2) were prepared by tracing the shorelines from perimeter maps obtained from the analysis of aerial photographs and topographic maps (7.5 minute U.S. Geological Survey maps). The size and complexity of each lake determined the number of transects needed to obtain an

appropriate bathymetric profile. Little Lake, which is the smallest of the lakes at about 6 ha, was mapped at 20 m transect intervals; Long Lake, which is about 25.9 ha, was mapped using a 30 m interval; and the Middle (30.3 ha) and East Grand Calumet Lagoons (5.1 ha), the largest of the lakes, were studied using 50 m transect intervals. Intervals were measured by determining the perpendicular intersection of adjacent shorelines and then measuring the distance between points using a calibrated line (Cole, 1994). Points were then marked where they would be visible from the water using flagging tape. Depths were recorded to the nearest 0.1 m at discrete points along each transect from a boat. A Hummingbird 3-D depth-finder was used to sample nonwadeable areas, while depths were recorded in centimeters using a Philadelphia rod in wadeable areas. Coordinates were then plotted using Grass 4.0, and a detailed bathymetric map was drawn using Winsurf 5.0 (Golden Software, 1994).

Morphometric parameters were calculated from these maps, following the procedures of Lind (1985) and Wetzel and Likens (1979). Surface morphometric measures included maximum length (l), maximum width (b), mean width ($\bar{b}$), surface area (A), shoreline length (L), shoreline breath, and the shoreline development index (D_L). Subsurface morphometrics included volume (V), maximum depth (z_m), mean depth ($\bar{z}$), relative depth (z_r), and basin slope. Morphoedaphic index calculations followed Ryder, *et al.* (1974). Temperature and dissolved oxygen were measured monthly between February 1992 to August 1997 at near bottom stations at the approximate center of each lake.

The four lakes were too shallow to develop a stratified profile. Most parts of each lake are less than 2 m in maximum depth. A digital meter (Dow Corning Inc., Pocket Meter M90) was used to measure dissolved oxygen (DO; 0.0 to 20.00 ± 0.1 mg/L), temperature (-0.5° to 100° ± 0.1° C), pH (0 to 14 ± 0.1 SU), specific conductance (0.0 to 1999 ± 1 μS), and total dissolved solids (TDS; 0.0 to 1000 ± 0.1 mg/L). The oxidation-reduction potential (E_h) was measured using a digital meter (LaMotte, Inc., ORPTestr, -200 to 1100 ± 5 mv). Dissolved oxygen was calibrated using Winkler titration (American Public Health Association, 1989). Water samples were taken at the deepest level of the water column (near bottom) along predetermined transects using a Kemmerer water bottle sampler. Water samples from each lake were analyzed at the Indiana Dunes National Lakeshore Aquatic Laboratory for nitrite, nitrate, ammonia, hardness, alkalinity, and reactive phosphorous using the appropriate methods (American Public Health Association, 1989).

RESULTS AND DISCUSSION

Origin. The analysis of aerial photographs of the Grand Calumet Lagoons suggests that these water bodies originated following closure of the river's mouth by dune movement. The East and Middle Lagoons were extensive backwaters at the turn of the century when dune movement separated them from the Grand Calumet River. These two ponds are separated by a large lateral dune that arises in the foredune ridge near Lake Michigan, suggesting that the two lakes along

Table 1. Morphometric characteristics of four lakes from northwestern Indiana.

	East Grand Calumet Lagoon	Middle Grand Calumet Lagoon	Little Lake	Long Lake
Maximum length (l)	1730 m	1290 m	437 m	138 m
Maximum depth (z_m)	3.0 m	3.0 m	1.2 m	1.8 m
Maximum width (b)	330 m	370 m	273 m	378 m
Perimeter (L)	4250 m	4060 m	1516 m	4622 m
Shoreline development (D_L)	2.3 m	2.7 m	1.7 m	2.5 m
Surface area (A)	264,090 m^2	318,181.8 m^2	63,029 m^2	272,000 m^2
Volume (V)	663,634 m^3	633,181.8 m^3	5,044 m^3	304,000 m^3
Mean width ($\bar{b}$)	152.7 m	246.7 m	144 m	197 m
Mean depth ($\bar{z}$)	2.5 m	2.0 m	0.8 m	1.1 m
Relative depth (z_r)	0.5 m	1.5 m	0.6 m	0.3 m
Volume development (D_v)	> 1	> 1	> 1	> 1
Basin slope (M)	0.027	0.025	0.024	0.018
Morphoedaphic index (MEI)	25.75	33.28	79.38	53.3

with the Grand Calumet River were once part of a single, continuous watershed. Long Lake is an 8,000-year-old successional lake formed by the regression of Lake Michigan (R. Whitman, pers. comm.). The eastern end of Long Lake has been filled in, creating a separation between Ogden Dunes and the extensive wetlands previously occurring along the Little Calumet River. Long Lake is extensively vegetated and numerous beds of pondweeds (e.g., *Potemogeton*) and water lilies (*Nuphar* and *Nymphea*) have created a vegetated mat that is filling the shallow lake. An increase in nutrients has caused the degradation of this fragile system. Little Lake is the former southwestern corner of Cowles Bog, a large palustrine wetland filled with *Typha*. The levee along its northern shore separates Little Lake from Cowles Bog. To accommodate an electric substation on its northwestern shore, Little Lake was deepened and a narrow access corridor to an electric tower was built into the water. A natural area on the southeastern shore has fallen woody debris, emergent aquatic macrophytes, and submergent stands of *Ceratophyllum demersum* and *Myriophyllum spicatum*. The diversion of groundwater has flooded the area between the South Shore railroad tracks and the levee.

Bathymetry and Morphometrics. Bathymetric maps of the four lakes are shown in Figure 2, and their morphometrics are listed in Table 1. These lakes have surface to volume ratios that are very low, a feature characteristic of the natural lakes found in northwestern Indiana. The deepest lake is the East Grand Calumet Lagoon, whose mean depth is 2.51 m. The shallowest lake was Little Lake, whose mean depth was 1.17 m. The basin slope (M) of these lakes ranges from 0.0184 to 0.027, confirming their shallow depths when compared

to their surface area. The shoreline development index (D_L) also shows little variation; the index ranges from 1.703 to 2.73 (Table 1). These values of the shoreline development index are consistent with those from most lakes that develop increased littoral regions (Wetzel, 1983). The lakes trend east to west in latitudinal profile, they are elongate, and they have irregular shorelines.

All four depressional wetlands lack major inflows. All four lakes are subject to atmospheric inputs primarily as a result of air emissions from industrial sources. The majority of the allochthanous input into Middle and East Grand Calumet Lagoon is probably the result of urban and residential development, which generates a higher volume of runoff because of an increase in the area covered by an impervious surface. Little Lake receives leaf litter from the surrounding forest. Inputs of particulate matter in Long Lake are the result of air-suspended material from the adjacent dunes. The shallow depth of all these lakes contributes to their eutrophic condition because dissolved oxygen and light penetrates to the benthic region despite the presence of suspended solids in the water.

Temperature and Oxygen. The four study lakes do not thermally stratify during either summer or winter. Dissolved oxygen is present in the entire water column, and a permanent oxidized microzone is present (Table 2). The mean dissolved oxygen level for the Middle Grand Calumet Lagoon was approximately 62% saturation, while the other three lakes had mean dissolved oxygen levels between 82% to 88% saturation. The amount of dissolved oxygen is strongly linked to temperature. The lowest amount of dissolved oxygen is detected when the temperatures are warmest (0.81 to 0.83 mg/L in Long and Little Lakes, respectively). Supersaturated dissolved oxygen values can occur because of the large aquatic macrophyte population that grows in all portions of the lake. Extreme diel fluctuations may occur because nocturnal respiration by these large plant beds can cause an oxygen deficit.

pH. The pH was highly variable for lakes located in an area of relatively homogeneous geologic and edaphic conditions. The pH ranged from 6.70 to 10.02 (Table 2). All four lakes are found along the edge of Lake Michigan and accept drainage from Oakville Maumee-Brems Soils (Furr, 1981). The dune, beach, and lacustrine silts, sands, and gravel form a thin but laterally extensive surficial aquifer. The sediments of Little and Long Lake arose from drained Adrian muck, while the sediments of East and Middle Grand Calumet Lagoon are Oakville fine sand soils with slopes of 18% to 40% (Furr, 1981). Several sites in East Grand Calumet Lagoon had pH values above 10 SU. Locally elevated pH values may be the result of isolated, narrow belts of slag rock that were buried after the dunes were mined (R.D. Kovach, U.S. Environmental Protection Agency, pers. comm.). Little Lake and the East Grand Calumet Lagoon consistently had the greatest variation in pH (Table 2).

In general, fresh water within the study area is not sensitive to acidification because the water is well buffered (Fenelon and Watson, 1993; Willoughby, 1995; Duwelius, *et al.,* 1996). Fenelon and Watson (1993) reported median pH values from groundwater well samples of about 7.3; four extreme pH values were

Table 2. Mean and standard deviation for monthly field and water chemistry data collected from February 1992 to August 1997 at four lacustrine wetlands in northwestern Indiana. The range is given in parentheses.

Parameters	East Grand Calumet Lagoon	Middle Grand Calumet Lagoon	Little Lake	Long Lake
Alkalinity (mg/L as $CaCO_3$)	128 ± 37.5 (78-298)	138	139 ± 50.0 (44-330)	96 ± 24.4 (52-240)
Hardness (mg/L as $CaCO_3$)	204 ± 39.5 (110-310)	198	194 ± 47.6 (106-282)	132 ± 35.5 (90-342)
pH (SU)	8.2 ± 0.46 (7.2-10.02)	8.34 ± 0.10 (8.17-8.93)	8.1 ± 0.67 (6.7-9.7)	8.0 ± 0.38 (7.0-8.57)
Temperature (° C)	5.3 ± 0.22 (4-20.7)	5.0 ± 0.15 (3.9-20.9)	8.1 ± 5.8 (4.2-23.6)	5.8 ± 0.38 (4.1-22.7)
Chloride (mg/L)	110 ± 35.6 (68-238)	—	74 ± 25.61 (30-147)	30 ± 19.45 (2-106)
Specific Conductance (μS/cm)	609 ± 213.6 (130-1339)	131.5 ± 0.6 (130-1326)	491 ± 195.8 (204-1260)	248 ± 62.1 (40-374)
Dissolved Oxygen (mg/L)	9.02 ± 3.03 (3.4-15.0)	4.50 ± 0.07 (3.4-10.7)	8.52 ± 3.08 (0.83-15.0)	8.00 ± 3.42 (0.81-15.0)
Dissolved Oxygen (% saturation)	88 ± 26.14 (40-155)	62 ± 10.45 (51-100)	87 ± 27.36 (11-150)	82 ± 27.86 (10-132)
NH_3 (mg/L)	0.13 ± 0.15 (0.01-0.65)	0.14 ± 0.28 (0.01-0.5)	0.19 ± 0.35 (0.02-2.2)	0.15 ± 1.87 (0.01-2.3)
Nitrate (mg/L)	0.40 ± 0.60 (0.1-2.5)	0.50	0.3 ± 0.62 (0.01-2.4)	0.3 ± 0.61 (0.01-2.3)
Nitrite (mg/L)	0.003 ± 0.124 (0.001-1.0)	0.005	0.001 ± 0.01 (0.001-0.04)	0.001 ± 0.002 (0.001-0.009)
Reactive Phosphorus (mg/L)	0.030 ± 0.054 (0.01-0.28)	0.07	0.05 ± 0.05 (0.01-0.23)	0.02 ± 0.03 (0.01-0.16)
Total Phosphorus (mg/L)	0.135 ± 0.09 (0.02-0.4)	0.153	0.12 ± 0.26 (0.01-1.58)	0.075 ± 0.08 (0.01-0.35)
Oxidation-Reduction Potential (E_h; mv)	163 ± 115.1 (110-400)	152.5 ± 143.4 (-60-400)	375 ± 141.4 (275-475)	235 ± 82.5 (90-365)
Total Dissolved Solids (mg/L)	66.8 ± 7.49 (48.6-67)	65.85 ± 0.61 (65.3-66.7)	63.5 ± 0.07 (63.4-63.5)	59.5 ± 0.96 (58.4-61.6)

reported from wells screened in slag. Slag is dominantly alkaline-earth-silicate glass, and water in contact with it has an elevated pH. Duwelius, *et al.* (1996) conducted a more extensive survey of the groundwater in area wells and found that the pH ranged from 5.3 to 12.1(median = 7.2). Half of the 118 samples from wells had pH values between 6.9 and 7.6. For most of the groundwater in the United States, pH ranges from about 6 to 8.5 (Hem, 1985). Duwelius, *et al.* (1996) found that samples with an elevated alkaline pH were usually from shallow groundwater wells in contact with slag or industrial waste.

Conductivity and Major Ions. Specific conductance is a measure of the ability of a substance to conduct electricity across a unit length at a specific temperature. Dissolved substances increase the conductivity of water; measurements of specific conductance provide an indication of the amount of dissolved substances in water (Hem, 1985). The specific conductance of pure water is low, less than 10 μS/cm (Hem, 1985). In general, the surface waters of our study had moderate conductance. Conductivity was consistent among wetlands and ranged from 40 to 1,339 μS/cm (mean = 369.9 μS/cm; Table 2), which was considerably lower than the conductivity reported for groundwater wells (106-5,980 μS/cm; median = 828 μS/cm). Half of the 125 well samples had specific conductance values between 450 and 1,540 μS/cm (Duwelius, *et al.*, 1996). The East Grand Calumet Lagoon had the highest conductivity of the four lakes studied.

Alkalinity measures the capacity of a solution to neutralize acids (Hem, 1985). In this study, alkalinities ranged from 44 to 330 mg/L as calcium carbonate (mean = 121 mg/L). Duwelius, *et al.* (1996) recorded alkalinities from groundwater wells in northwestern Indiana that ranged from 24.9 to 1,260 mg/L as calcium carbonate (median = 249 mg/L). Little Lake had the lowest alkalinity (Table 2). Acidity measures a solution's capacity to neutralize bases. Acidity was not detected in any sample.

Water is considered very hard when values exceed 180 mg/L as calcium carbonate. All of the lakes have very hard water (mean = 198.7 mg/L) with the exception of Long Lake (mean = 132 mg/L; Table 2). Fenelon and Watson (1993) found that non-contaminated “natural” groundwater samples from the Indiana Dunes National Lakeshore never exceeded 200 mg/L. Groundwater samples collected from areas adjacent to the heavily industrialized areas surrounding the Grand Calumet River ranged from 400 to 500 mg/L.

Freeze and Cherry (1979) placed groundwater samples into two categories based on total dissolved solids (fresh and brackish water). Fresh water generally contains less than 1,000 mg/L of dissolved solids. Water having between 1,000 and 10,000 mg/L of dissolved solids is called brackish (Freeze and Cherry, 1979). In general, the surface waters in this study represented fresh water. The amount of dissolved solids was similar in each lake and ranged from 48.6 to 67.0 mg/L (mean = 63.9 mg/L; Table 2). Duwelius, *et al.* (1996) found that groundwater wells had dissolved solid concentrations that ranged from 95 mg/L to 6,780 mg/L; the median concentration was 674 mg/L. A comparison of dissolved solid concentrations between paired shallow and deep wells showed that the highest values come from shallow wells.

The oxidation-reduction potential (E_h) of water is an index of the exchange activity of electrons among elements in solution. E_h measures the electric potential, using the potential of a hydrogen electrode as a reference point of zero. A positive potential indicates oxidizing conditions in the water; a negative potential indicates reducing conditions, which determines the valence states of metals (Hem, 1985). The oxidation-reduction potential at the study sites ranged in a stepwise progression from -60.0 to 475 mv (mean = 231.4 mv). Duwelius, *et al.* (1996) found that groundwater from wells was generally reducing (75%), and E_h ranged from -446 to 159 mv (median = -64.5 mv). Reducing conditions increased with increasing well depth. With the exception of the East and Middle Grand Calumet Lagoon, few of our study sites ever showed reducing conditions; more than 90% of the sites were in an oxidized condition.

Chloride is the dominant anion in water, and its concentration ranged from 2.0 to 238 mg/L (mean = 71.3 mg/L; Table 2) in the lakes studied. Duwelius, *et al.* (1996) found that the concentration of chloride in groundwater wells ranged from 1.4 mg/L to 2,600 mg/L (median = 37.8 mg/L). The wells that had the highest concentrations of chloride (greater than 1,000 mg/L) were shallow (less than 4.5 m deep) and were found in areas containing fill near interstate highways. High chloride concentrations indicate contamination by the fill materials and deicing salts. The Secondary Maximum Contaminant Levels are suggested concentration limits for substances in drinking water that do not result in adverse health effects but may limit the use of the water because of unpleasant taste, odor, or color. The suggested limit for chloride is 250 mg/L, a value that was not exceeded in the study lakes.

Nutrients. The concentrations of nitrate plus nitrite, ammonia, and reactive and total phosphorus were determined. Nitrogen concentrations were generally low; NO_3, NO_2, and NH_3 occurred in concentrations of less than 1.0 mg/L. Total phosphorus levels were high (mean = 0.100 mg/L). The surface waters of the study lakes all had high concentrations of nutrients.

Ammonia levels ranged from 0.01 to 0.78 mg/L (mean = 0.15 mg/L; Table 2). This range was lower than that reported from groundwater well samples (0.1-96 mg/L; median = 0.50 mg/L) by Duwelius, *et al.* (1996). Fenelon and Watson (1993) found ammonia concentrations at the Indiana Dunes National Lakeshore to range from 0.05 to 0.20 mg/L. Long and Little Lakes had the highest mean ammonia concentrations. Their mean values were over twice as high as the values observed in the Grand Calumet Lagoons. Duwelius, *et al.* (1996) reported that half of the 125 samples from groundwater wells had ammonia (nitrogen) concentrations less than the detection level (< 0.01 mg/L).

The concentration of nitrate plus nitrite was low, ranging from 0.001 to 2.5 mg/L (mean = 0.38 mg/L; Table 2). These concentrations were higher than those found by Fenelon and Watson (1993). Their values for the concentration of nitrate plus nitrite in groundwater samples from the Indiana Dunes National Lakeshore ranged from below detection level (< 0.01 mg/L) to 0.02 mg/L and were within the range reported for natural groundwater samples (range = 0.02 to 0.96 mg/L; median = 0.06) in northwestern Indiana.

Table 3. A comparison of select physical, spring chemical, and trophic status variables for a variety of natural lakes in northern Indiana (N = nitrogen and P = phosphorus).

	Physical Variables (m)			Chemical Variables		
Lake	Volume (m^3)	Mean Depth	Maximum Depth (z)	N-Total (mg/L)	P-Total (mg/L)	Trophic Status
Northwest						
Middle Grand Calumet Lagoon	0.6 x 10^6	2.5	3.0	0.645	0.217	Eutrophic
East Grand Calumet Lagoon	0.6 x 10^6	2.0	3.0	0.809	0.153	Eutrophic
Little Lake (Porter)	0.05 x 10^6	0.8	1.2	0.863	0.190	Eutrophic
Long Lake (Porter)	0.3 x 10^6	1.1	1.8	0.992	0.100	Eutrophic
North-Central						
James Lake (Kosciusko)	9.348 x 10^6	8.2	19.2	1.854	0.025	Eutrophic
Tippecanoe Lake (Kosciusko)	35.143 x 10^6	11.3	37.5	1.650	0.024	Mesotrophic
Lake Wawasee (Kosciusko)	82.946 x 10^6	6.7	23.5	1.107	0.007	Mesotrophic
Webster Lake (Kosciusko)	4.977 x 10^6	13.7	13.7	1.773	0.029	Eutrophic
Winona Lake (Kosciusko)	20.657 x 10^6	9.1	24.4	2.159	0.041	Eutrophic
Lake Maxinkuckee (Marshall)	55.042 x 10^6	7.3	26.8	0.757	0.024	Mesotrophic
Northeast						
Dallas Lake (LaGrange)	12.303 x 10^6	10.8	29.3	1.582	0.048	Eutrophic
Olin Lake (LaGrange)	4.914 x 10^6	11.7	25.0	1.819	0.011	Mesotrophic
Oliver Lake (LaGrange)	18.300 x 10^6	12.2	27.7	1.287	0.007	Mesotrophic
Sylvan Lake (Noble)	10.879 x 10^6	4.3	11.0	1.397	0.166	Eutrophic
Crooked Lake (Steuben)	19.825 x 10^6	6.1	23.5	0.841	0.017	Mesotrophic
Hamilton Lake (Steuben)	20.475 x 10^6	6.3	21.3	1.352	0.031	Eutrophic
Long Lake (Steuben)	1.887 x 10^6	5.1	9.7	3.460	0.104	Eutrophic
Marsh Lake (Steuben)	1.403 x 10^6	6.1	11.6	1.262	0.084	Eutrophic
Lake James (Steuben)	30.514 x 10^6	7.3	26.2	0.771	0.021	Mesotrophic
Pigeon Lake (Steuben)	1.143 x 10^6	4.6	11.6	4.087	0.033	Eutrophic

The total and reactive phosphorus levels in the lakes of northwestern Indiana were higher than those in lakes from the remainder of northern Indiana (Table 3). The total phosphorus concentrations in the lakes of northwestern Indiana were an order of magnitude higher than those for other lakes measured during the National Eutrophication Survey (U.S. Environmental Protection Agency, 1976). Total phosphorus concentrations in the four study lakes ranged from 0.01 to 1.58 mg/L (mean = 0.1 mg/L; Table 2). The reactive phosphorus in the four study lakes was about 25% of total phosphorous with the exception of East Grand Calumet Lagoon, which was less than 25% (Table 2).

Comparison to Natural Lakes. Ponds and lakes along the nearshore of Lake Michigan are shallow, eutrophic depressions that have steep littoral slopes formed by the erosion and movement of sand dunes. The lakes of northwestern Indiana are significantly different from other natural lakes in northern Indiana. The lakes of northwestern Indiana have an average maximum depth of 2.3 m in contrast to average lake depths of 9.38 m and 7.45 m for north-central and northeastern Indiana, respectively (Table 3). The deeper lakes of central and eastern Indiana stratify and develop thermoclines. The lakes of northwestern Indiana

never stratify because they are not deep enough. These lakes rarely attain average depths greater than 2.0 m (mean = 1.6 m; Table 3). The maximum depth of north-central Indiana lakes ranged from 13.7 (Webster Lake, Kosciusko County) to 37.5 m (Tippecanoe Lake, Kosciusko County). Northeastern Indiana lakes ranged from 9.7 m (Long Lake, Steuben County) to 29.3 m (Dallas Lake, LaGrange County) in maximum depth.

Most of the large lakes of northern Indiana are either eutrophic or mesoeutrophic, based on the trophic index developed by the Indiana Department of Environmental Management (1986). The index uses fifteen measurements (based on data from 307 samples collected during the mid-1970s) to characterize the trophic status of inland Indiana lakes. The measurements include broad categories of nutrients, dissolved oxygen, light penetration, total plankton, dominance of blue-green algae, and the abundance of cells in vertical tows from the thermocline and from the littoral zone.

The lakes studied in the Indiana Dunes National Lakeshore are eutrophic or hypereutrophic, exhibit rapid cycling of nutrients, and show predictable crashes in dissolved oxygen during diel cycling. These lakes also had low levels of total nitrogen but high levels of total phosphorus (Table 3). Average total nitrogen for lakes in north-central Indiana ranged from 0.757 mg/L (Lake Maxinkuckee, Marshall County) to 2.159 mg/L (Winona Lake, Kosciusko County), while the lakes in northeastern Indiana had higher concentrations, ranging from 0.771 mg/L (Lake James, Steuben County) to 4.087 mg/L (Pigeon Lake, Steuben County). Total phosphorous for lakes in north-central Indiana ranged from 0.007 mg/L (Lake Wawasee, Kosciusko County) to 0.041 mg/L (Winona Lake, Kosciusko County), while total phosphorous in northeastern lakes ranged from 0.011 mg/L (Olin Lake, LaGrange County) to 0.166 mg/L (Sylvan Lake, Noble County). The total phosphorous in northwestern Indiana lakes is similar to the amount in mesoeutrophic lakes in north-central and northeastern Indiana (Table 3). The presence of an oxidized microzone in the lakes of northwestern Indiana limits autochthonous cycling of nutrients causing permanent loss of phosphorus and nitrogen to the sediments.

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TRENDS IN INDIANA HOUSE FINCH COUNTS: A COMPARISON OF INDIANA AUDUBON SOCIETY MAY, SUMMER, AND CHRISTMAS BIRD COUNTS, 1980-1995

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ABSTRACT: The house finch (*Carpodacus mexicanus*), first released in New York in 1940, has expanded its range throughout North America, making its first appearance in Indiana in the mid-1970s. The finch's first appearance in an annual Indiana Audubon Society bird count occurred in 1980, when two individuals were counted in Porter County during the Indiana Audubon Society Big May Day Bird Count. Five individuals were counted in the 1981 summer count, and a single individual was counted in the 1981 Indiana Audubon Society Christmas count. Since then, the annual Indiana Audubon Society bird counts have shown a dramatic increase in house finch numbers in Indiana. Trend analysis of the Indiana Audubon Society May, summer, and Christmas counts reveal that the Christmas counts are increasing at the greatest rate, followed by the May counts, and then the summer counts. Moving average plots of house finch counts show that count trends have been exponential with interruptions. House finch populations may be approaching their upper limit in Indiana.

KEYWORDS: Bird populations, *Carpodacus mexicanus*, Christmas bird counts, house finch, Indiana.

INTRODUCTION

The house finch (*Carpodacus mexicanus*), a Western species first released in New York in 1940 (Hill, 1993), has expanded westward, making sporadic appearances in Indiana from the mid-1970s to the early 1980s (Clay and Clay, 1981; Heller and Wise, 1982; Hill, 1993; Gill, 1984; Wiggins, 1987). The house finch was first recorded in the 1980 Indiana Audubon Society May count, when two individuals were observed in Porter County in northwestern Indiana (Hopkins, 1980). Five individuals were reported in the 1981 summer count (Jackson, 1983), and a single house finch was reported in the 1981 Christmas bird count (Mason and Mason, 1982). The number of house finches reported in subsequent counts has increased dramatically (Figure 1). The first breeding record for the house finch in Indiana occurred in Adams County in 1981 (Heller and Wise, 1982).

Studies of the house finch in Indiana have focused on the Christmas count data and the impact of the house finch on house sparrow (Wise and Walls, 1988; Hamilton and Wise, 1991), American goldfinch, and purple finch populations

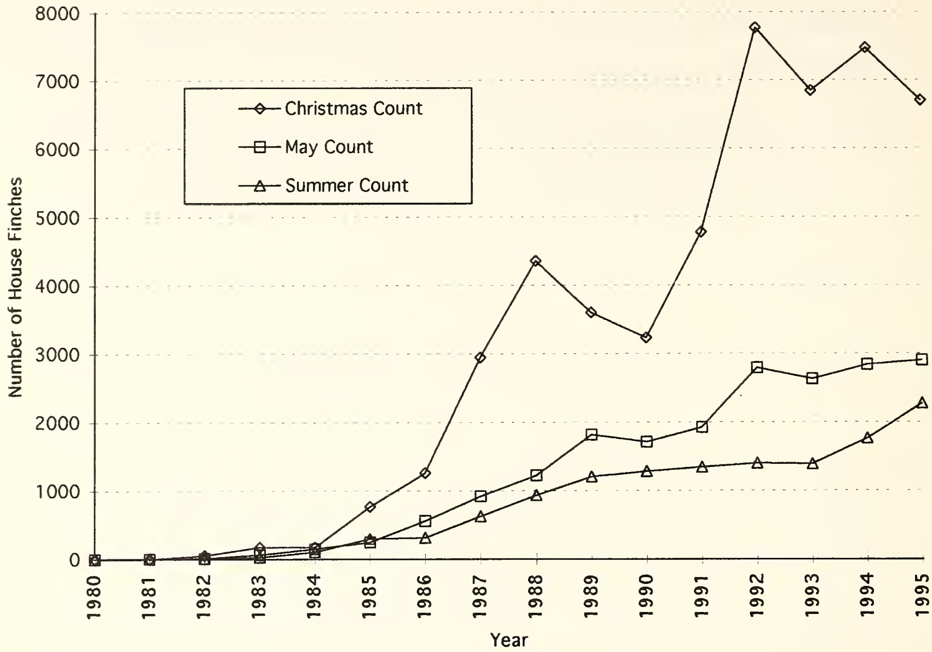

Figure 1. The Indiana Audubon Society house finch counts from 1980 to 1995.

(Hamilton and Wise, 1991). House finches appear to negatively impact house sparrow populations in the northeastern United States (Kricher, 1983). In Indiana, however, house sparrow populations may have declined prior to the arrival of the house finch (Hamilton and Wise, 1991).

What trends are reflected in the Indiana Audubon Society May and summer house finch counts? How do the Indiana Audubon Society May, summer, and Christmas count trends for this species compare with each other? Can these trends be used to predict the size of the future house finch population?

