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RESOLUTION: The following resolution concerning our environment was recently approved by the Academy membership: “Be it resolved that the Nebraska Academy of Sciences, as the principal organization representing the scientists of the State, is greatly concerned with the deterioration of the environment. The scientific talent of Nebraska is considerable, and it is hoped that individually-collectively it may be better utilized by both State and federal agencies in addressing problems of destruction of trees, native prairie, groundwater resources and habitats.”

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NEBRASKA ACADEMY OF SCIENCES

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Many thanks to those individuals who served as manuscript reviewers for the current volume. In the interest of anonymity, they are not listed here. However, their contribution is deeply appreciated and they have all been thanked individually.

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HANNIBAL WOODS: AN EASTERN DECIDUOUS FOREST REMNANT IN HOWARD COUNTY, NEBRASKA

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ABSTRACT

Hannibal Woods is a small, oak-ash (Quercus macrocarpa/Fraxinus pensylvanica) forest relict located on the south and west sides of Dannebrog, Nebraska. The site was first studied in 1996 as part of a botanical survey of the Loup River Valley. Since the initial work, plant collections have been made several times each growing season through 2005, and an annotated list of plant species has been compiled. This study reports a total of 271 plant species representing 62 families including 86 species that are new records for Howard County. The mature bur oaks at this site average 84.0 cm in diameter. Species that are uncommon in central Nebraska include Agastache nepetoides, Arabis hirsuta var. pycnocarpa, Botrychium virginicum, Bromus ciliatus, Bromus latiglumis, Carex grisea, Carex leavenworthii, Carex molesta, Elymus villosus, and Ulmus rubra. Hannibal Woods is botanically significant in that it supports the growth of plant species which are more representative of sites further east, such as the lower Platte and Missouri River Valleys.

† † †

Hannibal Woods is a unique natural area located on the north side of Dannebrog, Howard County, Nebraska (S 1/2 of the SE 1/4 of the NW 1/4 SEC 11, T13N, R11W). It consists of a presettlement, relict stand of bur oak/green ash, interrupted by several grassy clearings and a walking trail that connects the village of Dannebrog with Hannibal Woods. Prominent associated species are Cornus drummondii (rough-leaved dogwood), Juniperus virginiana (eastern red cedar), Morus alba (white mulberry), and Ulmus rubra (slippery elm). This small temperate deciduous forest is associated with Oak Creek, a tributary of the Loup River that generally flows from the northwest to the southeast but meanders through the village of Dannebrog (Fig. 1). It joins the Loup River approximately 0.8 km (0.5 mi) to the east. At one time, Oak Creek provided the energy necessary to power the town’s mill. Hannibal Woods includes several spectacular examples of bur oak (Quercus macrocarpa) that exceed 150 years of age and an understory typical of temperate deciduous forest associations found farther east (Churchill 1979, Rothenberger 1985).

The forest is named for Lars Hannibal (1822-1882), the founder of Dannebrog, who first opened the area to Danish settlers in 1870 (Orr 1983). The ownership of this forest remnant has remained in the Hannibal Family and was protected from logging and exploitation, which likely would have occurred in east-central Nebraska where timber was relatively scarce. The Hannibal Woods area consists of approximately 16 Ha, but the forest remnant is only ~50% of this area which also contains sand prairie, grassy clearings, disturbed ground along the trail, and a water treatment facility for the village of Dannebrog.

This study documents 271 total plant species (228 herbaceous vascular plants, 39 woody plants and vines, 2 succulents, and 2 pteriodiophytes). A total of 62 plant families are represented which is approximately 45% of Nebraska’s 136 plant families. Species diversity is relatively high in comparison to other sites documented from central Nebraska (Nagel and Kolstad 1987, Rothenberger 2000). Becker (1980) surveyed a comparable natural area, Hormel Park in Dodge County, Nebraska, and reported 289 plant species in an area of approximately 65 Ha. By comparison, Hormel Park contains relic stands of bur oak and Tilia americana (American linden) interspersed with green ash, Populus deltoides ssp. monilfera (eastern cottonwood), red mulberry, and Ulmus americana (American elm). Garabrandt (1988) documented 597 plant species at Neale Woods (Washington County) and Fontenelle Forest (Sarpy County). These sites are substantially larger (644 Ha) and more diverse than the Hannibal Woods natural area. Other examples of published county floras are
Banner with 432 species (Hardy 1991), Cumming with 499 species (Churchill 1979), Keith with 599 species (Sutherland and Rolfsmeier 1989), Seward with 599 species (Rolfsmeier 1988), and Dawes with 465 species (Urbatsch and Eddy 1973). However, these numbers are often an indication of collecting intensity rather than species diversity (Kaul and Rolfsmeier 1994).