MATERIALS AND METHODS

House finch count data collected annually by volunteers from the Indiana Audubon Society in the Christmas, May, and summer counts were compiled from records published in the *Indiana Audubon Quarterly* from 1980 to 1996. The data collection protocols for each of these counts differed, making their comparison difficult. The May and summer counts were conducted county-by-county. The Christmas count, on the other hand, is not county based but is conducted within a 15 mile (24 km) diameter circle around an established center. Unlike the May and summer counts, at least 8 hours must be spent at each Christmas count site. Christmas counts are taken over a two week period. The May count occurs on the second Saturday in May.

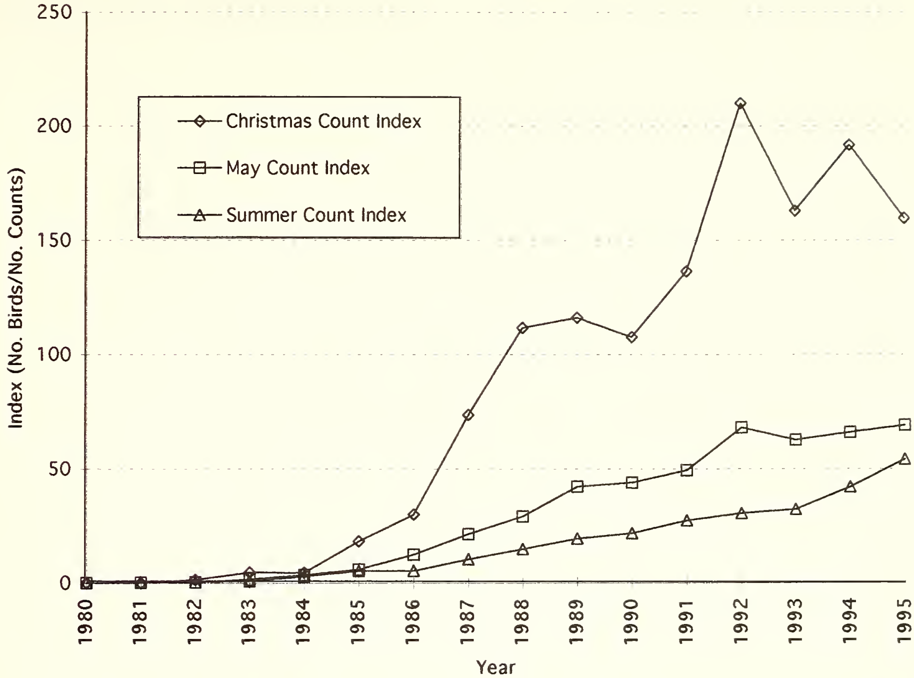

Figure 2. The Indiana Audubon Society house finch count indices from 1980 to 1995.

To compare data for the Christmas, May, and summer counts, a species detectability index was calculated for each respective count by dividing the total number of house finches observed in that count by the number of counties or Christmas counts participating each year. An index based on the number of field hours or the number of party hours could have been used, but those data were not complete for the period under study. The number of counties reporting each year reflects the total field effort and, by its nature, minimizes the variability in individual observer skill and the effort inherent in each respective count. The Christmas count trend, generated using the number of counts, is similar to the curve obtained by Hamilton and Wise (1991) using the number of Christmas count party hours.

The raw data for the Christmas, May, and summer counts were used to calculate a linear regression equation for each respective count (Figure 2). Linear regression analysis was also carried out using the index for each of the three counts (Figure 4). A moving average was calculated for each count based on the following formula and then plotted (Figures 5-7):

$$F_{(t+1)} = \frac{1}{N} \sum_{i=1}^{N} A_{t-i+1}$$

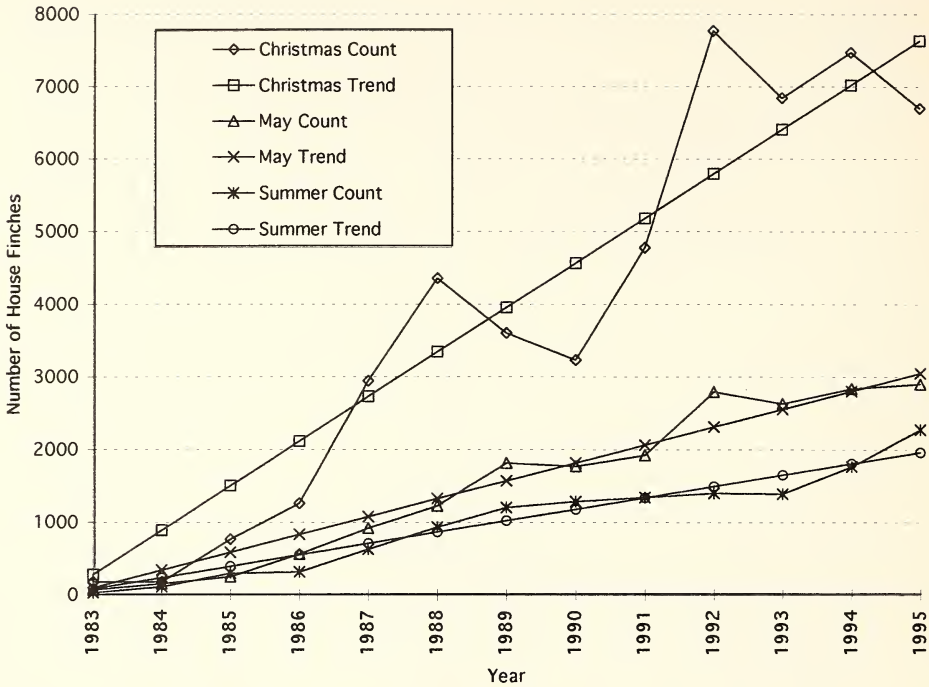

Figure 3. Indiana house finch count trends from 1980 to 1995.

where *N*, the number of periods included in the moving average, is 3, A_{t-i+1} is the actual value at time *J*, and $F_{(t+1)}$ is the forecasted value at time *J*. Data analysis was carried out using Microsoft Excel on a Macintosh Performa 6300CD.

RESULTS

House finch counts in Indiana have increased dramatically since the house finch was first reported in the Indiana Audubon Society's Christmas, May, and summer bird counts (Table 1). Plots of the count data from 1980 to 1995 demonstrate that the Christmas counts increased the most with the May counts and summer counts following in that order (Figure 1). The regression equation (Figure 3) calculated using the Christmas data had a slope of 644 (y = 644x - 1728), more than twice that for the May data, whose slope was 250 (y = 250x - 921), and more than four times that of the summer data, whose slope was 156 (y = 156x - 391).

Plots of the count indices for the period 1980-1995 (Figure 2) were similar to those for the raw data (Figure 1). Regression equations for the count indices for Christmas, May, and summer were calculated and plotted (Figure 4). The Christmas count index had a slope of 17 (y = 17x - 45), more than twice that of the May count index, whose slope was 6 (y = 6x - 16), and nearly five times that of the summer count index, whose slope of 3.6 (y = 3.6x - 11). Both the raw

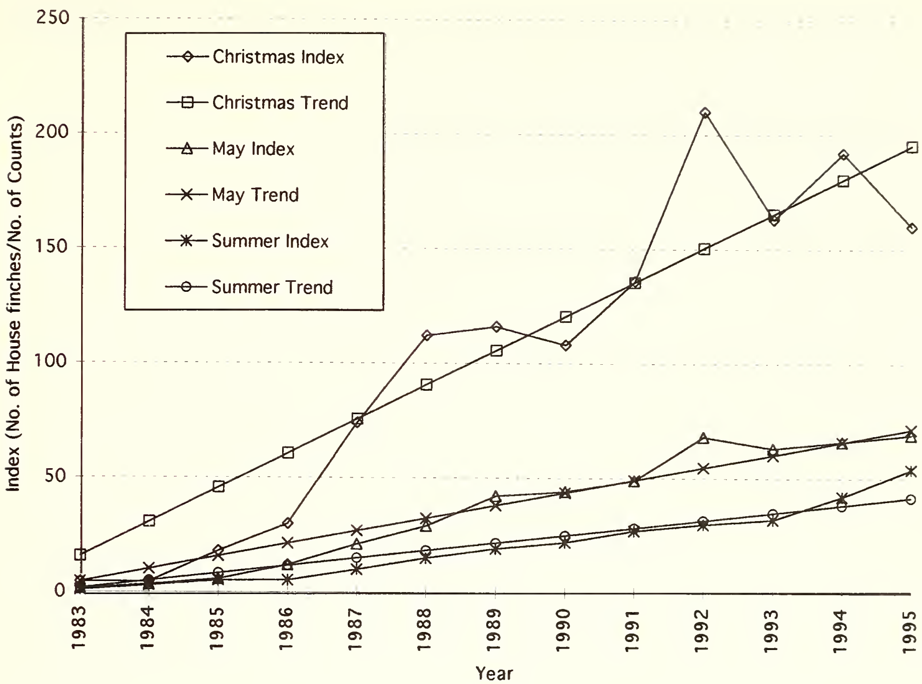

Figure 4. Indiana house finch index trends from 1980 to 1996.

Table 1. Indiana Audubon Society house finch count data.

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Christmas counts																
Number of counts	35	34	40	39	40	42	42	40	39	31	30	35	37	42	39	
House finch count	0	1	56	179	178	766	1259	2942	4357	3600	3226	4777	7769	6842	7474	
Christmas Index[1]	0	0.03	1.4	4.6	4.5	18	30	74	112	116	108	136	210	163	192	
May counts																
Number of Counties reporting	40	39	41	42	44	43	45	43	42	43	39	39	41	42	43	
House finch count	2	7	13	65	151	919	560	919	1225	1816	1711	1923	1793	2629	2838	
Index[2]	0.05	0.18	0.32	1.5	3.4	21	12	21	29	42	44	49	68	63	66	
Summer counts																
Number of Counties reporting	12	19	29	35	39	57	60	61	63	62	59	49	46	43	42	42
House finch count	0	5	9	30	109	298	316	625	934	1202	1280	1340	1398	1385	1763	2269
Index[2]	0	0.26	0.31	0.86	2.8	5.2	5.3	10	15	19	22	27	30	32	42	54

[1] Christmas Index = House finch count/Number of Christmas counts.
[2] Index = House finch count/Number of counties reporting.

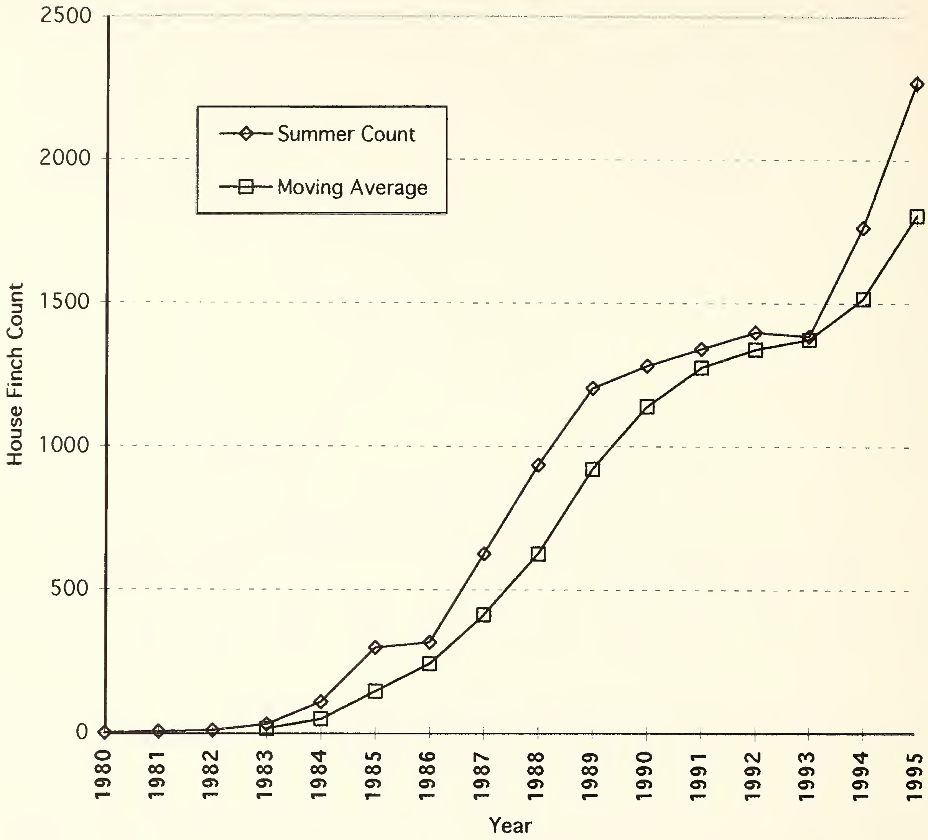

Figure 5. Moving average plot of the Indiana summer house finch counts.

count data and the count indexes demonstrate that the counts of wintering house finches in Indiana are growing at a greater rate than the May and summer counts.

Inspection of the Christmas count data (Figure 1) and the Christmas count indices (Figure 2) reveals a curvilinear trend from 1980 to 1994 with a break occurring between 1988 and 1990. May counts show a similar trend with a break in 1989-1990. Summer counts show a sigmoidal growth pattern from 1980-1993, followed by a renewal of count increases in 1994. Moving average plots of the raw data from the summer and Christmas counts clearly show exponential growth through the 1980s that slowed in the early 1990s and then was followed by continued growth into the mid-1990s (Figures 5 and 6). The May house finch data do not show an obvious slowdown in growth in the early 1990s (Figure 7).

DISCUSSION

Ideally, small-bodied birds with a high reproductive potential and large brood sizes have an annual population growth potential of 50 to 100 percent (Ricklefs, 1973). Counts of wintering house finches in Indiana are increasing faster than

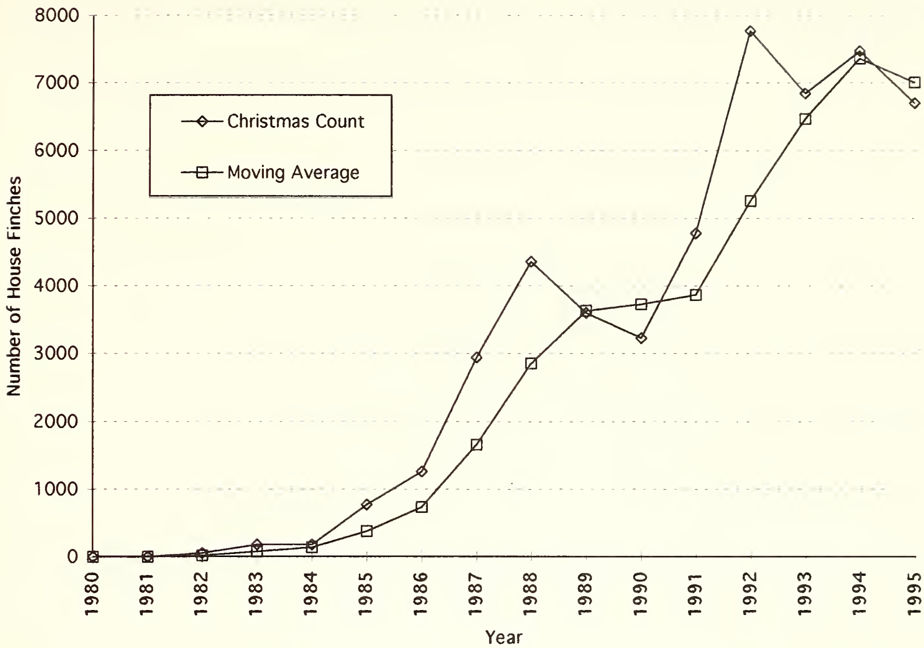

Figure 6. Moving average plot of the Indiana Christmas house finch counts.

the May or summer counts; the winter counts are increasing exponentially with interruptions. This growth might represent the early stages of a sigmoidal growth curve for a population expanding into a new environment. House finch population growth east of the Mississippi based on Christmas count data from 1962 to 1971 was exponential (Bock and Lepthein, 1976). Counts of individual house finches concentrated in wintering flocks would be expected to yield larger numbers per unit effort than more dispersed populations that occur during either the spring migration or summer breeding season. Observers who watch bird feeders during the Christmas count should record most of the house finches tallied. The Indiana data, smoothed somewhat by using an index obtained by dividing the raw data by the number of counts (or participating counties), also revealed similar trends.

Banding (Wiggins, 1987) and other studies (Hill, 1993) show that some house finches leave Michigan and other more northern localities during the winter. The southerly movement of the house finch into Indiana during the winter is reflected in the size of the Christmas counts. The wintering population is also increased by the finch's breeding success in the previous summer in Indiana and the surrounding States. May population counts consistently fall between the Christmas and summer counts, reflecting flock dispersal and the onset of the breeding season. Summer counts are consistently lower than either the Christmas or May counts.

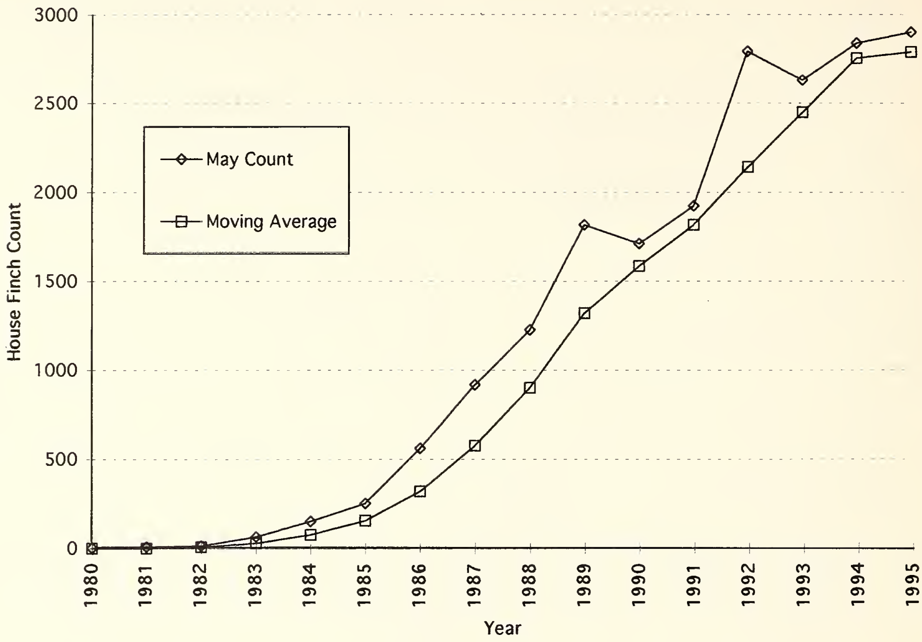

Figure 7. Moving average plot of the Indiana May house finch counts.

A number of density-dependent (recruitment, population size, dispersal, mortality, reproductive rate, competition, predation, and disease) and density-independent (climate, toxins, habitat alteration, backyard bird feeding, etc.) factors act to mediate growth and regulate house finch population size. The four principal ecological factors that limit bird populations are habitat, food supply, climate, and disease (Gill, 1995). Subtle social forces, such as territory size, aggressiveness, dispersal rates, and recruitment, also influence the rate of population growth. Recruitment of young birds into the local population varies inversely with adult mortality. The availability of winter feed to great tits (Van Balen, 1980) decreases the recruitment of young birds into the breeding population (lower adult mortality results in fewer vacancies in the local population), suggesting that backyard feeding may increase the dispersal rates of the house finch.

House sparrows, introduced into the U.S. in the early 1850s, benefitted from the existence of feed and grain stores as well as from horse droppings that contained undigested seeds. The coming of the automobile coupled with the decline in the number of feed stores stabilized house sparrow populations (Kastner, 1986). The recent increase in the popularity of backyard bird feeding has no doubt favored house sparrow populations as well as the populations of other species, including the house finch, that feed on the commonly served backyard bird foods.

In all seasons, 97% of the house finch diet is vegetable matter (Hill, 1993). The house finch prefers small sunflower seeds (oil) over milo, millet, or striped sunflower seeds, and, especially during winter months (Hill, 1993), benefits from the increasing popularity of backyard bird feeders (Bent, 1968). The use of feeders has stimulated a shift in the morphology of the house finch bill, allowing the finch to open sunflower seeds more efficiently (Sprenkle and Blem, 1984).

The decline observed in the 1989 and 1990 Christmas counts may reflect the negative impact of the severe drought that persisted in the mid- to late 1980s on nesting success. The negative impact of the drought on the populations of other bird species was observed in Michigan and Wisconsin during the same time period (Blake, *et al.*, 1989). In addition, Bock and Lepthien (1976) found that the house finch does not prosper in extraordinarily wet years. The decline in the Indiana 1993 Christmas count may reflect the negative impact of the excessively wet 1992 breeding season on nest success. Eastern house finch populations, however, seem to have adapted to wetter climates (Root, 1988). Christmas, May, and summer data for 1994 and summer data for 1995 indicate an increase in house finch numbers following the 1993 decline.

House finches suffer from pox on their feet and legs, which, when spread to the bill and eyes, leads to blindness and death (Hill, 1993). A contagious conjunctivitis infection now being reported by bird banders in house finch populations in the East may also lead to blindness and limit population growth. Competition with other bird species that occupy similar niches may also limit an otherwise explosive population increase in house finches.

CONCLUSIONS

The regression equation for the Christmas counts projects a wintering house finch population of more than 10,000 birds by the year 2000. Continued exponential growth could take population size well above that figure. Continuation of the May trends would result in slightly more than 4,000 birds by the year 2000, and a continuation of the summer trends projects the presence of nearly 3,000 birds by the year 2000.

The ultimate impact of increased house finch numbers on other bird species may begin to reveal itself when house finch numbers reach levels closer to Indiana's carrying capacity for this and similar species. Are competitive interactions with house sparrows, American goldfinches, and other species that share similar niche characteristics already limiting house finch population growth? What is the carrying capacity for the house finch in Indiana? How does backyard feeding effect the demographics of the house finch and other bird species?

As with house sparrows in the 19th Century, the arrival of house finches may be a mixed blessing. House finch depredations on commercial crops in California and Hawaii have been documented (Hill, 1993) as has the negative impact

of the house finch on house sparrow populations (Kricher, 1983). For bird enthusiasts, the house finch endears itself through a more attractive, melodious song than the house sparrow. Are control measures for the house finch needed? More work is needed to determine the long-term effect of the house finch on other bird species as well as agricultural crops.

The data collected by the dedicated volunteers who participate in the annual bird counts, although not always collected according to accepted scientific field methods, does provide a massive database for the many bird species that depend on Indiana habitats for their livelihood. Birds are sensitive indicators of the health of the environment, which justifies monitoring their population fluctuations and trends. A statewide program to standardize and train volunteers in data collection techniques would greatly enhance the value of future Christmas, May, and summer counts and provide the information to evaluate the status of Indiana's habitats well into the 21st Century.

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SEASONAL FLIGHT COUNTS IN THREE BIG BROWN BAT (*EPTESICUS FUSCUS*) COLONIES

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ABSTRACT: Big brown bats first appeared in maternity colonies in mid-March and increased to peak adult populations by the first week of May. Exits began an average of 1.5 to 15.1 minutes after sunset. The length of time for all bats to exit averaged 18 minutes in the smallest colony (peak count of 69 adults) to 44.1 minutes in the largest colony (peak count of 349 bats). Temperatures below 10° C or rain caused bats not to emerge. The fall population decline started in late August and early September, but some bats remained in the colonies through mid-November.

KEYWORDS: Big brown bat, *Eptesicus fuscus,* flight counts, populations.

INTRODUCTION

Most big brown bats (*Eptesicus fuscus*) hibernate alone in buildings in winter, at least in Indiana (Whitaker and Gummer, 1992; but also see Barbour and Davis, 1969 and Baker, 1983). Some hibernate in caves and mines (Beer, 1955; Beer and Richards, 1956; Phillips, 1966). The bats often move within and between roosts during the hibernation period (Goehring, 1972; Mills, *et al.*, 1975; Whelden, 1941). They start to form maternity colonies in March, and the colonies disband by early November (Mills, *et al.*, 1975; Whitaker and Gummer, 1992). However, few specific details on the buildup and decline are available.

The objectives of the present study were to examine changes in the number of big brown bats emerging at dusk from maternity colonies as related to season, weather, and bat biology. Specifically, we wanted to determine: (1) the dates of the beginning, progression, and completion of the spring increase and of the abandonment in the fall at maternity colonies; and (2) fluctuations in flight counts due to weather, the young becoming volant, bats moving, or other causes.

METHODS AND MATERIALS

Observations were made by Brian and Priscilla Leibacher at the Scotland Hotel in Greene County; by Darrel and Rita McKenzie at the Presbyterian Church in Roachdale, Putnam County (and two observations at the Jamestown church): and by Michelle Rakow at Mecca School in Parke County. The exits from the roosts were watched, and all the exiting bats were counted from approximately ½ hour prior to sunset until 15 minutes after the last bat left the roost. The data

recorded included the exit time of the first bat, the number of bats exiting each minute, temperature, wind, cloud cover, and the time the last bat exited. Temperature data were obtained from the National Weather Service and from on-site readings. All data were collected in 1989, except for supplementary data collected at the Scotland Hotel in 1995.

RESULTS

Jamestown and Roachdale. These colonies were both in churches. Only two observations were made at Jamestown (Table 1): the first was on 17 March, when 20 bats emerged, and the second was on 26 March, when 40 bats emerged. The first observations at Roachdale were on 26 March (23° C), when 24 bats emerged. None were seen on 7 April, probably because of the low temperature (6° C). On 14 April (13° C), 50 emerged; on 25 April (22° C), 148 emerged; and on 4 May (14° C, rain), 58 were counted. Maximum counts at Roachdale (Table 1) were 349 bats on 14 August (with young), and 306 bats on 14 May (pre-young). The Roachdale site is also used for hibernation by low numbers of bats (up to 5 per winter).

Scotland Hotel. This colony was in the attic of an old hotel. Observations were made on 15 March (temperature 4° C, cloudy), 23 March (11° C, clear), 30 March (11° C), 5 April (10° C, drizzle), 12 April (11° C, drizzle), and 20 April (17° C), but no bats were seen until 20 April, when 45 exited. The temperature and weather conditions on both 23 and 30 March were such that bats would have exited if present (insects were flying). The bats apparently had not begun returning by 30 March. No bats were seen on 5 or 12 April; however, it was raining on both those nights, which might have kept the bats from exiting. Unfortunately, no other nights were sampled. Therefore, we can only say that the first bats apparently returned between 30 March and 20 April. No bats hibernate at the hotel, as it is not heated in winter.

In 1989, 26 bats emerged on 12 October (15° C), 17 on 25 October (19° C), and none on 8 November (11° C). The bats had apparently left by the last date. Supplementary data were collected in 1995 (Table 1). Seventy-two bats exited on 4 September, but this number rapidly declined. The last bats seen exiting numbered 2 on 23 October (12° C). None exited on three nights in November or on 1 December. In 1995, bats were seen exiting from a heated building near the Scotland Hotel. The number exiting that building was 34 and 47 in late September, from 5 to 9 between 10 and 18 October, and 44 on 18 October. On 23 October and 2 November, 8 and 3 bats exited this building; none were observed on 9 and 13 November (temperatures 3° C and 4° C, respectively). However, on 1 December, 10 bats exited the building. Big brown bats exit in winter, especially on warm nights, and we believe these latter bats had begun hibernation.

Mecca. The colony at Mecca was in the attic of an old, but refurbished, school. Observations at Mecca School paralleled those at the Scotland Hotel. No bats were seen there during observations on 16 March (temperature -5° to 13°

Table 1. *Eptesicus* emergence counts at the Scotland (* = 1995 data), Mecca, and Roachdale (2 at Jamestown = **) colonies. Temperatures are in centigrade. R or C after the date indicates Rain or Cloudy.