Figure 1. The Hannibal Woods Study Area, Howard County, Nebraska.
The Hannibal Woods site contains several vascular plants that are rare or uncommon in central Nebraska, including Agastache nepetoides (catnip giant hyssop), Arabis hirsuta var. pycnocarpa (rock cress), Botrychium virginicum (rattlesnake fern), Bromus ciliatus (fringed brome), Bromus latiglumis (ear-leaved brome), Carex grisea (inflated narrow leaf sedge), Carex leavenworthii (Leavenworth sedge), Carex molesta (troublesome sedge), Elymus villosus (hairy wild rye), and Ulmus rubra (slippery elm). An area of alluvial sand hills encroaches on the southeast side of the property, while Nebraska Highway 11 borders Hannibal Woods on the west. This border of sand prairie on the southeast, Nebraska Highway 11 on the west, and a low, drainage area or area of disturbance on the east allows for encroachment by weedy species and prairie plants not normally adapted to a forest environment. The original Dannebrog Danish cemetery (Oak Ridge Cemetery) was sited in the 1870's on the southeast side of Hannibal Woods where it remains in use today and contributes to the historical significance and diversity of the site.

METHODS

Hannibal Woods was originally surveyed botanically in 1996 and 1997 as part of a study of the Loup River Valley by the University of Nebraska - Kearney and the Nebraska Game and Parks Commission. Since that time, plant collections were made several times each year from 1998-2005. Maps and the original survey were obtained at the Howard County Register of Deeds Office in St. Paul. Historical information was provided by Mrs. Ray (Shirley) Johnson (Personal communication, 21 December 2005). A Richter diameter tape was used to measure diameter at breast height (dbh) of mature bur oak trees, and average size class was calculated. A voucher specimen of each collected plant species was placed in the University of Nebraska – Kearney Herbarium. Nomenclature follows the Great Plains Flora Association (1991) except where recent revisions (ex. the wheat grasses) have gained acceptance (Flora North America Editorial Committee, eds. 1993 et seq.).

RESULTS AND DISCUSSION

The Hannibal Woods site is botanically rich and relatively diverse in comparison to other floodplain forests of central and western Nebraska. As is typical in the Great Plains, Poaceae (the grass family) and Asteraceae (the aster family) contribute 36.4 % of the total flora (Table 1). Cyperaceae (the sedge family) and Fabaceae (the pea family) are also significant combining for a total of 28 species from 13 genera. The soils that border the lower Oak Creek area are well-developed silt loams of the Hord-Hobbs Association (Mahnke et al. 1974), and they support the luxuriant growth of bur oak, green ash (Fraxinus pensylvanica), and elm. The age and size class of the bur oaks indicate that this site was forested for several decades or more prior to settlement. The area likely resembled an oak-savanna maintained by frequent prairie fires that were reported by Danish settlers to have occurred in the Dannebrog area well into the 1880's (Orr 1983). As a result of fire suppression, understory vegetation becomes more dense and inhibits oak reproduction (Brudvig and Asbjoensn 2005). This helps to explain the present day species composition of Hannibal Woods where thickets of Prunus virginiana (chokecherry), rough-leaved dogwood, and red cedar border the area.

Even though the lower Oak Creek area was wooded, early Danish settlers in the area utilized cottonwood and willow from the nearby Loup River flood plain to construct rafters and roofing materials for their sod houses (Orr 1983). Over the years, continuous ownership and protection of the site by the Hannibal Family has been essential to the botanical integrity of this unique area.

Following the early years of settlement, the rapid population decline in the Dannebrog area could also have been a factor in the preservation of Hannibal Woods. Dannebrog's current population of 254 is significantly less than the Nebraska Census of 1910, which documented more than 1000 Danish immigrants in the Dannebrog area (Orr 1983). The Depression of the 1930's and numerous droughts and farm crises have contributed to a gradual human exodus from the area. Therefore, there has been little pressure to develop Hannibal Woods for housing or agricultural uses.