SCOTLAND				MECCA				ROACHDALE			
	Temp	No.	Exit times		Temp	No.	Exit times		Temp	No.	Exit times
MAR				**MAR**				**MAR**			
15 C	4	0		16		0		17**	15	20	7:05-8:10
23	11	0		23		0		26**	23	40	7:15-7:58
30	11	0		31		0		26	23	24	7:18-7:45
APR				**APR**				**APR**			
5 R	11	0		7		0		7 C	6	0	
12 R	11	0		29	21	195	8:06-8:26	14 C	13	50	7:34-8:15
20	16	45	7:50-8:01					25	22	148	7:50-8:30
26 R	17	0									
MAY				**MAY**				**MAY**			
3	15	69	8:05-8:24	3	15	242	8:07-8:31	4 R	14	58	7:30-8:00
10	14	54	8:10-8:25	10	13	239	8:01-8:29	14 C	17	306	8:10-8:35
17	22	12	8:14-8:25	18	19	225	8:07-8:34	22 R	13	1	
24	23	15	8:15-8:23	24	22	201	8:17-8:40	29 C	21	176	8:20-9:00
JUNE				**JUNE**				**JUNE**			
7	24	8	8:25-8:48	8 C	23	212	8:18-9:07	11 C	24	245	8:25-9:05
21	27	29	8:29-8:48					26 C	28	210	8:25-9:03
JULY				**JULY**				**JULY**			
5	27	88	8:26-9:03	5	30	227	8:13-8:44	16	27	314	8:25-9:10
12	28	91	8:26-8:43	26	29	181	8:21-8:52	31 C	23	187	8:27-9:00
19	22	92	8:20-8:43								
AUG				**AUG**				**AUG**			
2	21	58	8:17-8:30	7	17	224	8:13-8:44	14	25	349	7:55-8:35
16	21	55	7:54-8:16	16 C	23	122	7:59-8:17	27 C	26	190	7:50-8:15
31	27	54	7:43-7:59								
SEPT				**SEPT**				**SEPT**			
4*	22	72	7:30-7:45	13	15	29	7:20-7:42	13 C	12	39	7:07-7:45
13*	21	36	7:15-7:40	20	19	212	7:13-7:31	25 C	13	72	7:05-7:40
20*	18	23	7:10-7:28								
25*	12	12	7:05-7:25								
27	17	5	7:07-7:18								
OCT				**OCT**				**OCT**			
2*	18	13	6:50-6:59	4	3	7	7:06-7:09	6	9	55	
8*	10	4	6:54-7:05	18	4	0		16	15	60	
12*	19	5	6:38-6:47	25	21	66	6:06-6:37	24 C	20	118	
12	15	26	6:37-6:52					31	3	0	
18*	16	3	6:26-6:45								
23*	12	2	6:21-6:42								
25	19	17	6:15-6:35								
NOV				**NOV**				**NOV**			
2*	7	0		1	3	0		12 C	10	53	5:35-6:20
8	11	0									
9*	3	0									
13*	4	0									
DEC											
1*	10	0									

C, min/max Rockville), 23 March (-2° to 14° C), 31 March (2° to 10° C), and 7 April (0° to 13° C); the first bats were seen on 29 April (14° to 23° C), when 195 emerged. The bats returned between 7 and 29 April. The maximum number of bats prior to flight by the young was 242 on 5 May; this was also the overall maximum (Table 1). About 6 to 20 bats regularly hibernate at Mecca.

DISCUSSION

Establishment of Maternity Colonies in Spring. Bats began returning to two of the maternity colonies by at least 17 March (Jamestown) and 24 March (Roachdale), whereas limited data indicate the arrival of the first bats at Scotland between 30 March and 20 April. The fact that 45 (more than half the ultimate total) emerged on 20 April suggests that the first bats probably arrived at the colony in Scotland closer to 30 March than to 20 April. At Mecca, the spring buildup began between 7 April and 29 April. Their arrival was probably much closer to 7 April as the full complement was there on 29 April. Big brown bats start the spring buildup in central Indiana in March or early April. In the spring, the full complement of bats was attained by about 14 May at Roachdale and 3 May at Scotland and Mecca.

Exit Times. In 1989, exit time showed a pronounced correlation with sunset time. The bats usually emerged between 1 and 15 minutes after sunset (earlier on overcast days). Exceptions occurred on 4 May at Roachdale, when the first bat exited at 7:30 P.M. (sunset at 7:47; misty; and the count was low), and on 5 July, 7 minutes before sunset (no weather information). However, at the Scotland Hotel on the same day (5 July), the first bat exited 6 minutes after sunset. The first bats leaving the hotel on that date flew erratically and may have been young.

Amount of Time to Exit. During the 18 nights on which more than 1 bat exited in Roachdale, the number emerging ranged from 39 to 316 ($\bar{x}$ = 147.4). The bats took from 22 to 45 minutes to emerge, averaging 35.3 minutes. No bats emerged on 7 April, when the temperature was 6° C, and only one emerged on 22 May, when it was raining. The number exiting the Scotland Hotel averaged 44.8 (8-91 bats, n = 16) in 1989. The bats took an average of 17.9 minutes to exit (ranging from 8 to 37 minutes). On the one night when it rained at exit time, none emerged. The bats averaged 16.3 minutes to emerge in the autumn of 1995. On 14 nights, the number emerging from the Mecca School ranged from 7 to 242 ($\bar{x}$ = 170.1). The bats averaged 25.4 minutes to exit (ranging from 3 to 49 minutes). On 4 October, the temperature was 3° C, and only 3 bats exited (exit time 3 minutes); on 18 October, the temperature was 4° C, and none exited. However, a week later, 66 exited when the temperature was 21° C. Cold, rainy nights clearly deter bats from exiting.

Temperature. Exceptions exist, but temperature clearly influences the number of bats exiting. For example (Table 1), at Roachdale, 25 bats were counted on March 26, when the temperature was 23° C, but one week later with a temperature of 6° C, no bats exited. Lower temperatures on which bats emerged

were 3° C on 4 October at Mecca, when seven emerged; 14° C at the Scotland Hotel on 10 May, when 54 emerged; and temperatures of 14°, 9°, 12°, and 13° C at Roachdale when 58 (4 May), 55 (6 October), 39 (13 September), and 1 (22 May, a rainy night) emerged. Large numbers of bats generally did not emerge at temperatures much below 10° C. Usually, fewer bats exited at temperatures less than 15° C, except for 14 May at Roachdale, when over 300 emerged at a temperature of 13° C. The same was true at Mecca, where on 10 May approximately 240 bats were counted when the temperature was 13° C. On 4 October, also at Mecca (3° C), seven exited; on 18 October (4° C), none exited; on 25 October (21° C), 66 were counted. On 1 November (3° C), bats were heard, but they did not exit. The temperatures were somewhat low (ranging from 9° to 15° C) at Roachdale between 13 September and 16 October, and the number of bats emerging was correspondingly lower, ranging from 39 to 72. However, on 24 October, 118 bats emerged at a temperature of 20° C. The Scotland Hotel seemed to have an erratic count relative to temperature. After the first exit count of 45 on 20 April (17° C), no bats emerged on 26 April, when it rained; high counts occurred on 3 May (15° C; 69 bats) and 10 May (14° C; 54 bats). However, no more than 15 bats emerged on 17 May, 24 May, and 2 June, even though the temperature was above 21° C, and there was no rain. Perhaps many of the bats were at an alternate location at that time. No bats exited from the Scotland Hotel or the nearby building on 1 or 8 November, 1989, when the temperature was 11° C. However, bats did emerge from the nearby building on 1 December at a temperature of 10° C.

Rain. It rained on 5, 12, and 26 April at the Scotland Hotel (Table 1), and no bats emerged. Since no bats had been seen at this colony by 12 April, they might not have been present. Forty-five bats emerged on 20 April at the Scotland Hotel, but none emerged on the night of 26 April, when it rained. On successive dates at Roachdale (25 April, 4 May, 14 May, 22 May, and 29 May), the bats emerging numbered 148, 58, 306, 1, and 176, respectively. It rained on 4 and 22 May, the two nights when numbers were greatly reduced. Rain clearly reduced the number of bats emerging. Sunset apparently has a greater influence on exit time than temperature, although very low temperatures or rain might deter the bats from exiting; cloudy conditions may cause early departures.

Fall Decline. The bat populations started declining in August or September. By 2 August, the number leaving the Scotland Hotel was reduced to 58 and then tended to level out with 55 being seen on 16 August and 54 on 31 August. On 7 September, the exit count was only 5; on 12 October, the number was 26; on 17 October, 25; and no bats emerged on 8 November, even though the temperature was 10° C. The major drop in count at Mecca from 122 on 16 August (23° C) to 29 on 13 September (15° C) followed by an increase to 212 on 20 September (19° C) is hard to understand, as the temperature was relatively high on all three nights. No bats emerged at Mecca on 1 and 8 November (3° and 10° C, respectively). The Roachdale Church bats arrived earlier (26 March) than those at the other two main sites, although the earliest arrival date was at Jamestown.

The bats also left Roachdale later (12 November count of 53; 10° C) and may have been there even later. Bat numbers declined, and most of the bats had left the maternity colonies by early November.

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TRICHOME DENSITY DIFFERENCES AND BEAN LEAF BEETLE, *CEROTOMA TRIFURCATA* (FORSTER), FEEDING BEHAVIOR ON SOYBEAN PODS

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ABSTRACT: The pod trichome densities of eight soybean lines and one public variety were determined, and the associated aspects of bean leaf beetle, *Certoma trifurcata* (Forster), feeding behavior on soybean pods were investigated. Three-seeded soybean pods were removed from the top and the bottom of the plants of selected lines. The pods were divided into seven sections, starting from the peduncle and ending at the pod tip. Circular areas within each section were delineated, and the number of trichomes in each circle was determined. Data were analyzed for differences in trichome numbers among lines, within plant regions, and among sections of pods. The trichome density for different lines ranged from 495 to 924 trichomes/cm^2. Pods from the top of the plant had higher trichome densities than pods from the bottom. Soybean pod sections nearest the pod tip had the highest trichome densities, and the sections nearest the peduncle had the lowest. Free choice feeding assays were conducted in the laboratory with three-seeded pods from all lines. Field-collected adult bean leaf beetles were allowed to feed for forty-eight hours. The percentage of the surface damaged per pod section was estimated. Bean leaf beetles showed a stronger tendency to feed on pods at the peduncle end and the sections nearest it. These pod sections had significantly lower numbers of trichomes. Areas with the highest trichome densities had the lowest percentage of beetle damage. Lines HC83-193-5 and HC83-123-9 and the experimental cultivar "Anderson Velvet" had the greatest resistance to overall pod damage.

KEYWORDS: Bean leaf beetle, feeding behavior, host-plant resistance, pods, pubescence, soybeans, trichomes.

INTRODUCTION

Soybean, *Glycine max* (L.) Merrill, is attacked by many foliar and pod feeding insects (Kogan, *et al.,* 1988). The bean leaf beetle, *Cerotoma trifurcata* (Forster) (Coleoptera: Chrysomelidae), causes pod injury that predisposes the seeds to injury by secondary pathogens (Shortt, *et al.*, 1982) such as *Alternaria tenuissima* (Kunze ex Pers.), resulting in yield and seed quality reductions (Smelser and Pedigo, 1992a). The feeding behavior of first and second generation beetles is different. Second generation adults prefer to feed on soybean pods instead of leaves (Sims, *et al.*, 1984). The larvae feed on roots, root hairs, and *Rhizobium* nodules (McConnell, 1915). Bean leaf beetles are also important vectors of bean pod mottle virus in the southern United States (Hopkins and Mueller, 1983).

Bean leaf beetle management relies mainly on the use of insecticides. Despite their effectiveness, insecticides can create environmental problems. Research on alternative management strategies that minimize insecticide application has focused on the use of resistant plant material. This approach also has the potential to delay the development of insecticide resistance in the bean leaf beetle. Trichomes on foliage and/or pods can act as a physical barrier to inhibit insect feeding (Norris and Kogan, 1980).

Trichome density, the number of trichomes per unit area, has been shown to influence the behavior of several chrysomelid beetles. Lamb (1980) found that the trichomes on the pods of the mustard plant inhibited feeding by the flea beetle, *Phyllotreta cruciferae* (Goeze). Flea beetle feeding increased on pods whose trichomes were removed. Baur, *et al.* (1991) demonstrated through the use of dual-choice laboratory assays that trichome density influenced *Agelastica alni* L. oviposition and feeding on the gray alder, *Alnus incana* (L.). Palaniswamy and Bodnaryk (1994) showed that wild *Brassica* species having a leaf trichome density greater than 2,172 trichomes/cm^2 were highly resistant to flea beetle feeding. *Brassica* species with less than 30 trichomes/cm^2 suffered significant damage. Behavioral observations showed that high trichome densities act as a physical barrier to flea beetle feeding. A notable case of the influence of trichome density on a chrysomelid beetle is the effect of wheat leaf trichome density on the behavior of the cereal leaf beetle, *Oulema melanopus* (L.). Trichome density influenced cereal leaf beetle oviposition (Gallun, *et al.*, 1966; Casagrande and Haynes, 1976; Lampert, *et al.*, 1983), egg viability (Lampert, *et al.*, 1983), and larval survival (Ringland and Everson, 1968; Hoxie, *et al.*, 1975). Schillinger and Gallun (1968) found that pubescence deterred adult cereal leaf beetle oviposition on wheat leaves and resulted in abnormal behavior (*e.g.,* movement). Fewer eggs hatched on highly pubescent leaves, suggesting that the eggs may have become desiccated. In addition, trichome density reduced early larval stage survival. The larvae have to eat through the trichomes to reach the leaf surface. The composition of the trichomes ingested (*e.g.,* lignin and cellulose) caused an imbalance in the larval diet (Schillinger and Gallun, 1968).

Minimal information exists on trichome density and its effects on soybean pod feeders. The major objectives of this study were to (1) determine if differences exist in soybean pod trichome density and to (2) examine any relationship between trichome density on soybean pods and feeding behavior by adult bean leaf beetles.

MATERIALS AND METHODS

Trichome Density. Eight soybean lines (MBB80-169, MBB83-190, MBB80-133, MBB83-368, HC83-193-5, HC83-19-2, HC83-123-9, and L76-0038) known to demonstrate foliar resistance to the Mexican bean beetle, *Epilachna varivestis* (Mulsant) and one susceptible cultivar, "Williams 82," were planted on 28 May 1993 at the Purdue University Agronomy Research Center, West Lafayette, Indiana. Each line and cultivar was sampled and analyzed using a completely

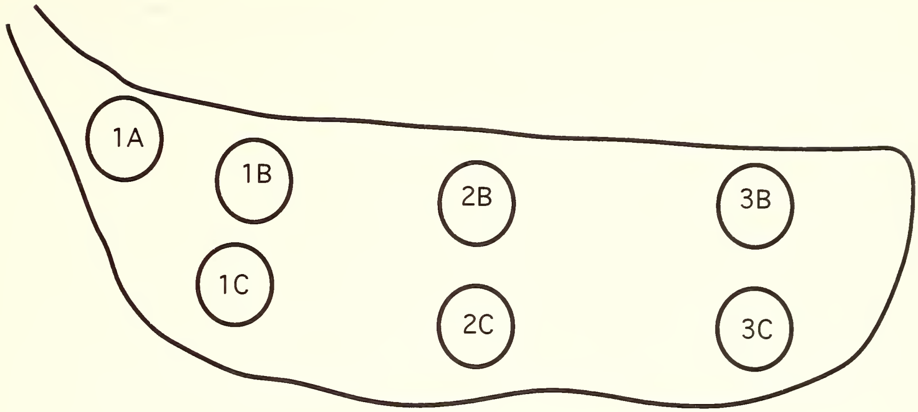

Figure 1. A diagram of a three-seeded soybean pod showing the areas where trichomes were counted.

randomized experimental design. The experimental area was 222.8 m^2 (12.1 m x 18.2 m) and previously had been planted to corn. Each line was planted in two-row plots 154.9 cm long and 76.2 cm wide, oriented north to south. Plots were separated by a 30.4 cm east to west alley. Blocks were separated on the ends with alleys 121.9 cm wide. Sixty-four seeds of each entry were planted per row with a Planet Junior® Sample Plot Planter (Swanson Machine Co., Champaign, Illinois) at a depth of 0.63 to 1.2 cm. Plants of "Anderson Velvet" were planted in a single row by themselves in the same area.

On 24 June 1993, a 18 x 14 mesh polyethylene screen (Lumite Co., Gainesville, Georgia 30503) was placed on a metal frame over the entire area to prevent insects such as the Japanese beetle (*Popillia japonica* Newman), bean leaf beetle, and grasshoppers (various species) from feeding on the foliage.

On 9 September 1993, approximately 30 pods were randomly collected from the top and 30 from the bottom of 5 randomly selected plants in the R6 growth stage (Ritchie, *et al.*, 1992). Pods were collected and placed into polyethylene bags (15.2 x 7.6 cm), transported to the laboratory, and stored at 2.8 ± 2° C.

Laboratory Evaluation. In the laboratory, 5 three-seeded pods per line were randomly selected from the 30 pods collected from the top and bottom of the plants from each line. Pods were divided into seven sections starting at the peduncle and ending at the apex of the pod (Figure 1). The section between the peduncle and the first seed was represented by the letter "A." Each of the three sections of the pod containing a seed were divided into an upper and lower section (nearest the dorsal and ventral sutures) represented by the letters "B" and "C," respectively. Circular areas within each section were delineated with a 0.5 cm cork borer (0.2 cm^2). The number of trichomes in each circle was counted with the aid of a 20x dissecting microscope. Data were analyzed by ANOVA (SAS Institute, 1988). The Student-Newman-Keuls Sequential Range Test (SNKS Range Test) was used to separate significant differences ($P \leq 0.05$) among lines, plant regions, and pod sections.

Table 1. The mean pod trichome density among selected soybean lines. Within column means followed by the same letter do not differ significantly (Student-Newman-Keuls test: $P \leq 0.05$, $n = 70$).

Line	No. of trichomes / cm^2
HC83-193-5	924.3 a
MBB80-169	831.7 a b
MBB83-190	803.7 a b
HC83-19-2	794.0 a b
MBB83-368	747.0 b
HC83-123-9	669.0 b c
MBB80-133	598.2 c d
L76-0038	548.5 c d
Williams 82	495.2 d

Bean Leaf Beetle Feeding Behavior Assays, 1993. Adult feeding preference assays were conducted on 9, 18, and 27 September and 7 October. Pods used for the assay were collected within 24 hours of the assay. Thirty three-seeded pods were collected from the top and 30 from the bottom of each line. Three-seeded pods of approximately the same size from seven of the lines plus "Anderson Velvet" were randomly placed on filter paper moistened with distilled water. The pods were placed equidistant around the perimeter of a Petri dish (2.5 x 15.2 cm). Fifteen field-collected adult bean leaf beetles of unknown sex and age were placed in each Petri dish and allowed to feed for 48 hours. The Petri dishes were placed on a laboratory bench at 22.2 ± 5° C at a 14:10 (L:D) photoperiod with a relative humidity of 85 ± 5% inside the Petri dishes. Three Petri dishes, each representing a replication, were evaluated each day.

Each pod was divided into 7 sections (see above). Both surfaces of the pod were evaluated. Feeding damage was visually estimated as the percentage of pod surface damaged per pod section. Average damage per section was determined by dividing the mean values by two, since both surfaces of the soybean pod were evaluated for damage. Average damage per pod was determined by summing the means of the percent damage per section for each line and dividing by the number of sections ($n = 7$). Pod section means for each line were determined by summing all the percent damage per section means for each section and dividing this value by the number of lines ($n = 8$). Due to the irregularity and roundness of the soybean pod, the actual area damaged by the bean leaf beetles was not measured. Because the data from the feeding assay studies were based on subjective visual observations on non-standard experimental units, formal statistics were not applied. However, the results were consistent for both years of the study, and a distinct range of feeding by the adult bean leaf beetles was noted in all assays (Tables 3-5). This information suggests that a feeding pattern exists.

Bean Leaf Beetle Feeding Behavior Assays, 1994. Adult feeding preference assays were conducted on 9, 12, 14, and 21 September. Pods used for this study were collected within 24 hours of the assay from the Purdue University Agronomy Research Center and the Environmental Entomology Laboratory. Identical lines were included in each assay. The experimental cultivar "Anderson Velvet" and the glabrous line D88-5320 were also included in the 1994 assay. The bioassay method was identical to that described above.

Table 2. The mean trichome density of pod sections averaged over soybean lines/cultivars. Within column means followed by the same letter do not differ significantly (Student-Newman-Keuls test: $P \leq 0.05$, $n = 90$).

Section	No. of trichomes / cm^2
3B	971.0 a
2B	831.0 b
3C	811.9 b
2C	671.8 c
1B	650.5 c
1A	544.8 d
1C	505.6 e

RESULTS AND DISCUSSION

Trichome Density Study. Significant differences ($P \leq 0.05$) occurred in trichome densities among lines ($F = 12.0$, $df = 8, 72$), plant regions ($F = 7.2$, $df = 1, 72$), and pod sections ($F = 365.9$, $df = 6, 432$). HC83-193-5 had the highest trichome density, while "Williams 82" had the lowest (Table 1). Significantly ($P \leq 0.05$) higher trichome densities were found on the pods at the top of the plant (759.8 trichomes/cm^2) than at the bottom (684.8 trichomes/cm^2). Trichome densities also varied significantly ($P \leq 0.05$) among sections of the soybean pod (Table 2). Section 3B had a significantly higher trichome density than other sections, followed by sections 2B and 3C, 2C and 1B, 1A, and 1C. Section 1C had a significantly lower trichome density than all other sections.

Differences in trichome density among lines may be the result of genetic variation. Bernard and Weiss (1973) reported that genetically controlled variation in leaf trichome density occurs in some exotic soybean germplasm. Zaiter, *et al.* (1990) demonstrated that trichome density is under genetic control and that differences in leaf trichome densities exist among soybean cultivars.

Differences in trichome density among plant regions is not unusual. Yapp (1912), working with *Spiraea ulmaria* L., and Stober (1917), working with herbs, reported that leaves on the upper part of the plant have more trichomes than leaves located toward the base. Ehleringer and Mooney (1978) reported that leaf pubescence reduces light absorptance and lowers heat loads. Reflection of solar radiation maintains the leaf temperature below the air temperature resulting in lower transpiration rates. Because the upper region of the plant receives higher amounts of direct solar radiation, trichomes may act as a barrier to reduce the amount of light reaching the pod surface, thus reducing moisture loss and desiccation. In addition, as demonstrated with soybean leaves, trichomes reduce wind movement which lowers transpiration rates from leaf surfaces (Woolley, 1964). Pods in the top region of the soybean plant are exposed to wind, thus increased trichome density would presumably reduce water loss. The plant canopy reduces wind movement among pods at the bottom of the plant creating a microenvironment in which trichome density is less important for reducing transpiration from the pod.

The differences in the trichome density on many plants could result from surface area expansion. Some young organs, such as leaves, fruits, and stems,

Table 3. The percent adult bean leaf beetle damage per pod section corresponding to 1993 and 1994 assay dates.

Section	9/18/93	9/27/93	10/7/93	9/9/94	9/12/94	9/14/94	9/21/94
1A	23.0	26.9	8.3	25.8	25.9	32.8	19.4
1B	11.5	13.0	1.9	11.4	12.9	18.0	9.0
1C	17.2	15.9	5.8	15.7	15.7	18.7	13.3
2B	0.7	1.1	0.10	2.5	6.0	4.6	2.5
2C	3.4	4.9	0.60	6.6	4.4	5.7	5.2
3B	5.8	0.72	0.95	3.9	4.8	5.0	4.2
3C	7.9	3.7	3.1	8.2	9.8	8.5	7.4

Table 4. The percent adult bean leaf beetle damage per pod (= line) corresponding to 1993 assay dates.

Line	9/18/93	Line	9/27/93	Line	10/7/93
Williams 82	21.7	L76-0038	28.5	HC83-19-2	5.0
L76-0038	13.6	MBB80-133	14.5	MBB80-133	4.7
Anderson Velvet	9.2	MBB80-169	13.1	MBB83-190	4.3
MBB80-133	9.0	HC83-19-2	9.5	MBB83-190	3.4
MBB83-190	8.9	Williams 82	4.4	Williams 82	2.9
MBB83-368	8.2	MBB80-190	2.9	L76-0038	2.7
HC83-193-5	5.9	MBB80-169	2.2	HC83-193-5	0.71
HC83-123-9	2.8	Anderson Velvet	0.71	Anderson Velvet	0.0

have a dense covering of trichomes. As the organ grows, the trichomes become spaced further apart, and, if new trichomes are not produced, growth results in lowered trichome densities (Johnson, 1975). With soybean, the continued expansion of the pod surface (the number of cells increases, and these cells elongate) moves the trichomes further apart and reduces trichome density (Jackai and Oghiakhe, 1989). At the time of sampling, the pod sections nearest the peduncle (1A, 1B, and 1C) had undergone more expansion than those farther from these sections, resulting in the gradient of trichome density over the length of the pod. Because expansion was less at the apex of the pod, sections closer to the apex (2B, 2C, 3B, and 3C) had higher trichome densities.

Bean Leaf Beetle Feeding Behavior Studies. Adult bean leaf beetles demonstrated a strong preference for feeding at the pod's peduncle end and the sections nearest it (Table 3, columns 2-4 and 5-8). The greatest damage occurred in sections 1A, 1C, and 1B, which had the lowest trichome densities (Table 2). The least damage occurred in sections 2B and 3B, which had the highest trichome densities. Field observations have shown that adult bean leaf beetles tend to feed on the peduncle end of soybean pods (L. Bledsoe, pers. comm.). The results of

Table 5. The percent adult bean leaf beetle damage per pod (= line) corresponding to 1994 assay dates.

Line	9/9/94	9/12/94	9/14/94	9/21/94	Percent Damage Per Pod (Ave./Year)
Williams 82	22.6	34.8	7.1	11.6	19.0
D88-5320	16.6	19.2	28.1	18.7	22.6
L76-0038	18.2	15.9	12.8	7.0	13.5
MBB83-368	9.9	15.9	10.6	9.9	11.6
HC83-19-2	17.9	12.8	6.4	7.1	11.0
MBB80-169	5.6	7.9	19.1	0.22	8.2
MBB80-133	11.8	6.3	31.0	18.2	16.8
Anderson Velvet	2.9	4.9	6.5	5.1	4.8
MBB83-190	7.1	4.5	16.5	10.3	9.6
HC83-193-5	3.7	1.7	4.9	1.8	3.0
HC83-123-9	0.11	1.1	3.7	6.0	2.7

these laboratory studies suggest that bean leaf beetles feed on the peduncle end and the sections nearest it because these sections have the lowest trichome densities. In addition, bean leaf beetles may be able to "mow" down the trichomes in these sections, making it easier to reach the pod's outer surface. Hulley (1988) demonstrated this behavior with the caterpillar, *Pardasena* sp. nr *diversipennis* Gaede, on *Solanum coccineum* Jacq.

Lines HC83-123-9 and HC83-193-5 as well as "Anderson Velvet" demonstrated the greatest resistance to adult bean leaf beetle pod feeding (Table 4 and 5). "Anderson Velvet" is highly pubescent. The high number of trichomes made it difficult to obtain reliable counts, so trichome density was not determined. The unsuitability of the various lines to bean leaf beetle feeding might also result from nutritional deficiencies or disproportionalities, biophysical deterrence, or physiological inhibitors (Barney and Rock, 1975). In addition, other genetically controlled factors might influence the degree of resistance (Clark, *et al.*, 1972).

Although more studies have been conducted to investigate the interaction of soybean leaf trichome density than pod trichome density with insect resistance (Chiang and Norris, 1983; Zhan, *et al.*, 1986; Gunasinghe, *et al.*, 1988; Lambert, *et al.*, 1992), research with other agricultural crops has demonstrated that pod trichome density is associated with reduced feeding by some insects. Chiang and Singh (1988) found that trichomes on the pods of cowpea, *Vigna vexillata,* contributed to resistance against the pod-sucking bug, *Clavigralla tomentosicollis* Stal. Jackai and Oghiakhe (1989) reported that trichomes on the pods of two cowpea varieties interfered with pod feeding and development of

the legume pod-borer, *Maruca testulalis* (Geyer), as well as *C. tomentosicollis.* They found that the insects were restless and had difficulty positioning their legs on the pod wall. Oghiakhe, *et al.* (1992) determined that greater trichome density on *Vigna unguiculata* pods reduced larval damage from *M. testulalis* (Geyer), and they concluded that trichome density was the major factor controlling resistance.

While some studies have demonstrated the effectiveness of soybean pod trichomes in reducing insect feeding damage, other studies show that increased pubescence is not always associated with resistance. Morse and Cartter (1937) found that glabrous soybeans were highly resistant to the soybean pod borer, *Laspeyresia glycinivorella* Mats., whereas pubescent varieties were highly susceptible. Broersma, *et al.* (1972) reported that soybean strains with 2,969 to 3,100 trichomes/cm^2 had significantly higher potato leafhopper populations than strains with 610 to 810 trichomes/cm^2. Turnipseed (1977) observed that potato leafhopper populations were less affected by trichome density than trichome length.

Very little information was found in the literature on the interaction of pod trichome density and bean leaf beetle feeding damage. Previous studies have only investigated the effect of pod pubescence on reducing seed quality loss due to bean leaf beetle feeding and subsequent invasion by *Alternaria tenuissima* (Shortt, *et al.*, 1982) and in relation to yield and quality reduction (Smelser and Pedigo, 1992a, b).

The existence of an inverse relationship between increased trichome density and feeding preference by bean leaf beetles for both soybean lines (Tables 4 and 5) and pod sections within the lines (Table 3) was found in this study. HC83-123-9 was a notable exception to this trend. This line showed a high level of resistance to bean leaf beetle feeding at a much lower pod trichome density (Table 1). HC83-123-9 is highly resistant to Mexican bean beetle and adult Japanese beetle foliar feeding (Cooper and Hammond, 1988), suggesting that factors other than trichome density may contribute to host plant resistance. Nevertheless, high trichome densities may inhibit adult bean leaf beetles from reaching the pod surface and feeding. Additional studies should be conducted to evaluate this behavior further.

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REMOVAL OF LEAD AND CHROMIUM FROM CONTAMINATED SOIL: COLUMN STUDIES

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ABSTRACT: Ethylenediaminetetraacetic acid (EDTA) and nitrilotriacetic acid (NTA) were evaluated in column studies (each 0.1, 0.01, or 0.001 M) for their ability to extract lead (Pb) and chromium (Cr) from contaminated soil (Pb_{tot} = 1300 mg/kg; Cr_{tot} = 4940 mg/kg; pH = 10.3) collected at an abandoned industrial facility. The EDTA was eluted at pH 3.0, 5.5 (ambient), and 10.0, and the NTA at pH 3.0 and 11.1 (ambient). The efficiency of Pb and Cr solubilization was influenced by solution pH and chelant-metal chemistry; the EDTA, a hexadentate ligand, solubilized both metals more effectively than did the quadridentate NTA. Lead and Cr removal increased with higher EDTA concentrations; however, higher NTA concentrations did not remove significantly greater amounts of Pb or Cr ($P < 0.05$). The 0.1 M EDTA at pH 3.0 and 10.0 removed 86.5% and 87.1% Pb after 200 pore volumes, respectively. The 0.1 M NTA (pH 3) recovered 29.5% soil Pb. The 0.1 M EDTA, pH 5.5, recovered 40.9% soil Cr, and the 0.1 M NTA at pH 11.1 removed 28.5%. The lower Cr removal compared to that for Pb may be explained by the chemical forms of each metal in the soil: 89.8% Cr occurs in residual forms, which are not readily extractable except by exhaustive processes. In contrast, only 45.7% Pb occurs in residual form. Initial flushing with 0.1 N HCl followed by chelant flushing did not significantly improve removal of either Pb or Cr. Pb removal via soil flushing was equal or greater in effectiveness to that by *ex-situ* processes.

KEYWORDS: Chromium, EDTA, lead, NTA, soil flushing.

INTRODUCTION

Soils at numerous industrial sites are contaminated with heavy metals (Richards, *et al.*, 1993; Cairney, 1987). Metal-rich sites pose potential hazards to public health and the environment via contamination of groundwater and surface water as well as through plant uptake.

The use of technologies which eliminate or reduce the hazardous characteristics of waste is now being given greater priority over traditional contaminant removal methods, such as excavation followed by landfilling. Available treatment technologies for remediating metal-contaminated soils include solidification/immobilization processes, soil washing (*ex-situ*), and soil flushing (*in-situ*).

Metals on weathered metalliferous sites occur in complex forms (Kabata-Pendias and Pendias, 1992), and their mobility is controlled by several chemical and physical phenomena, including soil pH, soil type, cation exchange capacity,

particle size, contaminant concentration, and the presence of organic and inorganic compounds. Many of these factors are interdependent (Reed, *et al.*, 1995). Metal removal efficiencies during soil flushing depend not only on soil characteristics but also on metal characteristics, extractant chemistry, and processing conditions. Chelating agents, such as ethylenediaminetetraacetic acid (EDTA) and nitrilotriacetic acid (NTA), bond with the metal to facilitate solubilization in the extraction medium. The ability to form stable metal complexes makes EDTA and NTA effective extractants for metal-contaminated soils (Davis and Singh, 1995; Elliott and Brown, 1989; Cline, *et al.*, 1993).

Chelants vary in effectiveness for Pb or Cr removal; the result is affected by the presence of different solid forms of the metals in the soils, differences in pH during extraction, and interference from other cations which complex with the chelate (Elliott and Brown, 1989; Brown and Elliott, 1992; Tuin and Tels, 1990; Hsieh, *et al.*, 1989; Shirk and Farrel, 1985). The solid forms of Pb or Cr present in a soil depend on the source of the contamination and also the extent of redistribution of the metal in the soil following contamination. After Pb or Cr is added to soil, they may be redistributed by the formation of secondary mineral precipitates, adsorption onto soil mineral particles, or by complexation with soil organic matter (Heil, *et al.*, 1996).

In certain situations, remediation via *ex-situ* processes may be difficult if a site contains utilities or structures. Thus, an *in-situ* treatment process (i.e., forcing an extractant through an intact soil to flush out metals) would alleviate some of these problems. In general, *in-situ* technologies are able to treat large volumes of soil more economically and more safely than *ex-situ* technologies because there is no excavation (Reed, *et al.*, 1995). However, little fundamental research has been carried out on the *in-situ* flushing of metals (Davis and Singh, 1995).

Recent soil treatment studies have assessed remediation effectiveness of soils spiked with soluble metal salts (Cline and Reed, 1995; Reed, *et al.*, 1995; Davis and Singh, 1995; Chen, *et al.*, 1995; Macauley and Hong, 1995). The removal efficiencies measured may be greater than those observed when washing contaminated soils which have been weathered for long periods. In the current study, the authors investigated the use of several solutions for Pb and Cr removal from a soil contaminated for decades with metals in various insoluble forms. Specifically, the objectives were to (1) assess the relative abilities of EDTA and NTA in the *in-situ* extraction of Pb and Cr from a contaminated soil and to (2) compare the effectiveness of *in-situ* and *ex-situ* metal removal from the soil. In a previous study (Pichtel and Pichtel, 1997), EDTA and NTA solutions were assessed for their relative abilities in the *ex-situ* washing of a Pb- and Cr-contaminated soil. Based on these studies, EDTA and NTA concentrations of 0.1, 0.01, and 0.001 M were selected as soil flushing solutions for the present study.

EXPERIMENTAL METHODS

The soil material, a mixture of native soil and industrial waste, was collected from a closed chemical facility in the United Kingdom. Sample preparation

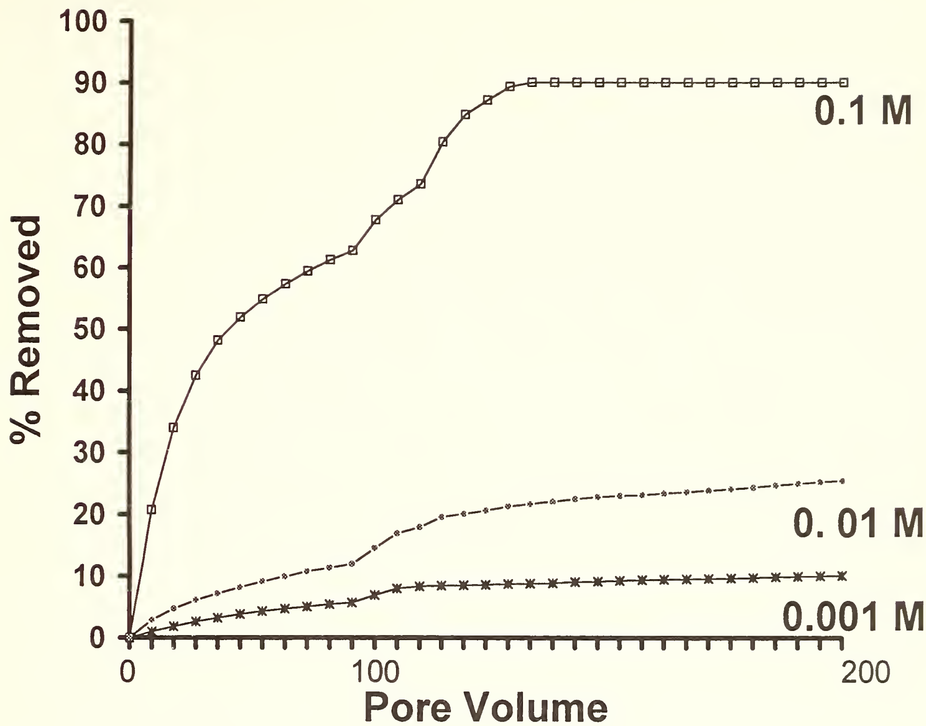

Figure 1. Pb recovery from soil using EDTA at ambient pH (5.5).

as well as the chemical and physical analyses are described elsewhere (Pichtel and Pichtel, 1997). The soil had a pH of 10.3, 1300 mg Pb/kg, and 4940 mg Cr/kg. The soil contained 82.8% sand-sized particles, making it suitable for soil flushing processes. A sand fraction of 50-80% or more typically increases the effectiveness of soil washing (U.S. Environmental Protection Agency, 1991).

Column studies were conducted using PVC columns measuring 2-cm internal diameter and 5 cm in length. Contaminated soil was packed in the column with a final bulk density of 1.1 g/cm^3. The column was plugged at both ends with rubber stoppers and glass wool. Flushing solutions were introduced from the bottom of the columns to saturate the soil. A flow rate of 2.0 ml/min was established for all columns on a Masterflex Model 7568 peristaltic pump. Extraction solutions included ethylenediaminetetraacetic acid (EDTA) and nitrilotriacetic acid (NTA) at 0.1, 0.01, and 0.001 M. Solutions were used at the ambient pH value (5.5 for EDTA and 11.1 for NTA) or at pH 3.0 using HCl, and 10.0 (EDTA only) using NaOH. In one set of experiments, a solution of 0.1 M HCl was passed through the columns for the first 100 pore volumes with subsequent flushing by either 0.1 M EDTA or 0.1 M NTA (ambient pH).

Column effluent samples were acidified with concentrated HNO_3. Concentrations of soluble Pb and Cr were measured via flame atomic absorption spectrophotometry (Perkin-Elmer model 2240, Norwalk, Connecticut; Perkin-Elmer,

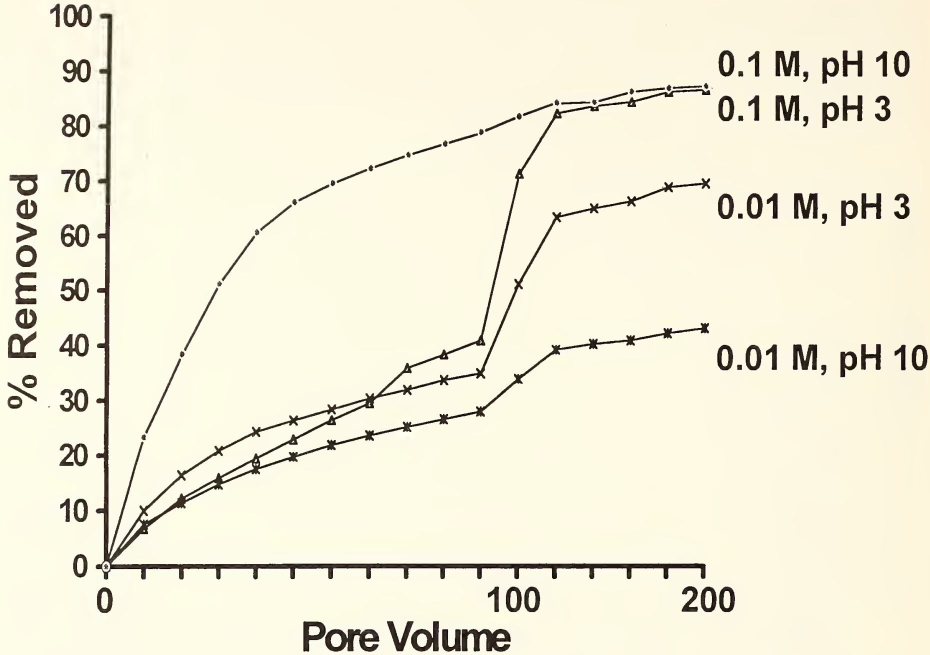

Figure 2. Pb recovery from soil using EDTA at pH 3.0 and 11.0.

1982). Detection limits of 0.19 and 0.08 mg/L were measured for Pb and Cr, respectively, using standards prepared from commercial reagents.

Comparison of metal levels removed from the soil by EDTA and NTA were performed using a one-way analysis of variance and the Student-Newman-Keuls Test, if a significant difference was detected ($P < 0.05$). SigmaStat (version 2.0 on a Windows format) was used for all calculations.

RESULTS AND DISCUSSION

Lead Removal Efficiencies. Lead removal by 0.1 M EDTA was initially rapid (Figure 1). The overall extraction process is consistent with the two-step metal desorption process described by Tuin and Tels (1990), Backes, *et al.* (1995), and Cline and Reed (1995); that is, a rapid initial desorption was followed by gradual release. The lower extraction efficiency after the first 20-25 pore volumes is presumably a result of stronger Pb binding to soil solids with decreasing metal contamination, because binding energies associated with low sorption densities are substantial (Benjamin and Leckie, 1981). Additionally, the removal of progressively more stable Pb minerals or a slow rate of release of Pb^{2+} from solid Pb phases may be responsible (Heil, *et al.,* 1996). Reed, *et al.* (1995) measured significant Pb removal from contaminated soil columns after only 1-4 pore volumes, after which little additional Pb removal occurred.

After 100 pore volumes, the 0.1 M EDTA solution at ambient pH removed 71% of the soil Pb, which was significantly greater ($P < 0.05$) than the 16.8%

and 8.0% removed by the 0.01 M and 0.001 M solutions, respectively (Figure 1). After 200 pore volumes, 89.8% of the soil Pb was extracted with 0.1 M EDTA; however, removal at 0.1 M and 0.001 M remained virtually unchanged. Common soil metals (*e.g.*, Ca^{2+}, Na^{+}, etc.) may compete with Pb for the chelating agent so that excess chelant quantities (i.e., well above equimolar concentrations) are needed to ensure complete contaminant removal (Reed, *et al.,* 1995). A chelant concentration of at least 0.00025 M is required for 1:1 concentrations of Pb:extractant.

The 0.1 M EDTA solution at pH 3 removed 82.2% Pb after 100 pore volumes, and 63.3% was recovered with the 0.01 M solution (Figure 2). Heil, *et al.* (1996) measured increased Pb removal from three soils as EDTA pH decreased. The solubility of many Pb minerals, including $Pb(OH)_2$, PbO, and $PbCO_3$ as well as other Pb-crystalline solids, will increase as pH is decreased (Lindsay, 1979). Protonation weakens the metal-lattice bonds, increasing the dissolution rate. Both proton- and ligand-enhanced dissolution mechanisms may be operating simultaneously (Stumm and Wieland, 1990).

When the EDTA pH was increased to 10, the 0.1 M solution removed 84.2% Pb after 100 pore volumes, and the 0.01 M solution removed 39.2% (Figure 2). At pH values of 11 or above, EDTA is present in the completely ionized tetranegative form and binds strongly to transition metal cations. EDTA was found effective for Pb recovery from soil at high solution pH values in studies by Elliott and Brown (1989). Lead solubilization may be partly the result of solubilization of soil organic matter or the formation of Pb hydrolysis complexes (Heil, *et al.,* 1996). Heil, *et al.* (1996) found, in alkaline solutions, that a high percentage of EDTA complexed with Ca and, to a lesser degree, with Mg and other cations. The soil in the current study contained 8.2% Ca and 6.0% Mg (Pichtel and Pichtel, 1997); both may compete with target metals for the chelant. The log stability constants for $CaEDTA^{2-}$ and $CaNTA^{-}$ are 10.7 and 6.4, while the K_s for $MgEDTA^{2-}$ and $MgNTA^{-}$ are 8.8 and 5.4, respectively. The K_s for $PbEDTA^{2-}$ and $PbNTA^{-}$ are 18.0 and 11.3, respectively (Martell and Smith, 1974).

The present data demonstrates equal or greater Pb extractability in columns compared to batch extractions. In batch studies, 0.1 M EDTA was successful, both at pH < 4.5 and pH > 12.5, in removing > 90% soil Pb after a single washing (Pichtel and Pichtel, 1997). Lead removal efficiencies were high in columns compared to batch studies (Reed, *et al.,* 1995). Lead release during column flushing is apparently enhanced by the higher concentration gradient.

The quantities of Pb removed from contaminated soils via chelant extraction varies. A solution of 0.08 M EDTA removed over 90% of soil Pb from a Pb battery-contaminated soil (Elliott and Brown, 1989). Brown and Elliott (1992) measured 80% Pb recovery from the same soil at pH 4.0 and 0.04 M EDTA. Tuin and Tels (1990) measured variable Pb extraction from contaminated soils using EDTA following acidification.

An increase in NTA concentration resulted in an insignificant increase in Pb solubilization (Figure 3). After 200 pore volumes, the 0.1 M NTA solution at

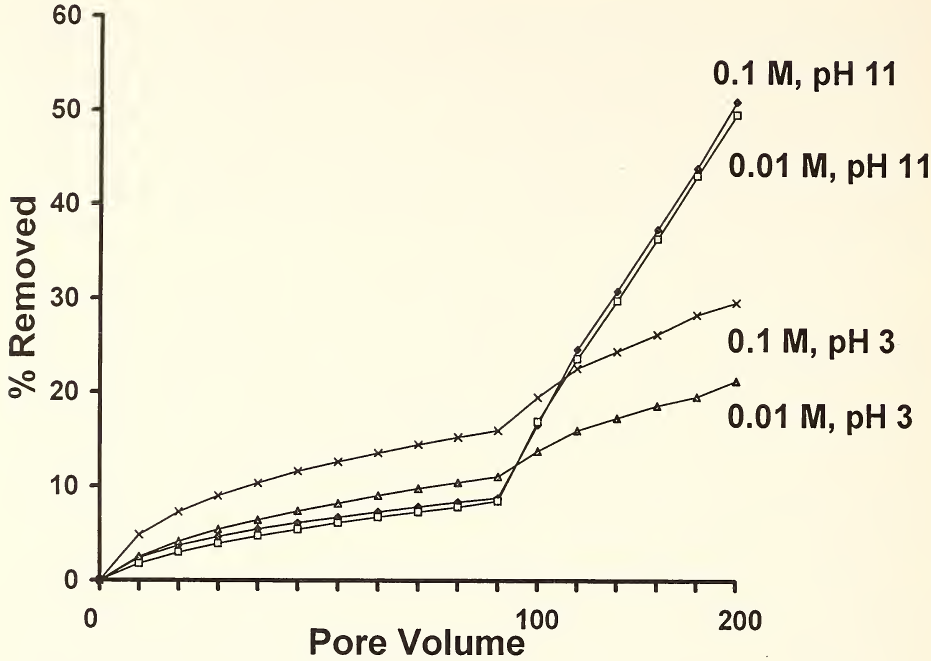

Figure 3. Pb recovery from soil using NTA at pH 3 and ambient pH (11.1).

ambient pH (11.1) removed 50.9% of the soil Pb, which was not significantly greater than the 49.5% removed by the 0.01 M solution. The 0.1 M NTA solution at pH 3 removed 22.5% after 100 pore volumes and 29.5% after 200 pore volumes. A total of 21.2% was recovered with the 0.01 M solution after 200 pore volumes (Figure 3). In batch studies, a range of 12% to 38% Pb was removed from this soil in 0.1 M NTA under acidic conditions (Pichtel and Pichtel, 1997), which was not significantly different from those measured in the current *in-situ* study.

Lead recovery in NTA was less than that accomplished by EDTA (Figures 1-3). Average Pb removed was 87.9% in 0.1 M EDTA (across all pH values) compared to 40.2% for 0.1 M NTA. The lower extraction efficiency of NTA when compared to EDTA may be due to competition among other soil cations (e.g., Ca^{2+}) for the ligands or adsorption of the Pb-NTA complex to the soil surface. Elliott and Brown (1989) suggest that NTA:Pb ratios greater than 1:1 reduced Pb recovery because of adsorption of $Pb(NTA)_2^{4-}$ onto positively charged oxide soil components. Additionally, as a result of its weaker complexing ability, NTA is less capable than EDTA in preventing Pb hydrolysis under alkaline conditions (1989). Castle, *et al.* (1985) found a 10% EDTA solution to be superior to NTA in solubilizing Pb; a 90% to 95% removal was measured. In the present study, high concentrations of either EDTA or NTA did not reduce metal recovery.

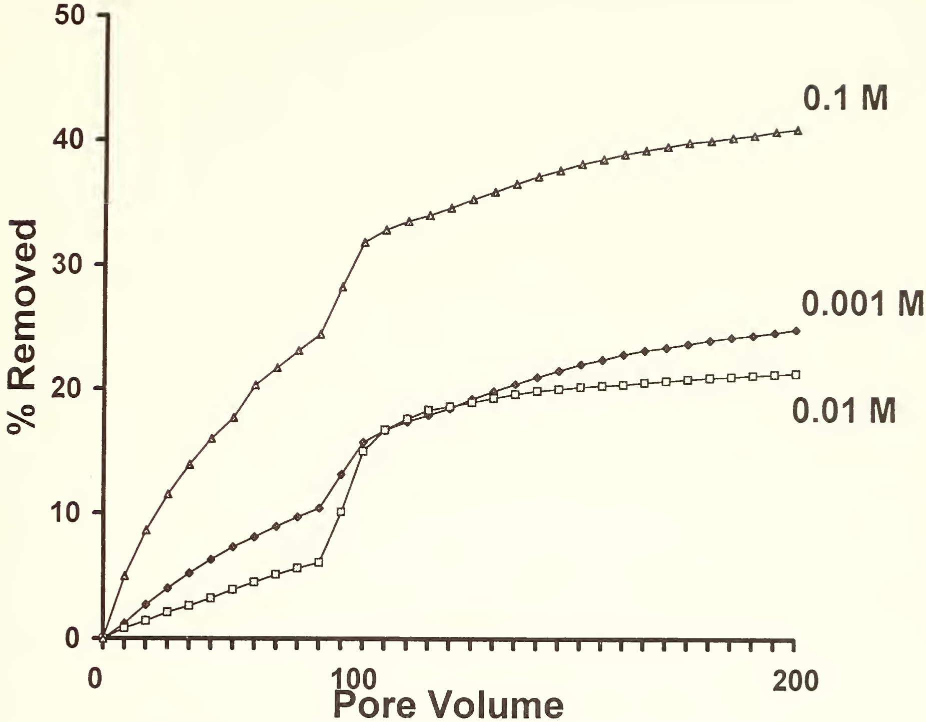

Figure 4. Cr removal from soil using EDTA at ambient pH (5.5).

Flushing the soil columns with HCl prior to chelant flushing did not significantly ($P < 0.05$) increase Pb-extraction efficiency (data not shown). Tuin and Tels (1990) measured 81% and 87% Pb removal from two soils which were first extracted by 0.1 M HCl followed by 0.1 M EDTA.

Chromium Removal Efficiencies. Overall, Cr removal from the soil was substantially lower than that of Pb (Figures 4-5). Tuin and Tels (1990) found Cr to be less readily extractable than Pb from four contaminated soils. Assink and Rulkens (1987) also measured only slight Cr removal from soil. Metal removal is based on the formation of soluble complexes. In the present study, the majority of soil Cr is not readily reactive; 89.8% occurs as the insoluble fraction (Pichtel and Pichtel, 1997). Therefore, a chelant concentration well above the stoichiometric amount is necessary for maximum removal. A minimum chelant concentration of 0.004 M is needed to form a 1:1 ratio of chelant:Cr for optimal recovery.

Increasing the EDTA concentration generally resulted in an enhanced recovery of soil Cr (Figure 4). A total of 40.9% soil Cr was removed with 0.1 M EDTA after 200 pore volumes at ambient pH, and 21.3% and 24.8% was removed at 0.01 and 0.001 M EDTA, respectively.

In batch studies, Cr recovery using EDTA at 0.1, 0.01, and 0.001 M was maximized at 34-36% up through pH 7 and, in no case, did a single EDTA wash-

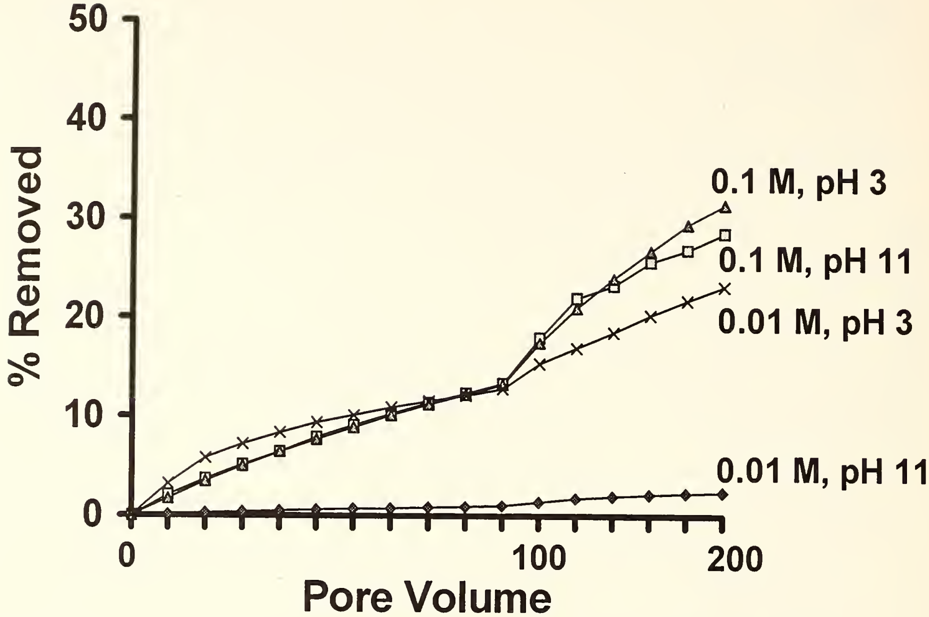

Figure 5. Cr removal from soil using NTA at pH 3.0 and ambient pH (11.1).

ing remove all the soil Cr (Pichtel and Pichtel, 1997). Hsieh, *et al.* (1989) found that Cr removal from a contaminated soil with EDTA ranged from 35-83% for 6 to 10 washing cycles, which demonstrates the difficulty of removing all adsorbed Cr. Shirk and Farrel (1985) measured only 12% Cr recovery from a contaminated soil using EDTA. The poor removal results for Cr may be a result of the presence of immobile Cr^{3+} species, occurring as oxide compounds (Tuin and Tels, 1990).

Chromium removal by 0.1 M NTA (ambient pH 11.1) after 100 pore volumes was 21.9%, while that by 0.01 M was 1.7% (Figure 5). Beyond pH 10.3 (*i.e.*, pKa_3), the chelant exists as NTA^{2-} and, to a lesser extent, as NTA^{3-}, both of which allow for partial complexation with the soil Cr. Precipitation as insoluble oxides is a strongly competing reaction in this pH regime, however. When the pH was set at 3.0, Cr removal after 100 pore volumes was essentially unchanged with 0.1 M NTA (20.9%); however, removal increased to 16.9% at 0.01 M. Banat, *et al.* (1974) found negligible Cr solubilization from two river sediments (pH 6.8 and 7.1) using NTA in batch studies, even after 200 h shaking time. In batch tests, Cr removal using 0.1 M NTA over a range of pH values did not exceed 14.0% (Pichtel and Pichtel, 1997).

The stability constant for the formation of $CrEDTA^-$ is 17 orders of magnitude higher than that for CrNTA (Martell and Smith, 1974); hence, the EDTA should be more effective at removing Cr from the soil. The weaker complexing ability of NTA limits its ability to prevent hydrolysis. Furthermore, since all

the functional groups of the EDTA are involved in the complexation, little opportunity exists for bridging to the soil surface (Elliott and Brown, 1989). Additional recovery of Cr at high pH may be limited by the strong affinity of basic cations such as Ca and Mg for the chelant. Ca^{2+} will strongly bind with the chelant at high pH. When the columns were first acidified with HCl, elution by EDTA or NTA (ambient pH) did not remove significantly greater quantities of Cr compared to chelant flushing alone (data not shown).

CONCLUSIONS

Removal of both Pb and Cr from a contaminated, strongly buffered alkaline mixture of soil and weathered industrial waste was typically enhanced in column studies when EDTA and NTA concentrations were increased. For a non-pre-treated (*i.e.,* non-acidified) soil, washing with EDTA above equimolar concentrations was more effective than washing with NTA. NTA is less expensive than EDTA, and less NTA is required, on a weight basis, to form 1:1 complexes with metals. The slow dissolution kinetics of the Pb- and Cr-solid phases may deter total metal removal by a chelant, and long-term flushing would be needed for complete metal recovery.

The extent of Pb and Cr solubilization is partly a function of pH. However, to completely acidify the soil would prove too costly due to the soil's extensive buffering capacity. In addition, high acid strengths destroy soil structure and dissolve much of the soil solids. From a practical standpoint, a soil solution at either pH extreme will be corrosive to field washing equipment. The recommended washing treatment for the alkaline soil/waste mixture studied, based on pH adjustment and other practical considerations, was 0.1 M EDTA without acidification.

For this study soil, *in-situ* processes appear to be equally effective as *ex-situ* processes due to the high concentration gradient for soil metals during the flushing process. Additionally, the particle size distribution of the materials is conducive to flushing; over 82% of the particles are present in the sand-sized fraction, which provides for high permeability and sufficient contact of extracting solution with the contaminants.