The average size class of mature bur oaks that were measured was 84.0 cm (dbh). This is especially remarkable when compared to a study in Seward County where the largest size class of mature bur oak trees was just 30 cm or greater (Beightol and Bragg 1993). Although the oaks appear to be reproducing, additional monitoring of Hannibal Woods should be made to determine if the mature oaks are replacing themselves or will ultimately be succeeded by other woody species.

Considering the frequency of severe windstorms in this area, it is also noteworthy that this mature stand of trees has survived for well over 100 years. Howard County lies in the “tornado alley” region of
Thirty-five tornados were reported between 1950-2001 with 19 of those occurring after 1982.

Table 1. The ten major plant families at Hannibal Woods.

<table>
<thead>
<tr>
<th>Families</th>
<th>Genera</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poaceae</td>
<td>35</td>
<td>61</td>
</tr>
<tr>
<td>Asteraceae</td>
<td>24</td>
<td>38</td>
</tr>
<tr>
<td>Fabaceae</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td>Cyperaceae</td>
<td>3</td>
<td>14</td>
</tr>
<tr>
<td>Polygonaceae</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Chenopodiaceae</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Brassicaceae</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Rosaceae</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Euphorbiaceae</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Verbenaceae</td>
<td>2</td>
<td>5</td>
</tr>
</tbody>
</table>

Total Species = 165
(~61% of total flora)

**ANNOTATED CHECKLIST**

The majority of taxa in this list are documented by voucher specimens deposited in the University of Nebraska – Kearney Herbarium. Species collected and observed were classified, based on site location and estimated abundance, using the following abbreviations:

**Site Descriptions**
D = Disturbed (roadside/trailside) sites where the soil has been disturbed, including trails, the border area between Highway 11 and Hannibal Woods, roadsides, and areas that border the trail.
R = Runoff/drainage areas; wet areas that border the site.
S = Sand prairie; open grassland that borders the site on the southeast side.
W = Woodland; gallery forest and sites that are shaded by trees.

**Rarity**
1 = Rare (single isolated individuals)
2 = Infrequent (widely scattered)
3 = Occasional (small groups/clumps)
4 = Common (thick patches)
5 = Abundant (large patches; many individual plants)

It should be noted that abundance estimates are somewhat subjective by nature. Some plant populations reflect seasonal variations, while others are often subject to the effects of disease, herbivory, and disturbance.

* Denotes new county record

**DIVISION CONIFEROPHYTA**

CUPRESSACEAE (Cypress Family)
*Juniperus virginiana* L. (red cedar). Invasive in forest openings as well as in the sand prairie. D-3

**DIVISION POLYPODIOPHYTA**

OPHIOGLOSSACEAE (Adder's Tongue Family)
*Botrychium virginianum* (L.) Sw. (rattlesnake fern). Very shade tolerant, understory species; encountered only twice. W-1

POLYPODIACEAE (True Fern Family)
*Matteuccia struthiopteris* (L.) Todaro (ostrich fern). One colony of this species was noted along the trail on the northwest side of the woods. This is likely an introduction. W-2

**DIVISION MAGNOLIOPHYTA**

ACERACEAE (Maple Family)
*Acer negundo* L. (boxelder). Occurring as an understory tree in gallery forest. W-3

*Acer saccharinum* L. (silver maple). Uncommon here, but one large tree was observed on the north bank of Oak Creek. W-1

AMARANTHACEAE (Pigweed Family)
Amaranthus retroflexus L. (rough pigweed). Invasive species along the trail. D-3

Froelichia florida (Nutt.) Moq. (field snake-cotton). Widespread in the sand prairie. S-4

Froelichia gracilis (Hook.) Moq. (slender snake-cotton). Along the trail and in the sand prairie on the southeast side. S-3

ANACARDIACEAE (Cashew Family)
*Rhus glabra L. (smooth sumac). Disturbed trailside sites on the east side. D-4

Toxicodendron radicans (L.) O. Ktze. (poison ivy). Growing as a shrub on the edge of thickets and as a vine in wooded areas. D-3; W-4