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DISTRIBUTION OF LIMESTONE IN THE BRAZIL FORMATION (PENNSYLVANIAN) IN THE SUBSURFACE OF SOUTHWESTERN INDIANA AND WESTERN KENTUCKY

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ABSTRACT. Electric logs and samples of well cuttings indicate the existence of limestone bodies in the lower and middle Brazil Formation of southwestern Indiana and western Kentucky. The limestone bodies are elongated northeast-southwest, are as much as 60 feet thick, are as much as 3 miles in length, are interpreted to have formed on slight elevations on the sea floor, and were accumulated contemporaneously with adjacent terrigenous muds and sands until they were finally smothered by these terrigenous sediments.

KEYWORDS: Brazil Formation, limestone, Pennsylvanian, subsurface southwestern Indiana, subsurface western Kentucky.

INTRODUCTION

The Brazil Formation in Indiana lies below the Staunton Formation and above the Mansfield Formation in the Raccoon Creek Group (Figure 1). In the type area (Brazil, Clay County, Indiana), the Brazil includes rocks from the base of the Lower Block Coal Member to the top of the Minshall Coal Member (Hutchison, 1976). The Upper Block Coal Member is the only other named member of the Brazil Formation. The Brazil coals have irregular distributions along the outcrop and very limited distributions in the subsurface. Because the Minshall coal is of limited extent, the stratigraphic position of the base of the more widespread Perth Limestone Member, or of the sandstone that replaces it, was used in an earlier subsurface study (Droste and Horowitz, 1995) to mark the top of the Brazil. This "working" definition of the top of the Brazil is used in the present study. Following conventional usage, the base of the Brazil is placed at the stratigraphic position of the base of the Lower Block Coal.

This study expands geographically the earlier report of limestones in the Brazil Formation in Vanderburgh County, Indiana (Droste and Horowitz, 1995) by including all the subsurface area of southwestern Indiana and western Kentucky.

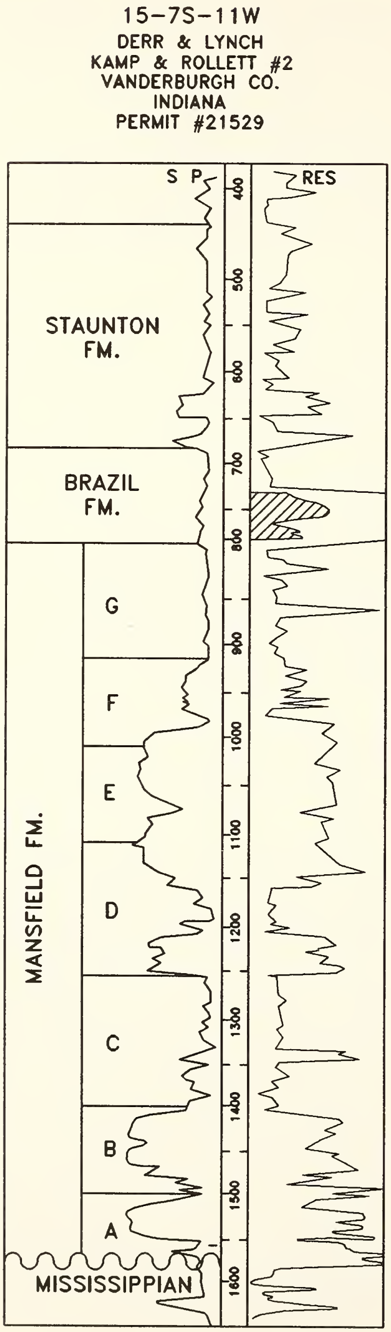

Figure 1. An electric log from a well in Vanderburgh County, Indiana, showing thick limestone in the Brazil Formation and the stratigraphic nomenclature used in this report. The position of the well is shown in Figure 4 at location 4C.

LIMESTONES OF THE BRAZIL FORMATION

Perhaps the only significant mention of limestone in Brazil rocks at the surface is the report of the fusulinid genus *Fusulinella* in an unnamed limestone between the Lower and Upper Block Coals in Clay County, Indiana (Shaver, 1981). The rather common occurrence of limestone in the Brazil in the subsurface initially appeared to be limited to Indiana. However, the authors have found "Curlew" (referring to the Curlew Limestone Member of the Tradewater Formation) on electric logs in Kentucky that are assigned to any of several limestone intervals in rocks equivalent to the upper part of the Brazil Formation of Indiana. One to three intervals of limestone, each less than 10 feet thick, are present in numerous wells in southwestern Indiana and western Kentucky. These thin intervals of limestone in the upper Brazil are principally wackestones that in places contain chert. Packstones are less abundant and typically are not cherty.

This report focuses on thick limestone intervals in the middle and lower part of the Brazil. Samples (well cuttings at 10-foot spacing) in the interval of high resistivity in the Brazil Formation in the Kamp and Rollett #2 well (Figure 1) record almost 60 feet of limestone, which is the thickest limestone interval for which samples were available for this study. The sample studies have been restricted to materials from the Brazil interval in wells on file at the Indiana Geological Survey. Samples from wells in Kentucky were not examined. Samples, typically taken at 10-foot intervals, from many wells in southernmost Vanderburgh County (Droste and Horowitz, 1995) form the basis for the following description of thick limestones in the Brazil interval.

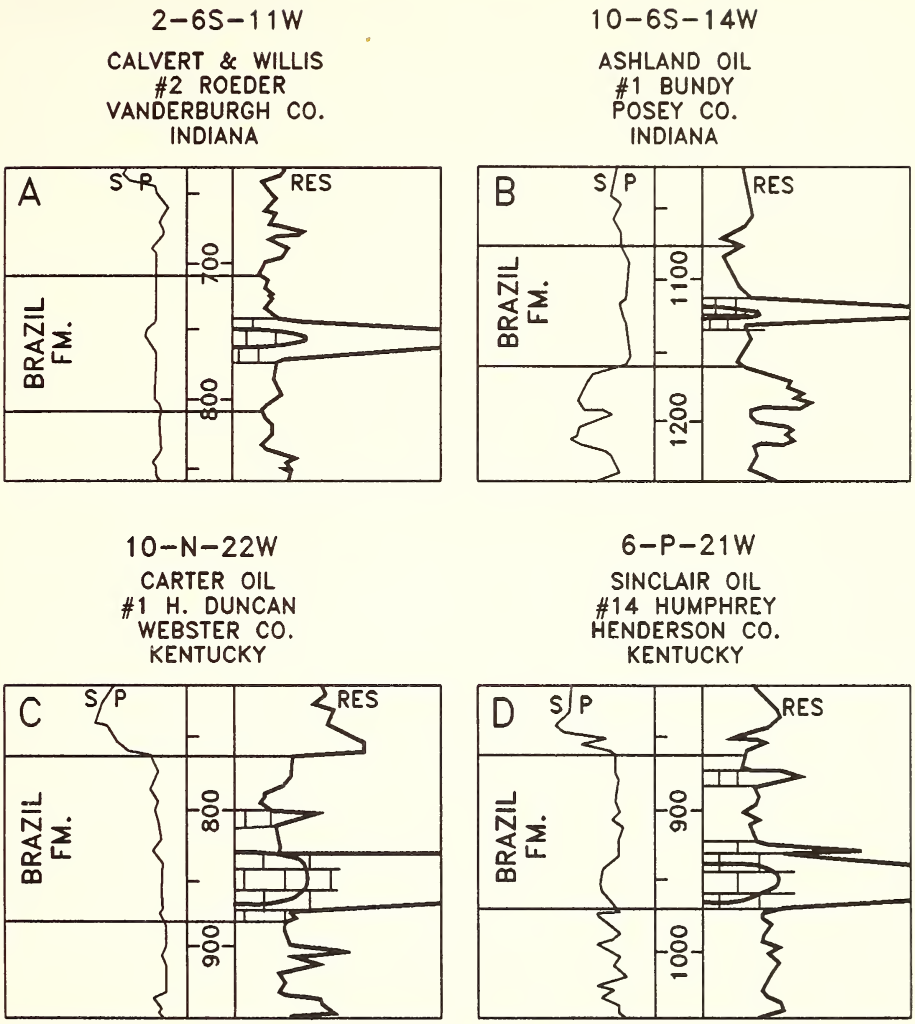

Figure 2. Typical electric logs from wells in Indiana and Kentucky that show limestone intervals from 20 to more than 40 feet thick. The positions of the wells are shown in Figure 4 at locations 2A, 2B, 2C, and 2D.

The biotic skeletal components of the limestone are primarily echinodermal fragments, bryozoans, and brachiopods, a typical late Paleozoic faunal association interpreted as living on shallow marine shelves. Other minor faunal components identified in sample fragments are mollusks, ostracodes, and trilobites. The sample from the basal 10 feet of the limestone contains mainly wackestone with lesser amounts of packstone. This interval is locally cherty, suggesting the presence of silica-bearing organisms, perhaps sponges. The next higher 10-foot interval shows a much reduced abundance of wackestone and a greatly increased abundance of packstone. Chert is seldom encountered in samples of

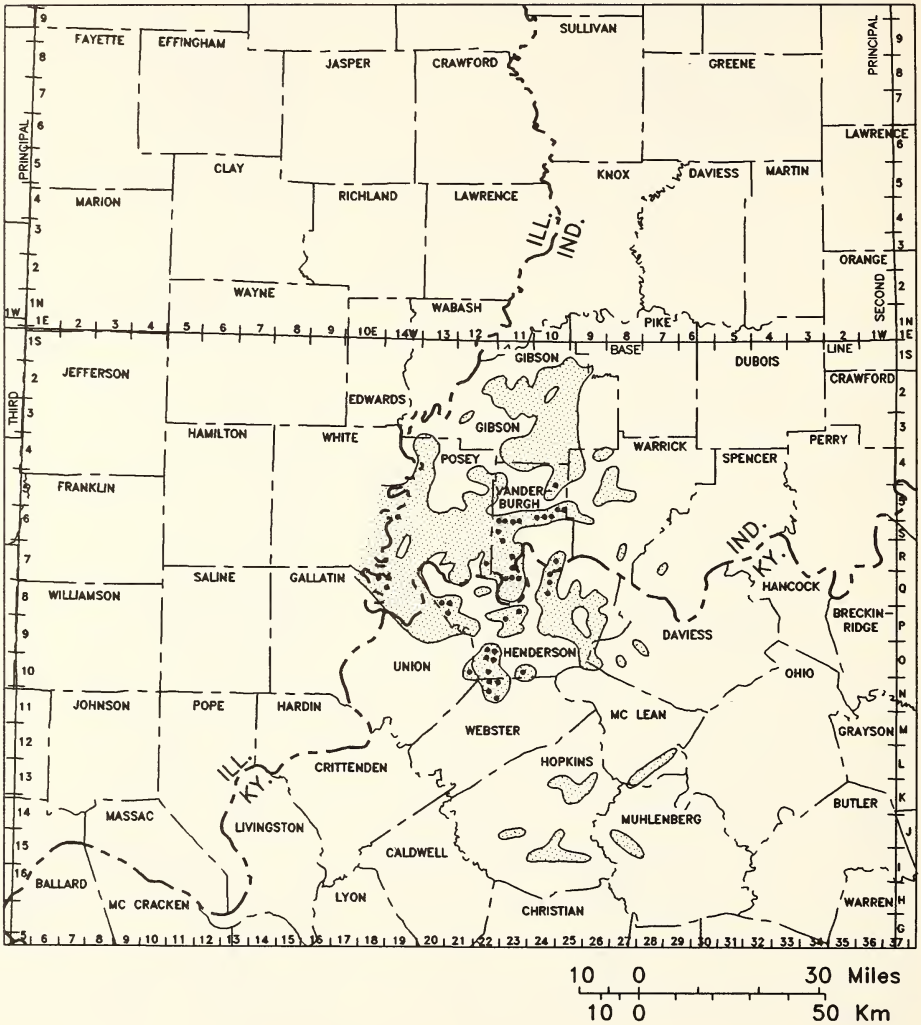

Figure 3. A map showing the distribution of thick limestone intervals in the Brazil Formation. Stippling indicates areas within which at least one well per section (square mile) contains an interval of limestone 10 or more feet thick. Heavy dots show locations of sections in which at least one well has a limestone interval 20 or more feet thick.

the second 10-foot interval. In the sample of the third 10-foot interval, grainstone is almost as abundant as packstone. Limestones more than 30 feet thick are composed mainly of grainstone and have the appearance of typical late Mississippian limestone. However, oolites, common in numerous late Mississippian limestones, have not been observed in the limestones in the Brazil Formation.

LIMESTONE DISTRIBUTION

The unusually thick limestone in the Brazil interval in southernmost Vanderburgh County (Figure 1) is an uncommon occurrence. Several electric logs

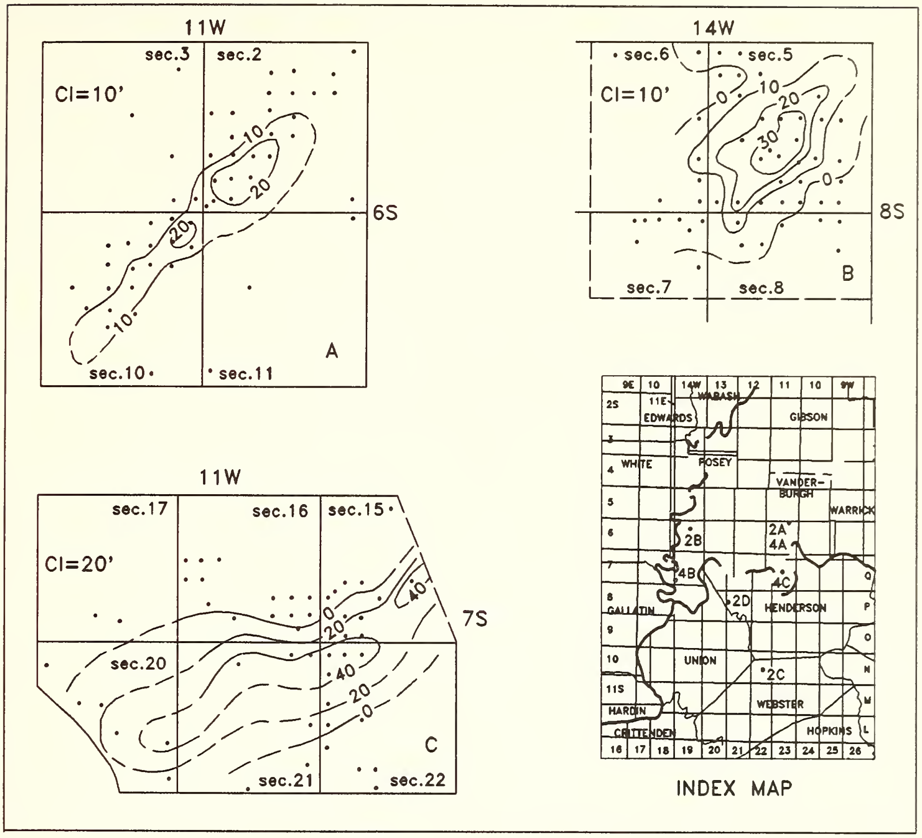

Figure 4. Maps showing the northeast-southwest alignment of the thick limestone bodies in the Brazil Formation of Vanderburgh County (A, C) and Posey County (B), Indiana. Contour interval as specified; dots indicate locations of well log control. For the location of these areas, see the index map.

from wells in other locations show the more typical thickness of Brazil limestone bodies (Figure 2). The thick limestone intervals in the two wells from Kentucky (Figure 2C and 2D) and from southernmost Vanderburgh County, Indiana (Figure 1), are in the lower Brazil. At two locations farther north in Indiana (Figures 2A, 2B), the thick limestone interval is in the middle Brazil. The environment suitable for limestone deposition clearly is younger in the more northerly locations in Indiana.

Limestone intervals ten or more feet thick in the Brazil Formation have a greater areal distribution in southern Indiana than in western Kentucky (Figure 3). The stippling in Figure 3 indicates areas where at least one well per section (square mile) contains an interval of limestone 10 feet or more thick, but within the shaded areas, the thicker limestone intervals are discontinuous even within a single section. The heavy dots (Figure 3) within the stippled areas mark

locations of sections where at least one well contains an interval of limestone 20 or more feet thick.

In several areas in Indiana, closely spaced wells with geophysical logs permit mapping of the distribution of single bodies of thick limestone. Two locations in Vanderburgh County and one location in Posey County (Figure 4) show the shape and orientation of the limestone accumulations. The limestone deposits are elongate in a northeast-southwest direction. These maps clearly illustrate, as noted above, that the thick limestone intervals are discontinuous within the same section.

The limestone intervals in the upper Brazil are thinner and more continuous than the thick limestone intervals in the middle and lower Brazil.

ENVIRONMENT OF DEPOSITION

We can only speculate about the environmental conditions that permitted the formation of the thicker limestone accumulations. Shallow marine shelf deposition was common to this area during the Mississippian Period and, at times, apparently continued into the Pennsylvanian based on the limited biotic evidence available. The fauna also indicates marine waters, and the abundance of echinodermal debris, presumed to be principally crinoidal plates, suggests that crinoidal thickets existed. These thickets would have needed a suitable substrate on which to grow and, in calm weather, sufficient energy in the form of waves and currents to bring in nutrients but not to carry sufficient terrigenous sand and mud to smother the thickets. Kvale, Furer, and Mastalerz (1996) have reported tidalites above the Lower Block Coal Member at the outcrop and in the shallow subsurface in Daviess County, Indiana. This confirms the presence of active tidal currents during Brazil time no more than 30 kilometers from the nearest subsurface carbonate buildup discussed here. The thickets are presumed to have been above storm wave base and probably would have been swept free of some accumulated carbonate or terrigenous debris during storms. The biotic debris is believed to have been produced locally as evidence is lacking for distant transport of skeletal debris to the site of deposition. Electric log correlations suggest contemporaneous terrigenous sands and muds accumulated adjacent to the loci of limestone accumulation.

The suggested environment of deposition for the thick limestone accumulations is as follows. Slight elevations on a shallow marine shelf permitted the establishment and growth of crinoid thickets above storm base. The accumulation of biotic debris accentuated the relief on the sea floor and permitted skeletal organisms to flourish. Accumulation continued until a change in currents or other water conditions led to smothering of the limestone bottoms by terrigenous debris. The northeast-southwest orientation of the elongate deposits may be the result of very minor tectonic control or slight variations in the rates of subsidence from area to area on the sea floor.

SUMMARY

The existence of thick normal marine limestone accumulations in the Brazil Formation clearly documents a strong marine influence in the environments of deposition in southwestern Indiana and western Kentucky during Brazil time. Crinoid thickets apparently colonized slightly elevated sites on the sea floor that were swept by waves and currents sufficient to bring in nutrients but lacking smothering terrigenous materials. Basal wackestones grade upward into packstones. In deposits 30 or more feet thick, the upper grainstones have the appearance of the better-known shallow water limestones of the underlying Mississippian rocks. The Brazil limestones were laterally contemporaneous with and were ultimately covered by terrigenous debris.

ACKNOWLEDGMENTS

The authors thank J.R. Dodd, H.H. Gray, S.J. Keller, and N.G. Lane for the critical review of several manuscript versions of this report.

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HERMAN T. BRISCOE (1893-1960): A SUPERIOR ROLE MODEL IN CHEMICAL EDUCATION AND ACADEMIC ADMINISTRATION

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ABSTRACT: Herman Briscoe was so outstanding in the Shoals, Indiana, public schools that after he finished high school in 1912 and took teacher training courses that summer at Indiana University, he taught in Shoals High School for the next six semesters. At the same time, he took summer courses at Indiana University. He completed an A.B. degree in chemistry with high distinction in 1917. Over the next five years, he served consecutively and briefly as Superintendent of Schools in Shoals, then enrolled in the Officers Training Program in the U.S. Army, was transferred to industrial work on chemical explosives, and, after the war, devoted brief periods of time to teaching chemistry at Stark's Military Academy, Harvard University, and Colby College before returning to Indiana University for graduate work in 1922. He joined the faculty at Indiana University in 1924, immediately after receiving his Ph.D., and became Professor of Chemistry in 1928. From 1925 to 1942, he directed the graduate work of 25 students, seventeen of whom earned a Ph.D. He was also the author or coauthor of 23 scientific papers and one U.S. patent. Between 1931 and 1951, he published several very successful chemistry textbooks. His standing as a chemistry teacher and public lecturer rose correspondingly. With the appointment of Herman B Wells as Acting President of Indiana University in 1937 and President in 1938, Briscoe was promptly selected, along with two other well-regarded faculty members, to serve on Wells' Self-Survey Committee. Many sound and basic changes in the University were recommended by the Committee, and within a few years, all the proposed changes were adopted. Early in this notable transformation, Briscoe became the first Dean of the Faculties. Soon, new responsibilities included his appointment as the first Vice President of the University. Functioning closely together as an administrative team, Briscoe and Wells became recognized as great role models. When Briscoe retired (1959), the most meaningful tribute to his excellence was made by Wells (Gaugh, 1959): Briscoe was the "wisest educational administrator in America." Following Briscoe's untimely death in 1960, a major residence complex was named after him, and the endowed Briscoe Professorship in Chemistry was established. Both serve as tributes to Dr. Briscoe as a role model in chemical education and academic administration.

KEYWORDS: Chemical education, chemistry as a changing science, Herman T. Briscoe, research is second in value only to teaching, structure and properties of matter, student guidance is basic in education, Herman Wells.

Residents of Indiana, especially members of the Indiana Academy of Science, can gain much satisfaction from learning about Herman Thompson Briscoe

(1893-1960). His influence in chemical education and various aspects of university administration as well as his character and ability to guide others in diverse matters was far greater than is commonly realized. The dimensions of Dr. Briscoe's professional life are extensively cited in *The Development of Chemistry at Indiana University 1829-1991* (Day, 1992) and formed the basis, along with other personal and professional appraisals of his life and contributions, of an unpublished biographical sketch prepared by the author in the 1980s (Day, 1987).

EARLY YEARS AND EDUCATION

Dr. Briscoe was born and raised on a farm near Shoals, Indiana. From his earliest years, he evidenced exceptionally high intelligence and pleasing personal qualities. In the modest Shoals High School, he consistently earned high grades while completing the following units of credit: English composition and literature 3, Mathematics 3, Latin 4, German 3, History 1, and Geology ½. After graduation, he took teacher preparation courses in the 1912 summer session at nearby Indiana University and received a Class A certificate for teaching. Beginning immediately, and during the following three academic years, he taught several courses—including Latin—at Shoals High School. Before the end of the 1914-15 school year, he had become the school's Principal. During the summers of 1913 and 1914, he took additional courses at Indiana University.

Briscoe returned to Indiana University on a full-time basis in the summer of 1915, and in October 1917, he received an A.B. degree in chemistry with High Distinction. In addition, he was elected to membership in Phi Beta Kappa. During his two years as a full-time university student, he was active in the strong debating program, which competed with Butler, DePauw, and Earlham. Wendell L. Willkie (1892-1944) was a fellow member of the debate group. In his second full year, Briscoe was President of the University's Indiana Debating League. Among other responsibilities, he was a member of the Indiana Club which emphasized the "ideals of high scholarship, and ambition for proficiency in dramatic attainments" (Day, 1987, p. 2).

At the end of the 1917 summer term, the 24-year-old chemistry graduate became Superintendent of Schools in Shoals! Briscoe served in this role until he enlisted as a private in an Officers Training Program in the U.S. Army in May 1918. The Army transferred him to the Hercules Powder Company in Ohio, where he remained, working on chemical explosives, until February 1919. From then until 1922, the readjusting former soldier held successive teaching assignments at Stark's Military Academy in Alabama, Harvard University, and Colby College in Maine. Finally, he returned to Indiana University to do his graduate work in chemistry (1922-1924). Under the guidance of Professor Frank C. Mathers, he received A.M. and Ph.D. degrees in chemistry.

His 149-page substantive and exceptionally well-written doctoral thesis was entitled "The Properties of Dolomitic Limes as Related to the Properties of the Stones, the Conditions of Burning, and Subsequent Treatments." The principal findings of his research were published in the 1925 issue of the *Proceedings of*

the Indiana Academy of Science. In 1926, a U.S. patent (1,588,253) was issued to Briscoe and Mathers covering some of his thesis work—a process for producing plastic dolomitic limes (Day, 1987, p. 3). In 1927, more of their research on the plasticity of finishing limes was reported in a journal published by the American Chemical Society, *Industrial and Engineering Chemistry.* This early focus on research in the laboratory was influential in shaping the substance and diversity of Briscoe's scientific interests and understanding.

Mounting teaching responsibilities—starting even before the completion of his doctoral work in 1924—diminished the time available for Briscoe's research activities. However, from 1925 to 1942, Briscoe supervised the graduate-level research of 25 different students, and 17 received Ph.D. degrees in chemistry from Indiana University. Most of the research was on the conductivity, chemical reactions, and physical properties of substances in nonaqueous solvents. Briscoe also authored or coauthored 23 publications: seven were in the *Proceedings of the Indiana Academy of Science,* nine in the *Journal of Physical Chemistry,* and the remainder were in various other journals. Two papers were concerned with teaching new concepts on acids and bases, and two others were on manpower management problems in World War II.

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PERSONAL LIFE

The author received many helpful letters from people who knew Briscoe very well during his student years and/or other periods of his later life. The author also had conversations with most of those who wrote to him.

Russel L. Hardy (A.B. '22 and A.M. '23) wrote in 1962 (Day, 1987, p. 40) that "... he [Briscoe] was born with intellectual honesty and this hereditary factor governed his life." Also, in this long and most sincere letter, he concluded that, "Herman's ... passion for an honest, thorough intellectual performance by his teachers ... is no accident nor surprise that it emerged as the dominating factor in his thinking and able planning for Indiana University during the remaining years of his life." At the time of his retirement in 1962, Hardy was Director of Electrochemical Production for the DuPont Company.

Hardy, Mrs. Briscoe (formerly Orah Cole), and Mrs. W.J. Sparks (Meredith Pleasant) provided considerable information about the swift and unexpected marriage of Herman and Orah. As Hardy (on file in the Chemistry Archives) commented, "He [Briscoe] seemed to be almost totally preoccupied by work" and he "... had no personal interest in any young lady at the time." But in May 1928, Meredith Pleasant, a chemistry graduate student, arranged for Orah, her roommate, to have a blind date with the young Associate Professor. Later, Meredith married a fellow graduate student, William J. Sparks, who eventually became one of the most highly recognized chemists in America. But the romantic fire she ignited through the blind date swept on and three months later Herman and Orah were married. During the brief courtship, Herman was elevated to the rank

of Professor of Chemistry. In a letter to the Sparks written in 1960 shortly after her husband's death, Orah stated: "Meredith, that blind date you arranged for us was back in May 1928. We never forgot who brought us together." The Briscoes had four children: Mrs. Stephen G. Ayers (Catharin Alice), Robert Herman, William Cole, M.D., and James Frederick (deceased in early childhood). Each surviving child married and had children.

TEACHING AND TEXTBOOKS

Briscoe's great interest in and effectiveness at teaching chemistry were reflected in the chemistry texts and laboratory manuals that he authored between 1927 and the early 1950s. His initial effort was a set of mimeographed notes on qualitative chemical analysis which focused on "the theories and principles of electrolytic solutions and the properties of the cations and anions which are involved in the various analytical procedures" (Briscoe, 1931, p. iii).

In his textbooks, enough substantive historical background was lucidly woven into the presentations to provide the student with both perspective and understanding. For example, Briscoe wrote "the path of thought which was followed during the centuries of alchemy and the dark ages did not lead toward truth . . ." (Briscoe, 1931, p. 38). To help the students understand more about nature through modern chemistry, he wrote (Briscoe, 1938, p. 38):

> Perhaps they [the alchemists] erred no more than we err at present in following rather blindly a path of thought and reasoning which would lead to a crossroads of uncertainty if we should follow it back to its origin. From this crossroads different routes lead out into darkness of the unknown, and, perhaps, only one of them leads to truth, which is always the ultimate goal.

In this vein, Briscoe elaborated on searching for paths leading to truth through the methods of science. Briscoe (1938, p. 38) referred to:

> John Dalton and the scientific world of his day [who] stood at such a crossroads. They were confronted with the question of the structure of matter. Dalton proved that matter consists of "atoms" by certain experiments in analysis which established the Law of Multiple Proportions . . . Soon after the theory was announced, knowledge of atomic weights began to accumulate. . . .

The first 142 pages of Briscoe's 279-page book were devoted to theories and general principles; the remainder of the book provided informative instruction on procedures along with clarifying explanations and stimulating questions. The book emphasized Briscoe's belief (1938, p. 38):

> . . . that laboratory work proves its worth forces him, to investigate for himself and to explain the results of his investigations in terms of his own knowledge and experiences.

Also of note was Briscoe's widely read 420-page book, *The Structure and Properties of Matter,* which was published in 1935. Briscoe started teaching this

subject in 1925. In 1934, while the book was in press, Robert E. Lyons, Professor and Head of the Department of Chemistry, described the forthcoming book as "a splendid interpretation of what is now known concerning the structure of matter in terms of the chemical behavior of matter" (Day, 1987, p. 4). This book was the first publication from the Chemistry Department that compared favorably with other first-class scientific books.