APIACEAE (Parsley Family)
Osmorhiza longistylis (Torr.) DC. var. longistylis (anise root). Scattered throughout woodland understory. W-4

Sanicula canadensis L. (black snakeroot). A very common understory species. W-5

APOCYNACEAE (Dogbane Family)
* Apocynum cannabinum L. (Indian hemp dogbane). Common roadside species and along the trail on the south and west sides. D-5

ASCLEPIADACEAE (Milkweed Family)
Asclepias arenaria Torr. (sand milkweed). On sandy sites, southeast side. S-3

Asclepias sullivantii Engelm. (smooth milkweed). Uncommon; collected in sand prairie. S-1

Asclepias syriaca L. (common milkweed). Trailside/roadside species; open areas especially near Highway 11. D-4

ASTERACEAE (Sunflower Family)
Achillea millefolium L. (yarrow). In sandy soil along the road and trail on the east side. D-2

*Ambrosia trifida L. (giant ragweed). Near woody thickets on the west side and along the road that borders the Danish Cemetery. D-4

*Arctium minus Bernh. (common burdock). A common herbaceous understory species. W-3

*Aster ericoides L. (heath aster). A native aster, widespread in this region; more common in upland prairie. S-3

*Aster lanceolatus Willd. (white paniced aster). Frequently occurring in moist, low areas on the east side of the site. S-3

Aster praealtus Poir. (willowleaf aster). Infrequently encountered near the trail on the east side of the study area. D-2

Bidens cernua L. (nodding beggar's ticks). Scattered with *Bidens frondosa* in low, semi-shaded drainage area on the east side. R-2

Bidens frondosa L. (devil's pitchfork). In semi-shaded drainage area on the east side. R-2

Carduus nutans L. (musk thistle). Fortunatley encountered only once along the trail on the west side. D-2

Cirsium altissimum (L.) Spreng. (tall thistle). Fairly common roadside species on the west side and along the edge of the woodland. D-3

*Cirsium vulgare* (Savi) Ten. (bull thistle). Invasive species along the trail, rarely encountered. D-2

Conyza canadensis L. (horseweed). Common roadside and trailside species in a sandy or silty soils. D-4

Erigeron annuus (L.) Pers. (annual fleabane). Sporadic in disturbed areas on the trail (south side). D-2

Erigeron strigosus Muhl. ex Willd. (prairie fleabane). Occasional plants occur within stands of *Bromus inermis* in clearings on the west side. D-3

Eupatorium rugosum Houtt. (white snakeroot). A plant of shaded and semi-shaded areas. W-2

*Galinsoga parviflora* Cav. (quickweed). Encountered mainly on the east side of the site along the road and near the cemetery. D-3

*Galinsoga quadriradiata* R. & P. (fringed quickweed). Semi-shaded habitat along the cemetery road on the east side. D-4

*Gnaphalium obtusifolium* L. (fragrant cudweed). A common sand prairie species. S-3

Haplopappus spinulosus (Pursh) DC. (cutleaf ironplant). Scattered in the sand prairie on the southeast side. S-3

*Helianthus annuus* L. (common sunflower). Along the trail on the southeast side. D-3

Helianthus petiolaris (plains sunflower). Scattered in sand prairie area. S-2

Helianthus rigidus (Cass.) Desf. (stiff sunflower). In the sand prairie that borders the site on the southeast side. S-3

*Helianthus tuberosus* L. (Jerusalem artichoke). Common to semi-shaded areas along the road (east side) and near Oak Creek on the west side of the site. W-3

Heterotheca villosa (Pursh) Shinners var. villosa (golden aster). Restricted to sandy, disturbed ground on the south side of the site. S-2

Kuhnia eupatorioides L. (false boneset). Scattered between the trail and Highway 11 on the west side. D-3
Lactuca canadensis L. (wild lettuce). Uncommon here; an invasive species on the west side of Hannibal Woods along the trail. W-2

Lactuca serriola L. (prickly lettuce). Invasive species in disturbed soil along the trail and along Highway 11. D-4


*Liatris lancifolia* (Greene) Kittell (tall gayfeather). Occasionally encountered in the sand prairie. S-2