In the same year (1935), Briscoe's *General Chemistry for Colleges* appeared. In 1937, he published a related treatment on general chemistry, *An Introduction to College Chemistry,* the fourth edition of which appeared in 1949. Following Dean Briscoe's death in 1960, William Briscoe discovered that his father had almost completed either another revision of one of his textbooks or an entirely new chemistry textbook.

Briscoe's philosophy of teaching was reflected within the preface to the last edition (4th) of *General Chemistry for Colleges* (Briscoe, 1949, p. viii):

> Instead of displacing the subject matter of what we may call classical chemistry, new information and new theories are discussed alongside the old. . . . If this practice serves no other purpose, it will help the student see that chemistry is a changing, developing science and, perhaps, will cause him to realize the possibilities that lie ahead of us [as] we extend and revise our present knowledge of the subject.

Even before the highly fruitful H.B Wells - H.T. Briscoe combination in academic planning and administration became acknowledged, Briscoe had gained recognition for his excellence in teaching chemistry as well as for the high quality of his chemistry textbooks (Wells, 1980). Many tributes emphasizing his interest in teaching were written following Briscoe's untimely death. Especially meaningful was the letter written by Frank J. Welcher (A.B. '29, Ph.D. '32), whose doctoral research was supervised by Briscoe: "He had the teacher's voice, the teacher's care of preparation, and above all, the teacher's passionate interest that students should fulfill themselves" (Day, 1987, p. 7). Perhaps the epitome of summations is in the measured words of F.T. Gucker, then Dean of the College of Arts and Sciences at Indiana University (Day, 1987, p. 7):

> When I came to Indiana University 14 years ago [1947] as chairman of the Department of Chemistry I knew Herman T. Briscoe through his books on general chemistry and on the structure and properties of matter. Like many others throughout the country who used these books in their classes, I admired the clear, lucid, and interesting style in which he presented chemical facts and theories.

The highly respected Gucker served as Chairman of the Department of Chemistry for four years before he became a Dean, a position he held until his age necessitated retirement from administrative responsibilities. One section of Briscoe Quadrangle (a dormitory complex) is now named in memory of Dean Gucker, who died in 1973.

SPEAKING ON CAMPUS AND THROUGHOUT INDIANA

Dr. Briscoe accepted scores of invitations to address various local and other largely in-state groups and organizations. The topics were substantive, and they were usually concerned with chemistry or science in general. A number of examples should suffice to show the breadth and scope of these talks. In 1925, he spoke to the Bloomington High School Science Club on "The Structure of the Atom." In 1928, he spoke before the Physics and Chemistry Sections at the Indiana State Teachers' Convention in Indianapolis on "The Electron Theory of Valence." "Atomic Theories" was the topic of his talk to the Indiana University Physics Club in 1933. In 1934, he addressed the campus YWCA on "Conflicts between Science and Religion." According to the campus newspaper (*Indiana Daily Student*), Briscoe "think[s] there exists no conflict between science and religion." In 1934, he participated in a symposium on "Teaching Methods in General Chemistry" at a regional meeting of the American Chemical Society in Louisville. In 1936, he spoke at the annual meeting of the Indiana State High School Chemistry Teachers' Association at Purdue. His topic was "Causes of Students' Difficulties in Chemistry." In 1937, under the auspices of the Indiana Section of the American Chemical Society, his topic was "Cosmic Rays" before a science club meeting at Hanover College. In 1938, as the new Chairman of the Department of Chemistry, he presented a paper at a Bloomington meeting of the Indiana Section of the American Chemical Society on a new perspective on "The Place of Chemistry in Indiana University." In 1939, he spoke twice at the Indianapolis Center of the Extension Division. The topics were "New Products of the Chemical Industry" and "Chemistry under Nazism."

SELF-SURVEY COMMITTEE

Soon after Herman B Wells became Acting President of Indiana University on 1 July 1937, he instituted a planning process by establishing a Self-Survey Committee. On January 15, 1938, the Trustees approved the appointment of three highly regarded faculty members to the committee—Herman T. Briscoe, Professor of Chemistry and a dedicated member of the College of Arts and Sciences; Wendell W. Wright, Professor of Education; and Fowler V. Harper, Professor of Law. Harper was designated Chairman, and Briscoe was Secretary. Of the three, Briscoe was the only alumnus of Indiana University. Wells stated in his autobiography (1980, p. 97) that "Wright was conservative, Briscoe was moderate, and Harper was liberal." All three worked together efficiently and with great thoroughness, understanding well the high importance of their assignment. No diminution in teaching load and related academic duties was noted for Briscoe and presumably the same applied to the other two Committee members.

Naturally, the Committee solicited the views of faculty members and others, both locally and nationally, on the best objectives for the University. As Clark (1973, p. 372) said:

> The organizational chart projected by the survey committee was a study indeed in a step from rigid simplicity and personal control to one of complexity. In fact the committee's charted proposal was more a prescription for revolutionizing the administrative system of the university than anything of the sort had been since the founding of the institution. Not only was this branch of university government to be updated, but it was to be brought into proper relationship with both the institutional and professional aims and objectives set forth in the general program.

In addition to proposing major administrative changes, considerable attention was given to faculty development and to strengthening both teaching and research. The Committee emphasized that Indiana University was far behind other Big Ten Schools in its level of support for faculty research by pointing out that in 1936-37 Indiana University spent only 1.7 percent of its total budget in support of original research as compared to an average of more than 10 percent at 135 publicly-controlled universities listed in the biennial survey of the U.S. Department of Education. The Committee also stated in their report that a marked increase in the effectiveness of the University would require a rigorous and comprehensive program of faculty recruitment to attract and hold the most promising talent in teaching and research.

One of the major recommendations of the Committee was to establish the office of Dean of the Faculties. The recommendation was promptly approved. The first Dean was Dr. Briscoe. On May 31, 1940, President Wells sent a mimeographed letter to every faculty member announcing the appointment effective the next day. The specific responsibilities of the Dean of the Faculties were listed as follows (Day, 1987, p. 21):

1. He will share with me general responsibility for the academic administration of the university and will receive and act upon all academic proposals and problems during my absence.
2. He will share with me responsibility for public appearances.
3. He will be an *ex officio* member of the general university standing and special committees unless at the time of the appointment of the committee, it is specifically stated that he will not serve.
4. He will be a member of all Faculties of the University, as is the President.
5. He will assume from time to time such additional responsibilities as may seem desirable.
6. He will continue to be in charge of the guidance program [This evolved from the Self-Survey Committee in May 1939. As stated by Clark (1977, p. 33): "Herman Briscoe almost single-handedly devised an advisory system which supplanted an older plan and prepared the way for instituting the Junior Division [now University Division]."]
7. He will continue as Chairman of the Department of Chemistry until a successor can be selected, seeking such relief there at present as possible for him to effect.

Many laudatory expressions of approval to Briscoe's appointment were immediately forthcoming. For example, Lee Norvell, then Associate Professor of English and Radio Director, wrote: "I honestly believe that his appointment will

receive the unanimous approval of the faculty. I know of no one else of whom this could truthfully be said" (Day, 1987, p. 21). In 1941, Briscoe's title was changed to Vice President, Dean of the Faculties. This change met with equally strong approval.

The Self-Survey Committee began deliberations early in 1938. By December 1939, Briscoe, Wright, and Harper had presented their full report to the faculty for thorough study and debate. In his comprehensive analysis of the report and its effects on the University, Clark (1973, p. 382) wisely concluded:

> For the university the immediate result of the self-study was the aid it rendered in a realignment of the institution to recognize new educational opportunities and to meet the needs of the near future. The luck of time and history favored Indiana University in 1940. Its administration and a major portion of its faculty no doubt became aware of the currents in post-Depression America of educational reform and were emotionally and intellectually prepared to accept change with little loss of momentum or desecration of tradition.

If Dr. Briscoe had not been afflicted with serious and lingering health problems (he had a cerebral hemorrhage in 1945, when he was only 52), many individuals have speculated that his remaining contributions would have been substantially greater, but his role on the Self-Survey Committee and in the adoption and implementation of its recommendations were scarcely surpassable.

CHAIRMAN OF THE DEPARTMENT OF CHEMISTRY

On March 22, 1938, Acting President Wells became President of the University. During his first nine months of service, major planning and systematic changes toward restructuring and energizing the institution, particularly in matters of academic organization and higher goals, were implemented. In August 1938, Dr. Lyons was almost 69 year of age, and he had been Head of the Chemistry Department since 1895. "On 4 August 1938 Dr. Robert E. Lyons submitted his letter of resignation as Professor of Chemistry and Head of the Department of Chemistry effective August 11, 1938 . . . ." (Day, 1992, p. 250). In his brief and courteous letter, Lyons strongly recommended that his successor should be Dr. Briscoe. The resignation and the recommendation were accepted by the Trustees on August 13. The making of an essentially new department began when Briscoe was designated Chairman.

Besides this new responsibility, his regular teaching duties, and his pressing service on the Self-Survey Committee, more "advancements" lay immediately ahead (Day, 1992, pp. 253, 255):

> Briscoe was soon assigned to other heavy responsibilities. Specifically these were under the title of Special Assistant to the President. This role was announced by President Wells in May 1939. Then on 1 June 1940 he became the first incumbent of the newly created office of Dean of the Faculties. One year later, shortly before he was succeeded by a new chairman of chemistry, his title was changed to Vice President, Dean of the Faculties.

> Briscoe was keenly aware of the concurrent developments in the American Chemical Society on the professional training of chemists. Already a program of the ACS was underway for the certification of institutions for such training. Naturally he wanted his department to qualify for certification as soon as possible. In essence he worked understandingly with the university administration to transform the department.

Aware of weaknesses in his Department, he moved promptly and wisely. For example, on August 26, 1938, Briscoe informed Dean Stout (College of Arts and Sciences) that William Degnan, a recent graduate at Yale, had accepted an instructorship at Indiana University effective immediately. Degnan was the first "outsider" appointed full-time to the chemistry faculty in the 20th Century!

An illuminating example of Briscoe's administrative genius is found in his twenty-page double-spaced report to President Wells on the Department of Chemistry (Briscoe, 1938). The one-paragraph transmittal letter read:

> I enclose herewith a statement concerning the present status and needs of the Department of Chemistry. In this I have attempted to outline my evaluation of the present department in all respects and to state conservatively my estimate of its immediate needs. It is my opinion that the department should take immediate steps to place itself on a par with some of our neighbors such as Northwestern, Nebraska, and Iowa and plan for a future when we may rival even our superior neighbors such as Illinois and Wisconsin. I should be glad to discuss this report with you at your convenience.

The report had eight sections. The titles and brief commentaries follow:

Section I. ADMINISTRATION AND ORGANIZATION OF THE DEPARTMENT. Considering the question of "the organization of chemistry at Indiana University as a school instead of a department of the College of Arts and Sciences," he wrote that: "It is my opinion that the work of the department is too intimately connected with the college and with the professional schools to allow organization upon an entirely independent basis." After further characteristically thoughtful commentary, he stated:

> It is my opinion that the department should be administered through a chairman appointed by the President and Board of Trustees for a definite period of time with the understanding that reappointment is possible and probable in the event of satisfactory service. The limitation placed upon the term of office should make change easy when it becomes desirable. The chairman should consider his entire staff as a committee for the consideration of the fundamental policies of the department with respect to curriculum, general departmental business, and student affairs. A good chairman who has sound ideas concerning such policies should be able to carry his staff along with him. If he cannot, he should be able to subject his own ideas to severe criticism and, perhaps, to alter them until they are more nearly in agreement with those of the committee as a whole. The chairman should assume the responsibility of carrying out the policies and regulations passed on to the department from the administration of the university and more particularly from the administration of the college. Only in matters which are left to the consideration of the department or in dealing with problems which arise in the department, [sic] should the department as a whole assume active participation.

The new (less than 90 days) Chairman had focused on his new responsibilities. This section was followed by his reflections on the Department's activities over the past several decades.

Section II. THE OBJECTIVES AND FUNCTIONS OF THE DEPARTMENT. The first Chairman concluded that "the department has four functions in connection with its position in the College of Arts and Sciences." He pointed out that first: "It must act as a service department for certain professional schools—training in chemistry on both the lower and the higher level of the curriculum." Second, he concluded that the Department "should offer to all the students of the university general courses in chemistry which will fit into the liberal education program of the College of Arts and Sciences." He emphasized that "the department should offer a special course to those students." Third, the Department should "provide professional training for the students who will become chemists in the industries." Finally, he noted that: "The department must provide for original work in the field of chemistry. Provision must be made for a modern and adequate program of graduate instruction, for the proper control and guidance of the research work done by students in the graduate school, and for the scholarly studies, investigative work, and writing of its staff. This function should be second to no other function in the department."

Section III. THE CURRICULUM OF THE DEPARTMENT. Almost one page was used to point out the deficiencies in the chemistry curriculum at that time. Briscoe summarized this section by saying: "our curriculum stresses the practical aspects in chemistry and makes little attempt to provide the necessary requirement for original and scholarly work." Then, he listed some very important changes that would have to be made at the undergraduate and master's levels. In beginning his analysis of the needs at the upper graduate level, Briscoe wrote that the upper graduate level "should be one that is designed for the few . . . . I would not go so far as to say that we should abandon the A.M. degree. We should, however, place emphasis upon a curriculum designed for the Ph.D." Briscoe wanted these basic but major changes made as quickly as possible.

Section IV. THE STAFF OF THE DEPARTMENT. The new Chairman wrote in effect that in all changes "we must have in mind primarily the graduate work in the department and the productiveness in research by members of the staff." The relatively long discussion devoted to enlarging the chemistry faculty is impressive. In the areas of organic chemistry and physical chemistry, Briscoe listed 14 persons whom he considered to be "representative of the kind of individuals whom I think Indiana University should seek." He expressed the opinion that "some of them, at least, might find an offer from Indiana University attractive." Those named included R.L. Shriner and Henry Gilman in organic chemistry and Henry Eyring and Farrington Daniels in physical chemistry. In the search for a Chairman to succeed Briscoe so that he could devote all of his time to central administration, the University was indeed fortunate that Shriner accepted the offer to join the faculty as Professor of Chemistry and Chairman of the Department.

In this section, Briscoe also referred to the need for additional new faculty members at lower academic ranks. Included was a person to teach and do research in biological chemistry. He pointed out that this individual would strengthen both biology and chemistry. (The appointment also added strength to the move of first-year dentistry to Bloomington in 1940-41.)

Once more, Briscoe emphasized that the persons selected should be "the graduates of institutions other than Indiana University." Concerning their credentials and promise, he emphasized that: "They should be selected also upon their records and promise along the line of research."

Section V. SPACE. His analysis and recommendations on space requirements were based on expectations for the future. Briscoe wrote: "With the growth of the department and the expansion of its program more space should be made available in the east wing now occupied by the Department of English." Aware of the dire needs for improvements in space as well as in general modernization in physical chemistry, he stated that: "The space on the third floor of this wing should be converted into a modern laboratory for physical chemistry."

Section VI. EQUIPMENT. Because he had high expectations for the Department, Briscoe wrote: "At present the equipment is entirely inadequate for undergraduate instruction, and there is practically nothing in the department in the way of first class modern equipment for research. . . . The appropriations of the department in the past has done little more than replace the chemicals, glassware, and supplies consumed during the previous year." His report on the dire needs in the Department reflected the thoroughness of his analysis.

Section VII. MISCELLANEOUS RECOMMENDATIONS. In this part of the report, various other matters were discussed. These matters included: "Funds from outside the university in support of research" (with elaborations on the need); Service to the People of Indiana; Research Directed at the Solution of Indiana Problems; and the value of adding "to the department a man trained in the field of nuclear chemistry." Briscoe felt that a nuclear chemist would be a valuable addition to the Department in view of the research program in physics and the possibility of tying these two important fields together.

Section VIII. LABORATORY FEES. His discussion of the problems in this area was concluded with the words: "Increased laboratory fees are recommended only in the event that the university is unable to provide for laboratory needs from other sources of income."

Section IX. CHANGES IN THE DEPARTMENT SINCE SEPTEMBER 20 (1938) AND PLANS FOR THE PRESENT YEAR. The final section of the November 1938 report was a listing of different internal actions that would advance the Department:

1. Representatives of leading companies should be invited to interview graduating students for employment.
2. Tuesday mornings were set aside by the Chairman to talk with students individually in his office to offer "guidance in the formation of plans for the future."

3. Because a "survey of the curriculum has not been made for many years," the Department was considering revisions "along the lines mentioned previously in this report."
4. Attention was being given to ways to "attract some conferences and meetings of importance to our campus."
5. A departmental committee was considering how the present standards of graduate work might be changed "to elevate these standards to a higher level of accomplishment."

Even before Dr. Briscoe succeeded Dr. Lyons, a central tenet of his thinking was that the leadership of the Department had to come from a highly qualified person with a good national standing in chemistry and with some promise of administrative capability. As Briscoe prepared to relinquish this post, he noted that his successor's principal education in chemistry and related areas should have been obtained elsewhere (Day, 1992, p. 281):

> Characteristically Briscoe moved quietly in searching for his successor. He sought and listened to the views of faculty members in the department and trusted leaders in chemistry elsewhere. This culminated in the selection and attraction of Dr. Ralph L. Shriner, the right person for the times and the needs of the department. He was a productive, resourceful, and widely recognized leader in both the academic and industrial world of chemistry.
>
> The public announcement of the selection was made by President Wells in the IDS [campus newspaper] of 15 July 1941. . . . The final decision was made by Briscoe and Wells in May. The board approved the appointment on 2 June and the formal notification [to Shriner] was made by Wells a week later.

In retrospect, one might say this about Briscoe's three-year chairmanship (Day, 1992, p. 279):

> He led the university in starting the department toward an ever expanding level of productivity in chemical education and research. Its stature and respect in professional chemistry acquired increasing significance. Within less than four decades it became a truly major department in this country. In this development all areas of the university shared equally in deriving the benefits from his wisdom, devotion, and credibility.

Briscoe's nature and the basis for his overall effectiveness were aptly expressed in the words of the trustworthy administrative secretary of his last sixteen years, Lucile B. Languell (Day, 1992, p. 280):

> He was not only a great administrator and teacher but he was also a true friend to all who sought his valuable advice. He was completely unselfish, always thinking of the interests of others, and it was his kindly ways that brought so many people to him for help with their problems. Among these people were not only faculty members but staff employees as well.

UNIVERSITY ADMINISTRATIVE RESPONSIBILITIES

After Dean Briscoe's principal responsibilities in the Department of Chemistry had been transferred to others (the end of the summer of 1941), he

discreetly remained aloof from departmental administrative matters, but he retained his academic office-laboratory in the chemistry building for several years. With pleasing frequency, he came to his office in the chemistry building from his main office in Bryan Hall (Administration), walked about in the building, and conversed with others. Obviously, he enjoyed being with chemists. He also made notable use of the chemistry library, which was directly below his office-laboratory. Briscoe's stroke in 1945, the consequent partial health impairment, and the increasing space needs of the Department ultimately required that he surrender his office-laboratory for other uses.

Between approximately 1941 and 1960, Day (1987, p. 22) noted that:

> Many academic and administrative developments occurred which bore the deep imprint of Dean Briscoe's counsel and had his creative participation. Several had been included in some degree in the deliberations of the Self-Survey Committee. Those issues in which he was notably involved included the Junior (University) Division, U.S. War Manpower Commission, School of Health, Physical Education, and Recreation (HPER), School of Optometry, School of Music, Graduate School, orientation of foreign students for study in America, Special Administrative Committee of the Presidency, and Academic Freedom.

In addition to these creative activities, additional responsibilities existed that were ongoing and equally demanding—budget preparation and control as well as meetings with the President of the University and school deans and departmental chairpersons in the College of Arts and Sciences.

Budgets. In the new administrative framework, budget preparation and the control of approved budgets became the responsibility of the Dean of the Faculties and Vice President. Every academic budget was under Dr. Briscoe's general control, but he exercised his authority so gently and constructively that departmental chairpersons and school deans could only conclude that his judgment was always fair and appropriate. For example, in 1983, then Professor Emeritus Harry Sauvain of the School of Business wrote to the author on his experiences as Acting Dean of the School of Business (Day, 1987, p. 23): "When I went to him with a proposal or a problem he would listen patiently while I told him all about it . . . I always went away feeling that I had had a fair hearing and that the decision was a just one."

Junior Division. As early as the mid-1920s, Briscoe believed that thoughtful student guidance was basic to education. Typical of his position was a 14-page memorandum which he sent to President Wells (written on October 3, 1941). The memorandum was "a proposal for the organization and administration of a lower division [in the University] consisting of the first year. It is based very largely upon the organization which I saw in operation at Yale and upon the organization at Nebraska."

Characteristically, the memorandum was prefaced with an "Introductory Statement" in which Briscoe emphasized (1941, p. 1) that, for students, "The first and sometimes even the second year are years of adjustment and explo-

ration; the last years are, and should be, years of concentration in one field . . ." Central to the entire presentation (Briscoe, 1941, p. 9) for establishment of a lower division was the following summation:

> Higher education must . . . have two primary objectives:
> (1) to broaden the base of a student's general education and
> (2) to provide training in some specialized field.
>
> The lower division must promote both of these objectives. It must extend his [and her] study into fields that he [and she] has not entered in high school or carry on studies previously undertaken to new depths. It must also promote the second objective sometimes getting him [or her] started on the ground floor of a specialized course, but more often in assisting him [or her] to find his [or her] field of specialization...

These objectives were amplified for the President in ten concluding statements labeled "The Essential Provisions of a Lower Division." The final provision specified that (Briscoe, 1941, p. 13): "Complete responsibility for the work of freshmen must be vested in the administration of the lower division, subject to general policies that are established by the general faculty of the university."

Briscoe's 1941 proposal to President Wells was adopted by the faculty after the name was changed to Junior Division. Immediately following the faculty action, the Board of Trustees gave their approval (Day, 1987, p. 24):

> The new Junior Division became operational almost at once, with Wendell W. Wright serving as the first dean. The first students enrolled in May 1942. . . . Over the years its structure and function remained essentially intact, but in 1970 the name was changed to University Division.

OTHER SPECIAL ADMINISTRATIVE SERVICES

Throughout Briscoe's approximately two decades of administrative service to the University, numerous other special contributions were made by the Vice-President and Dean of the Faculties.

War Manpower Commission. In December 1942, a year after this country had entered World War II, Paul V. McNutt, then Administrator of the Federal Manpower Commission, requested President Wells to release his long-time friend Briscoe for a limited time period to serve in Washington to help formulate policies on the use of academic institutions in the war effort. This request was promptly granted. In Washington, Briscoe represented all the institutions of higher learning in this country which were involved with Federal training programs. His work required numerous arduous round trips by train to Washington; in the interim, Prof. A.L. Kohlmeier served as Acting Dean of the Faculties. The demands placed on Briscoe in Washington heightened. By request, his service to the war effort was extended when Dean Briscoe was named Director of the War Manpower Training Bureau, placing him in the forefront of postwar educational planning. Professor Ford P. Hall relieved Dr. Kohlmeier and served as Acting Dean

until Briscoe's duties in Washington ended. The precise length of his service in Washington is unclear, but Briscoe's entry in *Who's Who in America* for 1958-59 states that he was a consultant to the Commission from 1942 to 1944.

School of Optometry. In 1945 in response to requests for the establishment of a School of Optometry, President Wells asked Vice-President Briscoe to prepare a report that would serve as the basis for policy discussions. Within the year, Briscoe had made a coast-to-coast survey. After considering all the facts, he concluded that the University had the responsibility to provide such training and that the programs in the School of Optometry would not conflict with those in Ophthalmology in the School of Medicine. However, owing to some persistent objection by the Indiana Medical Association and some ophthalmologists, Briscoe deferred action so all the alternatives could be considered. Ultimately, the issue was taken to the Indiana General Assembly, and a bill authorizing the School of Optometry was passed almost unanimously. Preprofessional work started in 1951-52. The first faculty member and essentially the creator of the School was Henry W. Hofstetter, who arrived in 1952. Until its designation as the School of Optometry in 1975, the program operated as the Division of Optometry in the College of Arts and Sciences. Until his retirement from administrative responsibilities in 1959, Dean Briscoe was responsible for the budgetary affairs of optometry at Indiana University (Day, 1987, p. 26).

School of Health, Physical Education, and Recreation. Early in 1945, Vice President Briscoe reported that the administration was considering consolidating all physical education programs into a single division under the administration of an academic dean (Clark, 1977). This change had been recommended by the Self-Survey Committee in 1939 and was approved by the general faculty in 1940. Although some uneasiness and opposition to the consolidation existed, the confidence-inspiring nature of Dean Briscoe aided the change. Support for a unified division was strengthened by Wendell Wright of the School of Education, who had also been a member of the Self-Survey Committee. The influence of Wright, Briscoe, and Wells contributed to the faculty consensus that led to the establishment of the new school in September 1945. Willard W. Patty became the first Dean (Day, 1987, p. 26).

School of Music. Dean Briscoe helped in the re-creation of the School of Music. The key element was the appointment of Wilfred C. Bain as Dean of the School in 1947. Close communication always existed between Briscoe and Dean Bain. These two opposites (in some respects) fit together in a productive way that was reminiscent of the match between Briscoe and Wells. The net effect was succinctly and poignantly expressed by Dean Bain at the time of Dean Briscoe's death in 1960 (Day, 1987, p. 27):

> Herman Briscoe was for me a distillate of human goodness with a wealth of wisdom. He was a creative thinker not only as a scientist but also as a patternmaker for the education of youth. As an academic elder brother he sought to administer unselfishly to the needs of each member of his academic family. As a trusted friend he exemplified the nobility of intellect as he dealt with problems outside the field of his immediate interest.

The Graduate School. The author noted in 1987 that (Day, 1987, p. 28):

> The three major architects in moving toward a redirecting and vitalization of graduate work were the new President Wells, the new Dean of the Faculties Briscoe, and the blunt and determined Dean of the Graduate School Fernandus Payne. All three were graduates of Indiana University and native Hoosiers. With the ascendancy of Wells to the presidency in 1938 they became an effective team, each with unique talents, that operated toward common goals.

Although these three men recognized the need for greater centralization of direction in the various graduate programs, several significant barriers to centralization existed which could not be quickly removed (Clark, 1977, p. 353).

In 1947, Dean Briscoe presented President Wells with a plan in which as much of the graduate work at the University as possible would be centrally coordinated and some degrees combined to minimize duplication. He proposed that the professional schools be granted greater freedom in setting their specialized standards. Realizing that this proposal would arouse concern and conflict, Briscoe tried to include the changes in planning going on as a result of the approaching retirement of Dean Payne. Nevertheless, implementation of the plan was delayed due to effective opposition. Some coordination was attained, but full implementation did not occur in Briscoe's lifetime.

By 1989, while Thomas Ehrlich was President of the University, extensive centralization between all the campuses of Indiana University had been achieved through the creation of the University Graduate School. Heading the program was George Walker, Professor of Physics and Vice President for Research and Dean of the University Graduate School. These changes required more than four decades, surely exceeding the original expectations. The changes that occurred, along with many other developments, are monuments to these two sons of Indiana—Herman Wells and Herman Briscoe.

Special Administrative Roles. At times, Dean Briscoe and others were asked to substitute for an absent President Wells (Wells, 1980, p. 302):

> Owing to Vice President Briscoe's natural closeness to the presidency of the university the frequent absence of the president from the university added to Briscoe's responsibilities. In October 1947 this became a major responsibility. Near that time an urgent request was made upon President Wells to head for some time (six months) the Education and Cultural Branch of the United States Military Government in Germany. The University Board of Trustees granted the request. To make this practicable the Board designated an administrative committee consisting of the President of the Board John Hastings, and Vice-President Briscoe, Wendell Wright, and Joseph Franklin. During this long interim many decision-demanding issues naturally arose and all were handled well by the committee, but without doubt the extra burden on Vice-President Briscoe was heavy.

During Briscoe's years in administration, the research, publications, and public statements of faculty members were occasionally the basis for criticism which in effect was a challenge to responsible academic freedom. "As frequent advis-

er to President Wells and a builder of a strong faculty, Dean Briscoe was always concerned in the maintenance of the university position" (Day, 1987, p. 29). One of the notable statements, which reflected Briscoe's feelings, was made by President Wells in a letter on May 16, 1955, regarding the work of Alfred Kinsey. The relevant portion was quoted by Clark in 1977 (p. 291): "Indiana University stands today, as it has for fifteen years, firmly in support of the scientific project which has been undertaken and is being carried on by one of its eminent biological scientists, Dr. Alfred C. Kinsey."