*Liatris squarrosa* (L.) Michx. var. glabrata (Rydb.) Gaiser. (scaly blazing star). The most common species of *Liatris* in this area. S-3

Ratibida columnifera (Nutt.) Woot. & Standl. (prairie coneflower). Common in the sand prairie and along the south side of the trail. S-3

Rudbeckia laciniataum L. (goldenglow). Uncommon plant found on the south banks of Oak Creek. R-2


Solidago canadensis L. (Canada goldenrod). A common roadside species on the northeast side; trailside on the east side. D-4

*Solidago gigantea* Ait. (giant goldenrod). A trailside species on the south side. D-3

Solidago missouriensis Nutt. (Missouri goldenrod). Common in sand prairie on the south side of the site. S-3

*Solidago gigantea* Ait. (giant goldenrod). A trailside species on the south side. D-3

*BIGNONIACEAE (Bignonia Family)*
*Catalpa speciosa* Warder (northern catalpa). In woody thicket near the trail; southwest side of the site. W-2

*BORAGINACEAE (Borage Family)*
*Hackelia virginiana* (L.) I.M. Johnst. (stickseed). Our most common stickseed inhabiting moist woods. W-3

*Lithospermum carolinense* (Walt.) MacM. (puccoon). Scattered within the sand prairie and in disturbed sandy soils on the south side. S-4

*BRASSICACEAE (Mustard Family)*
*Arabis hirsuta* (L.) Scop. var. pycnocarpa (Hopkins) Rollins (rock cress). Infrequently encountered in gallery forest understory. W-2

*Capsella bursa-pastoris* (L.) Medic. (shepherd’s purse). A common weedy species along the trail. D-3

*Hesperis matronalis* L. (dame’s rocket). A roadside introduction that has entered the area from the west side. D-3

*Lepidium virginicum* L. (pepper grass). This adaptable annual is especially common on disturbed, dry areas along the trail and the cemetery road. D-3

*Vernonia baldwinii* Torr. (western ironweed). Along Highway 11 and in disturbed, sandy prairie. S-3; D-3

*Opuntia fragilis* (Nutt.) Haw. (little prickly pear). Forming clumps or small colonies in the sand prairie. S-3

*Opuntia macrohiza* Engelm. var. macrohiza (plains prickly pear). A larger cactus typical of sandy or rocky prairie soils. Here it is common in the sand prairie. S-3

*CACTACEAE (Cactus Family)*
*Gleditsia triacanthos* L. (honey locust). Collections from both the east and west sides of the Hannibal Woods site. D-3

*CAMPANULACEAE (Bellflower Family)*
*Campanula rapunculoides* L. (creeping or rover bellflower). Occasionally encountered understory species. W-2

*CAPPARACEAE (Caper Family)*
*Polanisia dodecandra* (L.) DC. ssp. trachysperma (T. & G.) Itis (clammy-weed). Occasionally collected in the sand prairie near the trail on the southeast side. S-2

*CAPRIFOLIACEAE (Honeysuckle Family)*
*Lonicera tatarica* L. (Tatarian honeysuckle). Semi-shaded areas where the trail enters the mature forest. W-3

*Sambucus canadensis* L. (common elderberry). Along the edge of thickets and along the trail; southwest side. D-3; W-2

*Symphoricarpos orbiculatus* Moench (coralberry). Occasional understory species; trailside and bordering thickets. W-3
CARYOPHYLLACEAE (Pink Family)
*Cerastium vulgatum* L. (common mouse-ear chickweed). Forming mats in the trail; occasional in sunny forest openings. W-3
*Saponaria officinalis* L. (bouncing bet). Roadside plant along Highway 11 and the trail on the west side. D-2
*Stellaria media* (L.) Cyr. (common chickweed). East side near the cemetery road and trail. D-3

CELASTRACEAE (Staff Tree Family)
*Celastrus scandens* L. (bittersweet). Collected only in a trailside thicket on the west side. W-1

CHENOPODIACEAE (Goosefoot Family)
*Chenopodium album* L. (lamb's quarters). Common roadside weed (along Highway 11) and along the trail on the south side. D-3
*Chenopodium missouriense* Aellen. (Missouri goosefoot). In semi-shaded areas with *Agastache nepitoides* and *Urtica dioica* on the west side of Hannibal Woods. D-3
*Chenopodium pratericola* Rydb. (goosefoot). This fast-growing annual is mostly a trailside/roadside plant in this area. D-3
*Chenopodium simplex* (Torr.) Raf. (maple-leaved goosefoot). Semi-shaded areas along the trail on the west side and along the cemetery road. W-3
*Cycloloma atriplicifolium* (Spreng.) Coult. (tumble ringweed). Invasive species on sand prairie sites. S-3
*Salsola collina* Pall. (tumbleweed). A weedy species, infrequently encountered in the sand prairie. S-2
*Salsola iberica* Senn. & Pau (Russian thistle). Scattered on disturbed, sandy sites on the southeast side. D-3

COMMELINACEAE (Spiderwort Family)
*Commelina communis* L. (dayflower). Shaded roadside area near the Danish Cemetery; understory species. R-2; W-3
*Tradescantia bracteata* Small. (spiderwort). A common prairie plant in sandy soil. S-3
*Tradescantia occidentalis* (Britt.) Smyth (spiderwort). Sandy area along the trail on the southwest side. S-2

CONVOLVULACEAE (Morning Glory Family)
*Calyxestgia sepium* (L.) R. Br. (hedge bindweed). On sunny or semi-shaded sites along the trail growing mainly on the southwest side. R-3
*Convolvulus arvensis* L. (Field bindweed). Roadside/trailside plant on both the west and east sides of the site. D-3

CORNACEAE (Dogwood Family)
*Cornus drummondii* C. A. May (rough-leaved dogwood). A common understory tree in the gallery forest and in trailside thickets. W-4

CYPERACEAE (Sedge Family)
*Carex blanda* Dew. (woodland sedge). Common understory sedge; gallery forest. W-4
*Carex brevior* (Dew.) Mack. ex Lunell (fescue sedge). With *Poa pratensis* and annual bromes along the trails. D-4
*Carex emoryi* Dew. (Emory's sedge). Scattered in low drainage area on the east side. R-3
*Carex gravida* Bailey var. *gravida* (heavy sedge). Along the road and trails on the east and west sides. D-3
*Carex grisea* Wahl. ex Willd. (inflated narrow leaf sedge). Several small patches; uncommon understory species. W-2
*Carex leavenworthii* Dew. (Leavenworth sedge). Surprisingly abundant in Hannibal Woods understory. W-4
*Carex molesta* Mack. ex Bright (troublesome sedge). A rare species here collected from the understory flora. W-1
*Carex pellita* Muhl. (wooly sedge). Fairly common sedge in low roadside habitats. R-3
*Carex vulpinoidea* Michx. (fox sedge). Scattered within wet, low sites along Highway 11, southwest side. R-3
*Cyperus lupulinus* (Spreng.) Marcks (Houghton flatsedge). A trailside sedge in dry clay or sandy soils. D-3
*Cyperus odoratus* L. (rusty flatsedge). A flatsedge occurring in low wet areas on the east side of the site. R-3
*Cyperus schweinitzii* Torr. (Schweinitz flatsedge). A common plant in the sand prairie. S-4
*Cyperus strigosus* L. (straw-colored flatsedge). Collected in low wet areas on the east side of the site. R-3
*Eleocharis palustris* (L.) R. & S. (spikerush). On the east side of the site in low, wet areas. R-3

EUPHORBIACEAE (Spurge Family)
*Acalypha virginica* L. (three-seeded mercury). Understory herbaceous plant. W-3
*Euphorbia glyptosperma* Engelm. (ridge-seeded spurge). Scattered in sand along the trail on the south side. S-3
Euphorbia hexagona Nutt. (six-angled spurge). A common plant in the sand prairie on the southeastern side of the site. S-3

Euphorbia marginata Pursh (snow-on-the-mountain). Occasional in the sand prairie and along roadsides. D-2; S-3

Euphorbia missurica Raf. (Missouri spurge). Weedy trailside plant; south side. D-2

FABACEAE (Bean Family)

Amorpha canescens Pursh (leadplant). Plants are scattered in sandy soil. S-3

*Astragalus canadensis J. Morris (Canada milkvetch). Occasionally found in the sand prairie area. S-2

Dalea villosa (Nutt.) Spreng. (silky prairie clover). Typical sand prairie species; occasional here. S-2