RETIREMENT AND FAREWELL REMARKS

On June 30, 1959, and in accordance with the retirement policy which he helped establish more than twenty years earlier, Dean Briscoe retired from administrative responsibilities. Earlier that month the President wrote to Briscoe: "the Board of Trustees of Indiana University approved your administrative retirement on June 30, 1959 from the position of Vice President and Dean of the Faculties, with the understanding that you will continue as Professor of Chemistry and will, in addition, serve as Consultant to the President, on a part-time basis." The special letter then continued (Day, 1987, p. 30):

> It is the unanimous feeling of the Trustees of the University that the above-indicated approval for administrative retirement is given with the greatest reluctance. At the same time the Board extends its most sincere congratulations and appreciation for the splendid record you have made at Indiana University which has resulted in such great achievements for the benefit of the institution. The Board also is most happy that you will be able to continue in service to the University.

The pending change in Briscoe's status was known well before his actual retirement. In August 1958, as Chairman of the Department of Chemistry, the author wrote: "we would be delighted if you would be willing to come back into the Department of Chemistry following your retirement next year even if it should be on a very limited time basis" (Day, 1987, p. 30). President Wells was also informed of the Department's interest. In his response, Wells stated that "some of us also have had in mind asking Dean Briscoe to direct the University-wide effort in program development or to work in some similar general administrative capacity" (Day, 1987, p. 31). Thus, after July 1, 1959, the retired Dean and Vice President moved to a different office—but just as close to the President's Office—as Consultant to the President. There, he thoughtfully prepared commentaries and made suggestions on many administrative matters. As usual, he conferred and counseled with innumerable faculty and administrative colleagues.

Dr. Briscoe's health remained fairly good during the first year of his retirement. The winter months were spent with Mrs. Briscoe at their home in Florida. Indeed, Mrs. Briscoe wrote that in the summer of 1960: "He seemed glowing with health and good spirits for the first time in several years" (Day, 1987, p. 32). This period of good health continued until September 27, 1960, when

he suffered a coronary occlusion in his "retirement office" in Bryan Hall in Bloomington. He was promptly taken to the IU Medical Center in Indianapolis. On October 6, 1960, a second attack occurred, resulting in his death two days later.

On October 11, 1960, funeral services were conducted in Sarasota, Florida, where the Briscoes had owned a home since 1953. Simultaneous memorial services were conducted in Alumni Hall on the Bloomington campus. Participants in this service included the local Berkshire Quartet, Rev. W. Douglas Rae, John W. Ashton, Frank T. Gucker, Albert L. Kohlmeier, and the University Singers of the School of Music. President Wells and the new Dean of the Faculties Ralph L. Collins had gone to Florida to be with the Briscoe family and to attend the funeral. The *Indiana Daily Student* reported on that day that: "Not since the death in 1955 of Dr. William Lowe Bryan, President Emeritus of the University, have similar honors been paid to a member of the university staff" (Day, 1987, p. 32).

The November 1960 issue of *The Indiana Alumni Magazine* eulogized Dean Briscoe in an appropriate double-page tribute. These memorable words were spoken by his long-time close friend and colleague President Wells (Anon., 1960, p. 7):

> Dr. Briscoe served the University superbly as student, teacher, and administrator. Transcending this brilliant record was the influence of his rare spirit upon the University. He was a selfless man, never asking for personal recognition or power; yet because of his great wisdom and quiet strength his advice was eagerly sought by his colleagues. He had an unusual quality of personal loyalty and an exceptional capacity for friendship. He will ever live in the life of the great University he helped to build and in the hearts of his friends. We shall not look upon his likes again.

In the column "Late News Happenings," a statement appeared that "Plans have been announced by the University to establish through gifts an endowed chair in chemistry to be known as the Herman T. Briscoe Memorial Professorship." The planning and the "soft sell" program resulted in an endowment to which 315 individuals and corporations made contributions. Dr. Dennis Peters presently is the Herman T. Briscoe Professor of Chemistry.

This review of the "Superior Role Model" should logically conclude with a discussion of the retirement event and the substance of the remarks and actions of that memorable evening. Dean Briscoe's public retirement occurred in the Alumni Hall on June 5, 1959, at a banquet sponsored by the Indiana Alumni Association. Following dinner, two notable events occurred—the poignant, brief address given by the retiring Dean and the presentation of Marie Goth's impressive portrait of Briscoe to the University (Figure 1).

His long experience as well as his deep-thinking, problem-solving nature were evident in every part of his address. Dean Briscoe focused on the basic responsibilities of the University. Following a succinct historic introduction, his first penetrating remarks were entitled "We Face a Problem." Briscoe (1959, p. 8) stated:

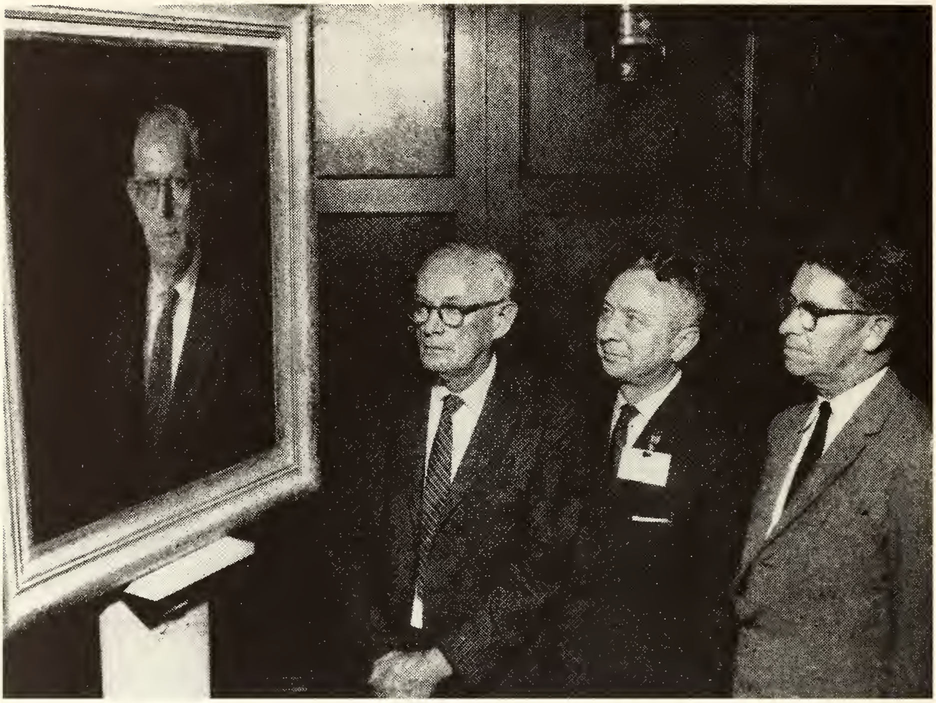

Figure 1. Beside the Briscoe portrait (left to right): H.T. Briscoe, Verling Votaw, Briscoe's former student and President of the Indiana University Alumni Association in 1959, and Ralph L. Collins, who succeeded Briscoe as Dean of the Faculties.

> As a University, we face the problem of how we can best perform our function, which we have said is to promote the progress of our society. There are many ways in which a university may aid the state and its citizens but, in my opinion, we can best perform our function through teaching and research, or in some areas such as art and music, by creative work.

Dean Briscoe (1959, p. 8), as part of this focus, emphasized the importance of teaching skills and "how to do a job and how to do it well." When elaborating on teaching responsibilities and goals, he stated (Briscoe, 1959, p. 8):

> The student should be made to realize his responsibility to his fellow men and to society in general. To properly assume this responsibility, the student must have some knowledge and appreciation of the world of science and of nature and his own place in it. He must have an acquaintance with the deeds, thoughts and dreams of other men as revealed in books, art and music.

The next topic was "Cultivate a Mind to Think." At this point, Briscoe (1959, p. 8) emphasized that "the ultimate goal of higher education should be to cultivate in the student a mind that will and can think for itself. . . ." Briscoe (1959, p. 8) gave special attention to the responsibilities of the teacher: "The test of good teaching is not found in the grades made by superior students, but in what the teacher can do and does do for the average and below average students."

Those who knew Briscoe well realized that he believed that good teachers encourage and help their students to learn as independently as possible but that they also expect the same students to work in cooperation with others. This point was brought out in the section on "Higher Education Needs Re-direction."

Special emphasis was given to research in the section entitled "Research Next to Teaching" (Briscoe, 1959, p. 9):

> And now I should like to speak briefly about research as another way in which a university serves society. The importance of research is only second to that of teaching. Research will make the world of tomorrow different from the world of today and it has made the world of today different from the world of the Caesars and the Pharaohs. Research is the search for new knowledge and once acquired this knowledge may or not prove useful .... Every unknown is a challenge, and the unsolved mysteries of the universe, of the atom and the molecule, and of plant and animal bodies are just as challenging as traveling beyond uncrossed horizons.

Briscoe (1959, p. 9) emphasized that:

> It is in the field of basic research that colleges and universities can best serve, and it is only natural that the teachers who impart knowledge should be most concerned with attempts to discover new knowledge. In the social sciences, such as economics, political science, and sociology, research throws light upon many of the problems that beset us in business, trade and industry, in government and in our complex social order. Research in these areas is, therefore, closely related to our welfare.

Briscoe (1959, p. 9) also spoke about "creative effort:"

> They do not solve man's problems of shelter and food and physical well being, but they are the food of his soul and spirit; they give him vision and hope; they provide him with beauty and satisfaction and contentment.

In his final statement on research, Dean Briscoe (1959, p. 9) said:

> We cannot, therefore, afford to neglect research. It must be supported by those who support higher education, because it is in the universities that much of the necessary basic research is done.

In his closing remarks, which were to be his last before the public, he stated (Briscoe, 1959, p. 9):

> To grow old in such an atmosphere is to have the glories of autumn and the joys of springtime all in one. It is not easy to leave and it will never be forgotten.

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INFLUENCE OF K FERTILIZER LEVELS AND PLANT DENSITY ON THE YIELD AND MINERAL CONTENT OF THE LEAVES AND VINES OF THE FLUTED PUMPKIN, *TELFAIRIA OCCIDENTALIS* HOOK.

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ABSTRACT: An experiment was conducted to evaluate the influence of K fertilizer levels and population density on the fresh weight yield and K content of the vines and leaves of the fluted pumpkin. The maximum yield of leaves and a high K content occurred at a population density of 40,000 plants/ha using K_2O at a rate of 100 kg/ha.

KEYWORDS: Fluted pumpkin, K fertilization, mineral content, plant density, *Telfairia occidentalis* Hook., yield.

INTRODUCTION

The fluted pumpkin (*Telfairia occidentalis* Hook.), which originated in West Africa (Irvine, 1969), belongs to the gourd or calabash family (Cucurbitaceae). The fluted pumpkin is a large perennial vine grown as a vegetable crop along the edges of the closed forest zone in southern Nigeria. The crop is usually propagated by seeds obtained from mature gourds of the previous harvest. The gourds are split open to extract the seeds a few days before planting. The crop is usually grown in the rainy season but is more profitably cultivated during the dry season, if the plots are irrigated.

In southern Nigeria, the fluted pumpkin is either inter-cropped with cassava or yam, or it may be cultivated alone. Most farmers do not maintain any specific plant density or level of fertilization; artificial fertilizers are costly, and most peasant farmers cannot afford them. The objective of this study was to evaluate the influence of K fertilizer levels and plant density on the yield and mineral content of the fluted pumpkin.

Table 1. Treatments as a function of fluted pumpkin density and K fertilizer level.

Treatment	Plants/ha	Fertilizer Level
T_1	20,000	50 kg/ha K_2O from 15-15-15
T_2	20,000	100 kg/ha K_2O from 15-15-15
T_3	20,000	133 kg/ha K_2O from KCl
T_4	20,000	266 kg/ha K_2O from KCl
T_5	40,000	50 kg/ha K_2O from 15-15-15
T_6	40,000	100 kg/ha K_2O from 15-15-15
T_7	40,000	133 kg/ha K_2O from KCl
T_8	40,000	266 kg/ha K_2O from KCl

MATERIALS AND METHODS

The investigation was conducted in the dry season (November 1988 - July 1989) at the University of Science and Technology's Research and Teaching Farm in Port Harcourt (4° 46′ N, 7° 01′ E) on a Typic Paleudult soil. The average rainfall was 2,000 mm per annum (Food and Agricultural Organization, 1984). The initial fertility of the soil was: pH, 4.50; total nitrogen, 0.06% (determined by the semi-Kjeldahl Method); available P, 22.36 ppm (ammonium molybdate method with absorbance and transmittance measured at 660 nm); exchangeable K, 41.48 ppm by flame photometry (Allen, *et al.,* 1974). The experiment used a split plot in a randomized complete block design in which two planting densities and four K fertilizer levels were factorially arranged and replicated four times. The planting densities were assigned to the main plots, while K fertilizer levels were in the subplots. Eight treatments (T_1 to T_8) were replicated 4 times in a randomized manner so that treatments had the following plant populations with a spacing of 1 m by 1 m; T_1-T_4, 20,000 plants/ha (2 seeds/stand); T_5-T_8, 40,000 plants/ha (4 seeds/stand). Each subplot measured 8 m by 4 m with an interplot distance of 1 m as well as a 1 m width round the experiment. Seeding was done on 25 November 1988, after plowing and disk harrowing. Manual weeding was done 3 weeks after planting and, subsequently, at 8, 17, and 25 weeks after planting.

Fertilizer Application. Fertilizer was applied at 9 weeks after planting. The ring (30-cm diameter) method was adopted at the following rates (Table 1): T_1 and T_5, 50 kg/ha K_2O from 15-15-15 (N-P_2O_5-K_2O); T_2 and T_6, 100 kg/ha K_2O from 15-15-15 (N-P_2O_5-K_2O); T_3 and T_7, 133 kg/ha K_2O from muriate of potash (KCl); and T_4 and T_8, 266 kg/ha K_2O from muriate of potash (KCl). N from urea and P from single superphosphate were added to T_3, T_4, T_7, and T_8 to bring their levels of N and P up to those of the NPK 15-15-15 used in T_1, T_2, T_5, and T_6. Therefore, only K varied, while similar N and P levels were maintained.

Mulching and Watering. Dry grass mulch (Okugie and Ossom, 1988) was applied at the base of each crop stand at the rate of about 3 t/ha. Watering was done twice a week at the rate of 2.65 mm irrigation/plot for the first 2 weeks after planting. Because of the increasing severity of the dry season, the rate thereafter

Table 2. The distribution of rainfall and irrigation during the course of the experiment.

Date	Rainfall (mm)	Irrigation (mm)	No. of Days With Up To 0.1 mm	Total Water Use (mm)
Nov. 1988	106.8	0.0	12	106.8
Dec. 1988	30.2	21.2	10	51.4
Jan. 1989	0.0	31.8	8	31.8
Feb. 1989	0.0	31.8	8	31.8
Mar. 1989	117.3	0.0	11	117.3
Apr. 1989	191.1	0.0	11	191.1
May 1989	124.3	0.0	13	124.3
June 1989	173.4	0.0	16	173.4
July 1989	175.1	0.0	19	175.1

was increased to 3.98 mm irrigation/plot twice a week but was discontinued on March 3, when the first heavy rain fell. Typically, farmers do not water their fluted pumpkin plots in the dry season and, as a result, lose much of their crop to drought. In this experiment, minimal irrigation was provided as a way of possibly improving crop growth, avoiding crop failure, and increasing crop yield. Table 2 shows the rainfall and irrigation distribution during the course of the experiment.

Harvesting and Sample Preparation. The first leaves and vines were harvested 7 weeks after planting; subsequent harvests were made every 4 weeks (Ossom, 1986) and continued until 27 weeks after planting. Individual plant yield was not determined. During harvesting, each vine or branch of a vine along with its leaves was cut off about 60 cm from the growing tip, and the total fresh weight of both vines and leaves was recorded. A 200 g sample/plot was taken from the weighed material, wilted overnight in the laboratory, and bagged. The samples were dried in a hot-air oven at 80° C for 5 days. Then, the dried samples were ground in a micro-hammermill using a 0.025 mm mesh screen. Analyses for N, P, and K (Allen, *et al.*, 1974) were conducted at 7, 11, 19, and 27 weeks after planting.

RESULTS AND DISCUSSION

Fresh Weight Yield of Leaves and Vines. Low fresh weight yields were obtained during the early harvests (7, 11, and 15 weeks after planting). Higher yields were recorded during later harvests (19, 23, and 27 weeks after planting), which coincided with the period of heavy rainfall. Though the effect of rainfall on the treatments was not specifically tested, the low yields at 7, 11 and 15 weeks after planting were probably due to the adverse effects of insufficient rainfall during that period. Conversely, the higher yields observed at 19, 23, and 27 weeks after planting can probably be attributed to the higher rainfall experienced during March. Cumulative fresh weight yield showed significant differences

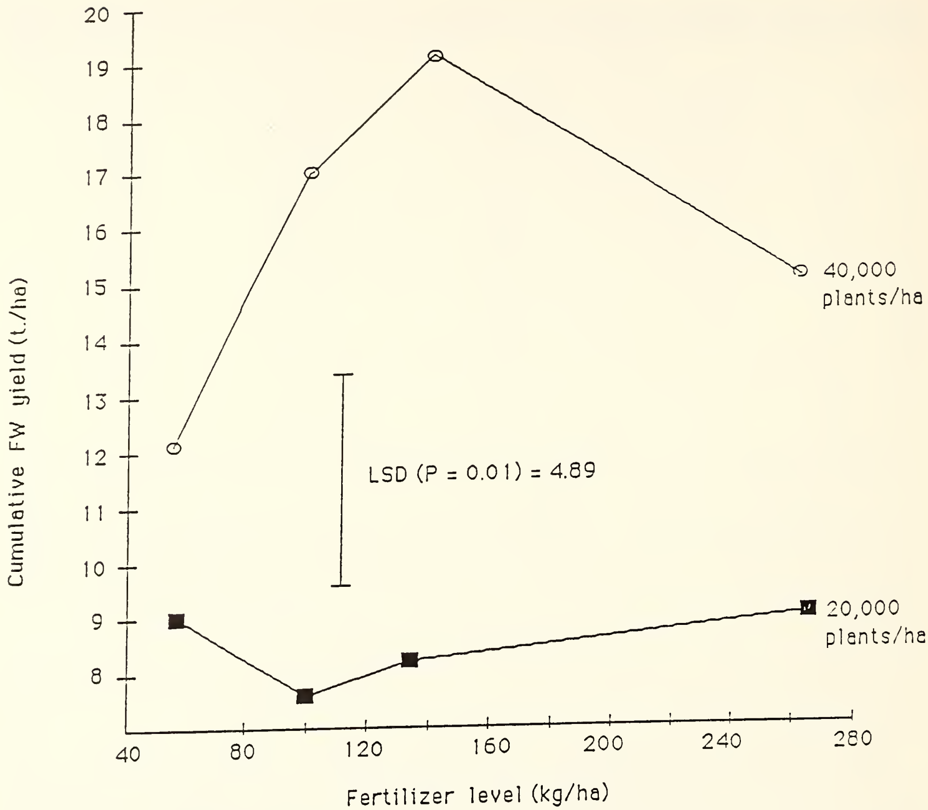

Figure 1. The effect of K fertilizer and plant density on the fresh weight yield (t/ha) of the fluted pumpkin.

($P = 0.05$) between treatments. Least significant difference tests for plant population density, fertilizer levels, and interaction indicated by A, B, and AB, respectively (Table 3), showed significant yield differences ($P = 0.05$) between treatments. Cumulative fresh weight yield was higher at a population density of 40,000 plants/ha than at 20,000 plants/ha.

Effect of Fertilizer Level on Fresh Weigh Yield. Different fertilizer levels did not influence cumulative fresh weight yield. However, a significant increase ($P = 0.05$) in fresh weight yield during harvests 11 and 19 weeks after planting was noted. The increased yields might have resulted from increased fertilizer availability (K fertilizer was applied 9 weeks after planting) and more efficient water use. Singh and Ghosh (1984) noted that graded doses of K increased the dry matter yield of maize, cowpea, and wheat. Hassan and Ayoub (1978) noted that NPK fertilization leads to increased yield in the onion.

Effect of Fertilizer by Plant Density Interaction on Cumulative Fresh Weight Yield. Increased fertilizer levels did not result in significant fresh weight yield increases, but the interaction between fertilizer and plant density did result in increased fresh weight yield at 40,000 plants/ha (Figure 1). At 133 kg/ha K_2O,

Table 3. The mean fresh weight yield (t/ha) of vines and leaves of fluted pumpkin as affected by plant density, K fertilizer, and harvest interval.

		Weeks After Planting							
Plants/ha	Treatment[1]	7	11	15	19	23	27	Total	Mean[3]
20,000	T_1	0.25	0.34	0.67	2.31	3.26	2.27	9.10	1.52bc
	T_2	0.16	0.21	0.43	1.53	2.88	2.23	7.44	1.24c
	T_3	0.23	0.31	0.61	1.79	3.06	2.21	8.21	1.37c
	T_4	0.26	0.35	0.69	2.29	3.49	2.41	9.49	1.58bc
40,000	T_5	0.44	0.54	1.14	2.99	4.13	2.97	12.21	2.04b
	T_6	0.64	0.77	1.57	4.28	6.33	3.83	17.42	2.90ab
	T_7	1.37	1.59	2.95	5.85	4.62	3.02	19.40	3.23a
	T_8	0.52	0.68	1.36	4.43	4.68	2.96	14.63	2.44b
A[2]	LSD[4] ($P = 0.05$)	—	0.32	0.96	1.79	0.80	0.45	4.32	0.86
B[2]	LSD[4] ($P = 0.05$)	0.30	0.32	1.67	0.85	0.96	0.98	5.08	0.85
AB[2]	LSD[4] ($P = 0.05$)	—	0.45	2.36	1.20	1.36	1.39	6.76	1.35

[1] See Table 1.
[2] A, B = Main effects; AB = Interactions.
[3] Means followed by the same letters do not differ significantly at $P = 0.01$, according to Duncan's New Range Multiple Test.
[4] Least significant difference test.

a plant density x fertilizer interaction was noted that resulted in yield differences when treatment means were compared using a least significant difference test ($P = 0.01$).

Effect of Plant Density on Cumulative Fresh Weight Yield. The highest fresh weight per harvest was obtained from T_7. More succulent, harvestable leaves and vines were produced at plant densities of 40,000 plants/ha than at densities of 20,000 plants/ha. The maximum fresh weight yield of leaves and vines was obtained from 15 to 23 weeks after planting. During this period, more soil water from rains was available compared to earlier harvests, when little or no rainfall occurred (Table 2). Since better fertilizer use is achieved in the presence of soil water, the fluted pumpkin probably made more and better use of the fertilizer applied earlier as indicated by the production of more vegetative yield. Plant population density exerts a prominent influence on the yield of a crop; hence, farmers need to increase the number of plants/ha to maximize growth. For most crops, yield is expected to increase with increasing density up to a certain point after which yields would decline. At higher densities, more leaves and longer shoots tend to be produced by the fluted pumpkin in the plant's effort to increase its photosynthetic area that might otherwise be reduced by mutual shading from nearby plants and plant parts. The favorable effect of increasing population density on yield agrees with reports from similar investigations using pigeon pea (*Cajanus indicus*; Abrams and Julia, 1974), cowpea (*Vigna unguic-*

Table 4. N concentration (%) in the leaf blades of the fluted pumpkin as affected by plant density, K fertilizer, and harvest interval.

Treatment[1]	Weeks After Planting 7	11	19	27	Mean	Std. Dev.
T_1	1.56	1.90	3.08	1.75	2.07	0.69
T_2	1.80	2.02	2.91	2.17	2.23	0.48
T_3	1.88	2.16	2.86	1.86	2.19	0.46
T_4	1.74	1.87	2.89	1.76	2.07	0.55
T_5	2.59	2.61	3.35	2.79	2.84	0.35
T_6	2.04	2.58	3.15	5.42	3.69	0.75
T_7	2.58	3.15	5.42	3.69	3.71	1.23
T_8	2.25	2.29	2.98	2.69	0.50	0.35
Mean	2.06	2.33	3.47	2.56	—	—
LSD[2] ($P = 0.05$)	0.54	0.28	0.39	0.38	—	—
Std. Dev.	0.39	0.44	0.86	0.82	—	—

[1] See Table 1.

[2] Least significant difference test.

Table 5. P concentration (%) in the leaf blades of the fluted pumpkin as affected by plant density, K fertilizer, and harvest interval.

Treatment[1]	Weeks After Planting 7	11	19	27	Mean	Std. Dev.
T_1	0.50	0.50	0.50	0.40	0.50	0.05
T_2	0.50	0.50	0.50	0.40	0.50	0.05
T_3	0.50	0.50	0.50	0.40	0.50	0.05
T_4	0.50	0.50	0.50	0.40	0.50	0.05
T_5	0.50	0.50	0.50	0.40	0.50	0.05
T_6	0.60	0.50	0.50	0.50	0.50	0.05
T_7	0.60	0.60	0.50	0.50	0.60	0.06
T_8	0.50	0.50	0.50	0.40	0.50	0.05
Mean	0.55	0.52	0.52	0.43	—	—
LSD[2] ($P = 0.05$)	0.10	0.02	0.02	0.09	—	—
Std. Dev.	0.05	0.04	0.00	0.05	—	—

[1] See Table 1.

[2] Least significant difference test.

Table 6. K concentration (%) in the leaf blades of the fluted pumpkin as affected by plant density, K fertilizer, and harvest interval.

	Weeks After Planting					
Treatment[1]	7	11	19	27	Mean	Std. Dev.
T_1	2.30	2.80	4.00	2.50	2.90	0.76
T_2	2.30	2.70	3.90	2.60	2.90	0.70
T_3	2.20	2.70	3.90	2.00	2.70	0.85
T_4	2.30	2.80	3.80	2.00	2.70	0.79
T_5	2.80	3.50	4.90	2.40	3.40	1.10
T_6	2.20	3.10	4.90	2.60	3.20	1.19
T_7	2.90	4.50	7.00	3.00	4.40	1.91
T_8	2.50	3.30	5.20	2.60	3.40	1.25
Mean	2.50	3.20	4.70	2.50	—	—
LSD[2] ($P = 0.05$)	0.37	0.55	0.74	0.41	—	—
Std. Dev.	0.27	0.61	1.08	0.33	—	—

[1] See Table 1.

[2] Least significant difference test.

ulate; Adetiloye, 1986), long beans (*Vigna sesquipedalis*; Choo, 1974), maize (*Zea mays*; Choudhary, 1981), sunflower (*Helianthus annus*; Ogunremi, 1979), and common bean (*Phaseolus vulgaris*; Leakey, 1972).

Because of the sparse rainfall and the small amount of irrigation provided during the early stages of the experiment, which was followed by heavy rainfall that improved the water balance within the plant and thus encouraged vegetative growth in the later stages of the experiment, the increased plant density probably resulted in more soil coverage, thus reducing evaporation and increasing yield. Gregory (1988) showed that fertilizer use does promote rapid leaf growth thereby enabling plants to cover the surface of the soil and bring about a reduction in evaporative losses and an increase in water use efficiency.

The increased fresh weight yield observed at a density of 40,000 plants/ha when compared to that at 20,000 plants/ha was in agreement with observations (Thompson and Taylor, 1975) on two cauliflower varieties, "Finney's 110" and "Kangaroo," in which the yield of the former increased considerably with increased planting density. The result also agrees with the findings (Farah, 1975) that yield and quality of tobacco were improved as plant density increased. In the present experiment, yield increases were probably associated with increased plant density and greater vegetative growth at these higher densities; maximum plant density has not yet been conclusively determined for the fluted pumpkin.

Mineral Concentration in the Leaves. At each harvest, irrespective of the plant population/ha, the relative concentration of N, P, and K in the leaf blades was K > N > P (Tables 4, 5, and 6, respectively). At each harvest, the concentration of N was generally higher in plants sown at 40,000 plants/ha than in those

sown at 20,000 plants/ha. P concentration did not markedly differ between plant populations at each harvest. K content did not vary proportionately with an increase or decrease in the level of K_2O applied as fertilizer. The observed trend for N accumulation in the vines and leaf blades was in agreement with earlier reports (Hassan and Ayoub, 1978) that noted that increased mineral content in onion resulted from increased NPK fertilization. In the present experiment, how crop density contributed to the differences in the amount of N in the leaves is not clear. However, the results agree with previous investigations (Orluchukwu and Ossom, 1988) that showed a significant difference in the concentration of P and K in the leaf blade of the fluted pumpkin grown under different management practices. At 27 weeks after planting, yellowing of the leaves and laboratory tests indicated a low concentration of N as was also observed at 7 weeks after planting prior to fertilization.

The mineral content of a plant organ depends, among other factors, on the age of the organ and the presence or absence of elements that can either antagonize or promote nutrient reactions, such as chemical fixation and reduction (Brady, 1974). N levels of below 0.05% are indicative of the onset of a deficiency (Purvis and Carolus, 1964). K levels below 0.3% to 0.5% show the onset of a deficiency (Purvis and Carolus, 1964). In this study, mineral levels were in the deficiency range prior to fertilizer application, but after fertilizer was applied, increased mineral concentration was found in the plant tissues. However, continued harvest without additional fertilizer application caused mineral levels to decline, giving rise to the deficiency symptoms observed towards the end of the experiment. The deficiency symptoms could also have resulted from the maturation of the pumpkin plants. Purvis and Carolus (1964) noted that N deficiency might occur during crop maturation.

The moisture holding capacity of the experimental plots was low for three reasons: (1) the sandy loam soil had a low water holding capacity; (2) temperatures during the dry season were high; and (3) desiccating winds were common. The available soil moisture was not at an optimum level in the early stages of the experiment, including the time when the plots were irrigated.

SUMMARY

The results of this experiment indicate that the yield of leaves and vines increases when fluted pumpkin is planted at high densities and fertilized. Maximum yields were obtained at 40,000 plants/ha at a K_2O application rate of 100 kg/ha. If farmers adopt this planting density and level of K fertilization, they should get high yields of leaves and vines from this crop. Though it is costly for farmers to obtain large numbers of fluted pumpkin seeds for planting, the high profits obtained from sales should offset the cost of purchasing the seeds. In the future, the relationship between irrigation and yield of fluted pumpkin vines planted during the dry season should be studied.

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FACTORS INFLUENCING REPRODUCTIVE SUCCESS IN MALE SPOTTAIL DARTERS (*ETHEOSTOMA SQUAMICEPS*, PISCES, PERCIDAE)

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ABSTRACT: The mating system of spottail darters is a form of resource defense polygyny in which females deposit eggs on the undersurfaces of benthic cavities defended by males. I investigated the (1) effect of nest site size on nest site defense by males and on brood size, the (2) timing and duration of nest site defense by males, the (3) effect of male size on nest site acquisition, and (4) female choice of nest sites and spawning partners. Field experiments with two sizes of artificial nest sites (tiles) conducted over two breeding seasons indicated that large tiles were defended more frequently by larger males and contained larger broods than small tiles. In both years, male size correlated positively with the total number of eggs defended, although in one year the relationship was not statistically significant. Some males defended nest sites for as long as 60 days, and six of 17 males that spawned in one year sequentially defended multiple broods. In laboratory experiments, male size was an important factor in the acquisition and defense of nest sites, and females chose the larger of two males as a spawning partner when nest site size was held constant.

KEYWORDS: *Etheostoma squamiceps,*female choice, male size, nest site defense, nest site size, Percidae, sexual selection, spottail darter.

INTRODUCTION

Resource defense polygyny occurs when a subset of the male breeding population is able to monopolize resources sought by females (Emlen and Oring, 1977). In such systems, males typically compete for resources, and intrasexual selection promotes characteristics that enhance resource acquisition and defense (Darwin, 1871). Male reproductive success may be influenced by the quality of the defended resource (Searcy, 1979; Alcock, 1987), the quality of the male (Cote and Hunte, 1989; Ryan, 1991), or both (Thompson, 1986), depending on the nature and extent of female choice.

Darters (Teleostei: Percidae) have a variety of reproductive modes, including broadcast, clumping, and clustering of gametes (Page, 1983). Page (1985) considered the most derived of these reproductive modes to be egg-clustering, a form of resource defense polygyny in which males defend cavities where females deposit eggs. This reproductive mode is ideal for studies of sexual selection because both competition among males and female choice can occur.

Aspects of sexual selection have been investigated in several egg-clustering percids, including the tessellated darter, *Etheostoma olmstedi* (Constantz, 1979,

1985), the johnny darter, *E. nigrum* (Grant and Colgan, 1983, 1984), the fantail darter, *E. flabellare* (Knapp and Sargent, 1989), and the waccamaw darter, *E. perlongum* (Lindquist, *et al.,* 1984). Mating strategies of the spottail darter, *Etheostoma squamiceps,* an egg-clustering species found in southern Illinois, western Kentucky, and southwestern Indiana (Page, *et al.,* 1992), have received limited attention. Information on the natural history of *E. squamiceps* comes largely from population studies in Illinois (Page, 1974). The sexes are of approximately equal size during their first year; thereafter, males become 5-15% larger than females. Females spawn at 1 year, while males generally become sexually mature in their second year; the maximum age of both sexes is 3+ years. During the breeding season, males defend cavities under solid benthic structures, usually rocks. Females attach a single layer of eggs to the ceilings of these structures. Clutch size (eggs spawned by a female at a specific time and location), based on counts of four aquarium spawnings, averaged 60 eggs (range 20-120; Page, 1974). Fractional spawning by *E. squamiceps* females has not been documented, but other members of the genus show this trait (Gale and Deutsch, 1985; Weddle and Burr, 1991), and fractional spawning may be widespread in the *Etheostomatini* (Hubbs, 1985). For example, the mean number of mature ova in 18 breeding females was 110 (range 28-357; Page, 1974), which exceeds the average clutch size and supports the possibility of fractional spawning. Males remain with the eggs until they hatch (5-15 days, depending on water temperature); females leave the nest after spawning.

Etheostoma squamiceps is classified as Endangered in Indiana (Indiana Department of Natural Resources, 1993), where its distribution is limited to the extreme southwestern corner of the State. The breeding season lasts from mid-March through late May (pers. obs.). Bandoli, *et al.* (1991) found that *E. squamiceps* will readily use artificial nest sites with no significant difference in mean brood size (eggs defended by a male at a specific time; may include clutches from more than one female) compared to natural broods under rocks. In that study, the mean number of eggs per brood was 368, but nests containing over 1,000 eggs were not uncommon, ranging from 5% (Bandoli, pers. obs.) to 15% (Page, 1974) of all broods examined. The average brood/clutch size ratio indicates that larger broods may contain 10 or more clutches.

The results of field and laboratory studies on the reproductive biology of *E. squamiceps* in southwestern Indiana are reported in this paper with emphasis on factors that influence male reproductive success. Questions asked were: Do males that defend larger nest sites have larger broods? How long does a male defend a nest site? Does male size influence the acquisition and defense of nest sites? Can males defend multiple broods? Do females select males as spawning partners on the basis of either male size or nest site size?

FIELD STUDY—MATERIALS AND METHODS

Experiments on nest site selection and reproductive timing were conducted at Carpentier Creek, a first-order tributary of the Bayou Creek drainage in Van-

derburgh County, Indiana. Carpentier Creek drains suburban areas interspersed with bottomland hardwood woodlots. Siltation and debris have reduced the number of available nest sites, limiting *E. squamiceps* densities and promoting the use of artificial nest sites (Bandoli, *et al.*, 1991).

The purpose of the field experiment was to investigate the response of *E. squamiceps* to variation in nest site size. If nest site size is important in determining male reproductive success, larger nest sites should be defended more frequently, attract more females, and contain more and larger broods. If male size is important in nest site defense, larger males should defend larger nest sites. Moreover, if females choose males on the basis of size, male size should correlate positively with brood size when nest site size is held constant.

These predictions were tested using two different lengths of half-cylindrical ceramic field tile (10 cm inside diameter) as artificial nest sites. Large tiles ranged from 14.5 to 16.0 cm in length and provided an average of 170 cm^2 of undersurface area for egg deposition, an area large enough to accommodate over 1,400 eggs. Small tiles ranged from 7.0 to 9.5 cm in length and provided an average of 90 cm^2 of undersurface area, enough to hold approximately 700 eggs. Pairs of tiles (one large and one small marked for individual identification) were placed in the stream with roughly 3-m intervals between pairs. To encourage tile use, rocks near tiles were removed. Twenty and 24 pairs of tiles were placed in the stream in early March of 1990 and 1991, respectively. Tiles were checked biweekly (1990) or weekly (1991) from mid-March through late May for *E. squamiceps* nests and guarding males.

Darters were captured by placing an aquarium net over one end of a tile and flushing any occupants into the net. Standard lengths of captured fish were measured prior to returning individuals to their respective tiles. Eggs in small nests were counted in the field; large nests were photographed and eggs counted directly from projected slides. Since *E. squamiceps* females deposit new eggs around rather than over existing eggs, photographs of nests under the same tile on consecutive censuses could be compared to ensure that only eggs deposited since the last census were counted.

In 1991, the reproductive activities of individual males were monitored over time by marking males with unique combinations of fin clips and subcutaneous injections of permanent ink. These markings allowed the investigator to ask if males could defend multiple broods, how long a male would defend a nest site, and if males change nest sites during a breeding season. Comparisons of nest site defense, brood size, and use of nest sites by females between large and small tiles were performed on combined data from both years. Analyses involving male size were performed separately for each year because identification of individual marked males was done in 1991 only. Statistics were generated using ABSTAT (Anderson-Bell Corp.) and S-PLUS (Statistical Sciences, Inc.). Means reported in the text are ± one standard error.

Table 1. Artificial nest site selection by *Etheostoma squamiceps*. The numbers in parentheses are standard errors.

Parameter	1990		1991	
	Large tile	Small tile	Large tile	Small tile
Mean number of tiles available per census[1]	15.8 (1.8)	14.6 (2.9)	21.1 (1.4)	20.4 (1.5)
Number of observations	77	73	231	220
% of tiles guarded at least once during the reproductive season	100	63.2	90.5	65
Mean % of tiles guarded per census	32.6 (7.1)	16.9 (8.2)	32.5 (3.6)	8.2 (2.7)
% of tiles with one or more broods during the reproductive season	44.2	16.4	66.7	25
Number of broods	23	11	21	5
Mean brood size	575.9 (77.8)	335.4 (34.0)	597.1 (56.8)	473.0 (134.9)
Number of guarding males captured (with and without broods)	31	16	25	11
Mean standard length of guarding males (mm)	70.4 (0.8)	66.4 (0.8)	72.7 (1.2)	67.2 (2.4)
Number of females captured	10	5	17	6

[1] Twenty and 24 pairs of tiles were placed in the stream in 1990 and 1991, respectively.

FIELD STUDY—RESULTS

In both years, the availability of large and small tiles was similar despite temporary losses due to flooding and disturbance by raccoons and humans (Table 1).

Are Larger Nest Sites Defended More Frequently? Males guarded large tiles more frequently than small tiles, with over 95% of the large tiles defended at least once during the breeding season. Across both years, a mean of 32.5 ± 3.2% of the large tiles were defended on each of 16 census dates, significantly more than the 10.9 ± 3.2% defense frequency for small tiles (paired t-test: $t = 6.17$, $df = 15$, $P < 0.001$).

Are Females Attracted to Larger Nest Sites? More females were captured under large tiles than under small tiles in each year (Table 1); combined data from both years showed this pattern to be significantly different from the equal use of large and small tiles expected by chance ($\chi^2 = 5.9$, $df = 1$, $P < 0.025$).

Do Larger Nest Sites Contain Larger Broods? Of the 60 broods found during the two breeding seasons, 44 (73.3%) were located under large tiles. Brood size was significantly larger for large tile nests ($\bar{X} = 586.0 \pm 48.3$, range 85-1632) than for small tile nests ($\bar{X} = 378.4 \pm 48.2$, range 134-781; two sample *t*-test: $t = 2.43$, $df = 58$, $P < 0.02$).

Do Larger Males Defend Larger Nest Sites? Males captured while defending tiles ranged from 55-81 mm in standard length; females captured under tiles ranged from 34-70 mm in standard length. Age estimates based on standard length (Page, 1974) place most of the males in the three year old cohort, whereas females ranged from one to three years. Two sample *t*-tests showed that the mean standard length of males captured under large tiles was significantly larger than that of males captured under small tiles in both 1990 ($t = 3.23$, $df = 45$, $P < 0.002$) and 1991 ($t = 2.34$, $df = 34$, $P < 0.02$; Table 1).

Do Larger Males Defend More Eggs? In 1990, 19 males were captured while guarding eggs under large tiles. For these males, standard length correlated significantly with the number of eggs defended (Spearman's rank correlation: $r_s = 0.67$, $P < 0.005$). A similar but nonsignificant trend was seen in 1991 (broods combined for males with multiple broods: $r_s = 0.40$, $P < 0.18$, $n = 13$).

Do Males Defend Multiple Broods? Of 35 males marked in 1991, 18 did not defend broods. Seventeen of these males were captured only once and may have spawned outside the study area. One male was captured on three different census dates and never had any eggs in his nest. Eleven males each defended one brood in the study area; two broods were defended by each of three males; and three males each defended three broods. All multiple broods were defended sequentially rather than simultaneously, and three males with multiple broods changed tiles between broods. Males with multiple broods defended nests from 30 to 60 days. Among spawning males, fitness (total number of eggs guarded during the breeding season) ranged from 134 (smallest single brood) to 2,580 (three sequential broods).

Do Males Change Nest Sites? Seven of 14 males with multiple captures in 1991 changed tiles at least once during the breeding season, although two of these males defended the same tiles for four and five consecutive weeks, respectively. The other seven males were consistently found under the same tiles, and three were among the six males known to have defended multiple consecutive broods. No significant difference existed between the mean standard length of changers ($\bar{X} = 72.4 \pm 2.5$) and nonchangers ($\bar{X} = 71.3 \pm 2.6$; two sample *t*-test: $t = 0.40$, $df = 12$, $P < 0.69$), and the mean number of observations per darter was similar for each group (4.4 and 3.5 captures/male for changers and nonchangers, respectively).

Table 2. Standard lengths (mm) of spottail darters during the first half (15 March - 16 April) and second half (23 April - 28 May) of the 1991 breeding season. The numbers in parentheses are standard errors.

Parameter	n	Mean	Range
Males first seen defending tiles			
First half of season	20	73.9 (1.0)	63-80
Second half of season	17	67.6 (2.1)	55-81
Males first seen defending eggs			
First half of season	6	76.2 (1.3)	71-80
Second half of season	13	69.2 (2.0)	59-81
Females captured under tiles			
First half of season	11	54.5 (1.9)	40-62
Second half of season	12	46.8 (3.0)	34-70

An unanticipated finding was that males first seen during the first half of the 1991 breeding season (early March through mid-April) were significantly larger in standard length than those first seen in the second half (two sample *t*-test: $t = 2.87$, $df = 35$, $P < 0.007$; Table 2). Similarly, the mean standard length of males which first spawned during the first half of that breeding season was significantly larger than that of males which first bred during the second half (two sample *t*-test: $t = 2.21$, $df = 17$, $P < 0.05$). Additionally, the mean standard length of females caught under tiles during the first half of the breeding season was significantly larger than that of females caught after this period (two sample *t*-test: $t = 2.11$, $df = 21$, $P < 0.05$).

LABORATORY STUDY—MATERIALS AND METHODS

Three sets of laboratory experiments were conducted during the 1990-1992 and 1995 breeding seasons in 38-L aquaria (50 cm by 25 cm; 30 cm deep) with natural substrate and tiles for nest sites. Darters were maintained on a 13L:11D photocycle and fed frozen brine shrimp augmented with live benthic invertebrates from local streams. Water temperature varied from 18°-22° C.

Male *E. squamiceps* used in laboratory experiments were determined to be in breeding condition based on coloration (Page, 1974) and had a mean standard length of 72.1 mm (range 60-83 mm). Females had distended abdomens indicating the presence of mature eggs and a mean standard length of 56.7 mm (range 35-72 mm). Standard lengths of most males were in the range expected for age 3+ (> 64 mm; Page, 1974). All females and most males were used in one trial only; any male used more than once was always paired with a different male.

Experiment 1: Is Male Size Important in Nest Site Defense? In each of 13 trials, two males (one 5-29% larger in standard length than the other) were placed in an aquarium containing a single large tile positioned to the right or left

of center by a coin toss. Trials lasted 10 days (1990) or 6 days (1995) with a total of 29-30 observations per trial. Observations were made at least twice per day (weekends) up to a maximum of six per day between 0730 and 2100 h with at least 1 h between observations. At each observation, the position of each male was scored as under the tile or on the substrate outside the tile (non-swimming darters rest on the bottom). The percent of observations each male was observed alone under the tile was determined for each trial; these observations were averaged across all trials, and a paired *t*-test was used to compare the mean tile defense frequencies of large to small males. In addition, the percent size difference between males for each trial was compared to the percent of time the larger male spent defending the tile using Spearman's rank correlation statistic.

Experiment 2: Does Nest Site Size Influence Female Choice of Spawning Site When Male Size is Held Constant? In each of 16 trials conducted in 1991 and 1992, two breeding males of similar size (less than 3% difference in standard length) were placed in an aquarium with one large tile (15 cm long) and one small tile (8 cm long). A gravid female was introduced within 24 hours. A coin toss determined whether the large tile was placed to the right or left of center, and the small tile was placed on the opposite side. Previous experiments showed that spawning in the laboratory occurred from 4 h to several days following introduction of the female, making constant monitoring impractical. Therefore, all trials were conducted by periodically examining all tiles for eggs and noting the positions of all darters in each aquarium. Observations were made at least twice daily (weekends and days on which experiments began or ended) up to a maximum of five per day. Observations were conducted between 0730 and 2100 h with at least 1 h between successive observations. Trials varied in length (mean duration 4.1 d) and ended 24 h after a female spawned or after 5 days without a spawn. The number of observations per trial ranged from 8-26 with a mean of 13.3. Darter positions were scored as under a specific tile or on open substrate. The percent of observations during which each tile was defended by a male was determined for each trial, and these values were used to calculate mean tile defense frequencies for large and small tiles across all trials. These defense frequencies were compared using a paired *t*-test. The tile under which spawning occurred was used to indicate female choice. A chi-square goodness of fit test was used to compare the observed distribution of spawning locations with the equal spawning under large and small tiles expected by chance.

Experiment 3: Does Male Size Influence Female Choice of Spawning Partner When Nest Site Size is Held Constant? In each of 26 trials conducted in 1991 and 1992, two males of different sizes (large males averaged 14.8% greater in standard length than small males) were placed in an aquarium with two large tiles, one on each side of the aquarium. A gravid female was introduced within 24 h. The duration of the trials varied as in Experiment 2 with a mean trial duration of 5.1 d. Observations were performed as in Experiment 2 with a mean of 19.1 observations per trial (range 8-28). The percent of observations individual darters were under tiles was determined for each trial, and these values

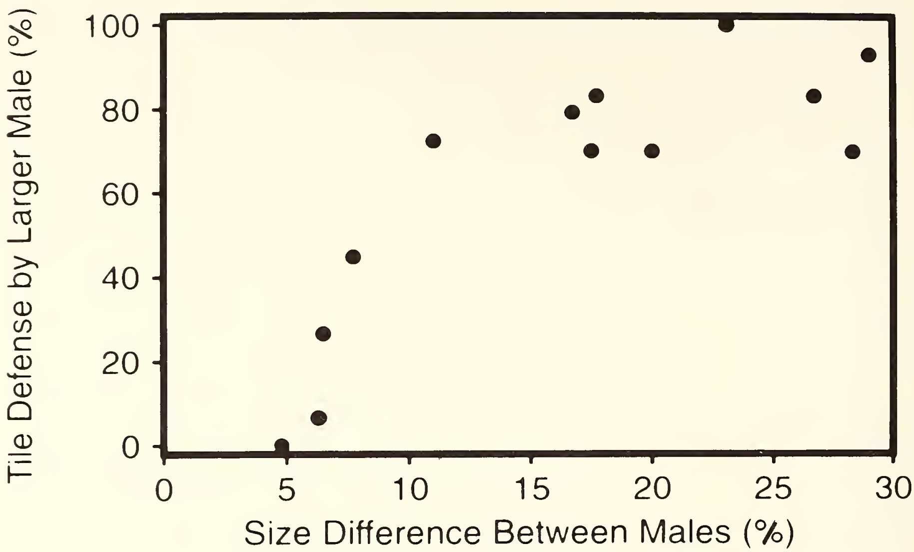

Figure 1. The relationship between male size (standard length) and nest site defense in 13 laboratory trials. Each trial had 29 or 30 observations of two males in an aquarium with a single nest site (tile). The horizontal axis is the difference in size between the two males expressed as a percent of the standard length of the smaller male. The vertical axis is the percent of the observations in which the larger male was alone under the tile.

averaged across all trials for large and small males. Mean tile defense frequencies of large and small males were compared with a paired *t*-test. When spawning occurred between observations, the male spawning partner was determined by noting which male defended the tile before and after spawning. A chi-square goodness of fit test was used to compare the observed distribution of spawning partners with the equal spawning with large and small males expected by chance.

LABORATORY STUDY—RESULTS

Experiment 1: Is Male Size Important in Nest Site Defense? Tiles were defended by males on 77% of the observations. The large male was alone under the tile 61.5 ± 8.9% of the time, significantly more than the mean for small males (15.0 ± 5.0; paired $t = 3.48$, $df = 12$, $P < 0.003$). Moreover, the greater the size difference between the males, the greater the percent of observations the larger male spent alone under the tile ($r_s = 0.78$, $P < 0.005$; Figure 1).

Experiment 2: Does Nest Site Size Influence Female Choice of Spawning Site When Male Size is Held Constant? Females spawned in 9 of the 16 trials. Eight clutches were deposited under large tiles; in one trial, two clutches were deposited by the same female, the first under the small tile (12 eggs) and the second 2 h later under the large tile (37 eggs). Overall, female choice of nest

site was significantly different than expected by chance ($\chi^2 = 4.9$, $df = 1$, $P < 0.05$).

Large tiles were defended by a male in 68.4 ± 6.1% of the observations, significantly more than the small tiles (36.8 ± 5.5%; paired $t = 3.77$, $df = 15$, $P < 0.002$). In trials where spawning occurred, this difference was also apparent before eggs were deposited. During this period, males defended the large tiles for 53.5 ± 10.8% of the observations versus 22.0 ± 7.6% for the small tiles, a significant difference (paired $t = 5.57$, $df = 8$, $P < 0.0006$). When the expectation of spawning site choice was altered from uniform (1:1) to one based on the observed defense frequencies prior to spawning (1:2.3 for small and large tiles, respectively), female choice of spawning site did not differ from expectations based on observed tile defense frequencies ($\chi^2 = 1.07$, $df = 1$, $P < 0.5$).

Experiment 3: Does Male Size Influence Female Choice of Mates When Nest Site Size is Held Constant? Females spawned in 13 of 26 trials. Eleven spawnings occurred with the larger male, one with the smaller male, and one female spawned with both (160 eggs with the smaller male, three with the larger male). Female choice of spawning partner was significantly different than expected by chance ($\chi^2 = 5.8$, $df = 1$, $P < 0.025$).

Large males defended tiles during 63.8 ± 4.8% of the observations compared with 45.8 ± 5.5% for small males, a significant difference (paired *t*-test: $t = 3.05$, $df = 25$, $P < 0.006$). Prior to spawning, the difference in tile defense frequencies of large and small males was not significant (66.3 ± 8.8% and 56.0 ± 10.4%, respectively; paired $t = 1.03$, $df = 11$, $P < 0.33$). However, females chose the larger male as a spawning partner significantly more than expected even when the expectation was modified by the observed before-spawning male defense frequency from 1:1 to 1:1.2 for small and large males, respectively ($\chi^2 = 5.04$, $df = 1$, $P < 0.025$).

DISCUSSION

The results from the field experiments indicated that nest site selection does affect male reproductive success as measured by the number of eggs defended. Large tiles contained both more broods and larger broods than did small tiles. In both field and laboratory experiments, males preferred large tiles as nest sites despite the fact that small tiles were capable of holding more eggs (at least 700) than the average brood found under large tiles (586 eggs). However, *E. squamiceps* broods can be much larger than 700 eggs, occasionally exceeding 1000 eggs (Page, 1974; Bandoli, *et al.,* 1991). The value of larger nest sites may be that they permit an occasional large brood and associated higher fitness.

The finding that larger males generally guard larger tiles suggests that male size is important in nest site acquisition and defense, a pattern also seen in the fantail darter (Seifert, 1963) and the johnny darter (Grant and Colgan, 1984). This finding was further supported by the laboratory experiments which showed that, when two males competed for the same tile, the larger male spent

more time defending the tile than did the smaller male, and exclusive tile defense by the larger male increased as the size difference between the males increased.

Field and laboratory observations indicated that females also prefer large tiles as spawning sites. However, these observations may be confounded by the fact that, before spawning, large tiles are more likely to be defended by males than are small tiles. Therefore, females may select the large tiles based on the frequency of tile defense by males rather than tile size.

When nest sites were of equal size, females preferred those defended by the larger male. This result was not confounded by unequal nest site defense frequencies before spawning and, therefore, may represent a real choice. In field experiments, male size varied directly with brood size among males defending large tiles, although the correlation was significant in one year only.

Male size has been shown to be an important parameter for female choice in a variety of fish species with breeding systems similar to *E. squamiceps,* including the redlip blenny (Cote and Hunte, 1989), river bullhead (Bisazza and Marconato, 1988), and mottled sculpin (Downhower and Brown, 1980). The value of male size as an object of choice by females has several potential correlates. First, larger males may be selected because they are better egg protectors (Cote and Hunte, 1989). *Etheostoma squamiceps* eggs in abandoned nests are quickly exploited by egg predators or lost to fungus (pers. obs.), and successful hatching may depend on the guarding behavior of the breeding male. Many *E. squamiceps* males showed a high degree of nest site fidelity, unlike *E. olmstedi* males, who abandon nests with large broods to seek new nest sites, leaving brood defense to smaller subordinate males (Constantz, 1985). Large males may be better at defending a nest, and females that choose them would be rewarded with higher fitness via increased egg survival, a pattern seen in the mottled sculpin (Downhower and Brown, 1980). Even if size is not a good indicator of the ability of a male to protect a brood, females may still gain from selecting large males if doing so results in a larger nest site. Large nest sites afford more room for egg deposition, an important factor when nest site availability is limited (Constantz, 1979). Further, large nest sites also contain larger broods. A female that adds eggs to a large brood may minimize the chance of losing her eggs to predators or filial cannibalism through the dilution effect (Kodric-Brown, 1983).

Finally, selection of large males may improve offspring quality. This hypothesis assumes that male size is an honest indicator of genetic quality (Kodric-Brown and Brown, 1984) with increased nutritional condition, better predator avoidance, and greater resistance to parasites as possible correlates. The first two correlates are difficult to quantify and cannot be addressed here. Resistance to parasites (Hamilton and Zuk, 1982) can be discussed. Strange (1992) found that 86% of 44 *E. squamiceps* examined from a southwestern Indiana stream were parasitized by enterogastric acanthocephalan worms (*Acanthocephalus dirus*) with the highest infection rate (100%) among the largest (oldest) darters. Additionally, the intensity of parasitism increased with age from 3.6 to 22.6 worms

per darter. Therefore, size alone appears to be an unlikely indicator of parasite resistance, although larger individuals might be better able to tolerate the unavoidable parasite load.

Male reproductive success in *E. squamiceps* is also influenced by the duration of nest site defense, a pattern seen in the egg-clustering johnny darter *Etheostoma nigrum* (Grant and Colgan, 1983). Some male *E. squamiceps* defended as many as three sequential broods, which required several weeks of nest guarding. The territorial mating system of *E. squamiceps* and *E. nigrum* imposes minimal mating costs on parental males (Gross and Sargent, 1985), making prolonged nest site defense advantageous. As new clutches are added to the brood, the time to complete hatching increases, and opportunities for additional spawnings occur.

In the field, the mean standard length of *Etheostoma squamiceps* males that bred early in the reproductive season was larger than those that bred later that season, a pattern also seen in the waccamaw darter (*E. perlongum;* Lindquist, *et al.,* 1984). Several potential benefits are associated with early reproduction. First, males that acquire nest sites early may have longer spawning periods, allowing them to recruit more females. Second, early spawning females had a larger mean standard length than those spawning later and may be able to produce larger clutches (Page, 1983). Third, early spawning may decrease competition for nest sites with bluntnose minnows, a sympatric cavity-nesting species that begins spawning midway through the spottail darter breeding season in southwestern Indiana (pers. obs.). Finally, water temperature influences egg development rate (Page, 1983), and temperatures of 20°-22° C have been found to maximize embryo survival in *Etheostoma lepidum* (Hubbs, *et al.,* 1969). Variable water temperatures in shallow streams make temperature prediction difficult, and males that acquire nest sites early are ready to spawn when stream temperatures become optimal. Females may also produce larger clutches at this time, a pattern seen in *Etheostoma rafinesquei* (Weddle and Burr, 1991).

The results of this study suggest that male reproductive success in the spottail darter is a function of (1) acquisition and defense of large nest sites, (2) early and prolonged nest site defense, and (3) female choice, all of which are influenced by male size. However, other factors not addressed in this study might also be important. These factors include the intensity of male breeding coloration (Kodric-Brown, 1983; Morris, *et al.,* 1995), the length and intensity of courtship and/or territorial displays (Grant and Colgan, 1984; Knapp and Warner, 1991), and the presence of eggs in the nest (Knapp and Sargent, 1989), any of which may influence female choice. These factors not withstanding, size appears to be an important factor in determining fitness in males and may be a factor in the sex-specific differences in age at maturity. Growth curves for *E. squamiceps* are similar for males and females during their first year but separate thereafter as males become increasingly larger than females (Page, 1974). Males may be delaying reproduction in order to maximize growth.

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