Lespedeza capitata Michx. (round-head lespedeza). Common on sandy soils along the trail on the south and southeast side. S-3

Medicago lupulina L. (black medic). Weedy plant; both trailside and recorded on the south and west. D-4

Melilotus alba Medic. (white sweet clover). A roadside plant near Highway 11. D-4

Melilotus officinalis (L.) Pall. (yellow sweet clover). Mixed with Bromus inermis mostly along the west side of the trail. D-3

Psoralea digitata Nutt. (palm-leaved scurf-pea). Common member of the sand prairie flora. S-3

*Psoralea lanceolata Pursh (lemon scurf-pea). Collected at only two locations in the sand prairie. S-2

Robina pseudoacacia L. (black locust). In woody thicket near the trail; southwest side of the site. W-2


Trifolium pratense L. (red clover). Trailside plant on the south side of the site. D-3

*Trifolium repens L. (white clover). Trailside plant on the south and east sides of the site. D-3

Vicia villosa Roth (hairy vetch). Common roadside plant along Highway 11 and the west trail. D-4

FAGACEAE (Oak Family)

Quercus macrocarpa Michx. (bur oak). Elegant stands of this oak along with Fraxinus pensylvanica dominate the Hannibal Woods overstory. Individual trees are likely over 150 years old. W-5

GROSSULARIACEAE (Currant Family)

Ribes americanum P.Mill. (wild black currant). Occasionally encountered in shrubby thickets and in the forest understory. W-3

Ribes missouriense Nutt. (Missouri gooseberry). A common shrub in shaded and semi-shaded understory habitat. W-4

HYDRANGEACEAE (Hydrangea Family)

Philadelphus coronarius L. (mock orange). Collected only once in a thicket with Cornus drummondii; possibly escaped. W-1

HYDROPHYLLACEAE (Waterleaf Family)

*Ellisia nyctelea (L.) L. (waterpod). A weedy, roadside plant on the east side. D-3

JUGLANDACEAE (Walnut Family)

*Juglans nigra L. (black walnut). Scarce; one small tree recorded in a shaded area along the trail. W-1

JUNCACEAE (Rush Family)

Juncus balticus Willd. (Baltic rush). Scattered in the low, drainage area on the east side. R-3

Juncus interior Wieg. (interior rush). Occasional clumps of this species occur in wet areas and sandy soil along the trail. R-3; D-3

*Juncus tenuis Willd. (path rush). Moist, sandy area along the trail on the southeast side of the site. S-3

LAMIACEAE (Mint Family)

Agastache nepetoides (L.) O. Ktze. (catnip giant hyssop). Growing in disturbed ground, semi-shaded area along the west side of the trail and occasionally in forest openings. D-3; W-3

*Glechoma heteracea L. (ground ivy). In grassy clearings along the trail. W-4

*Hedeoma hispida Pursh (rough false pennyroyal). Sandy ground on the southwest side and in the sand prairie. S-4

*Leonurus cardiaca L. (motherwort). Common along the trail in wooded areas. W-3

LILIACEAE (Lily Family)

*Asparagus officinalis L. (asparagus). Escaped into trailside sites and clearings. D-3

*Convallaria majalis L. (lily-of-the-valley). Introduction restricted to a single area on the west side of the forest. W-2

Polygonatum biflorum (Walt.) Ell. (Solomon's seal). Small colonies of this species were occasionally encountered on understory sites. W-2
Smilacina stellata (L.) Desf. (spikenard) A common understory species. W-3

LINACEAE (Flax Family)
*Linum rigidum* Pursh var. *rigidum* (stiffstem flax). Native flax in the sand prairie. S-3

MALVACEAE (Mallow Family)
*Callirhoe alchaeoides* (Michx.) A. Gray. (pink poppy mallow). Collected in sandy soil along the trail on the south side. D-2

MOLLUGINACEAE (Carpetweed Family)

MORACEAE (Mulberry Family)
*Morus alba* L. (white mulberry). Occasional large trees along the trail and along fence lines. W-4

NYCTAGINACEAE (Four O’Clock Family)
*Mirabilis nyctaginea* (Michx.) MacM. (wild four-o’clock). Common near the cemetery road; along the trail and near Highway 11. D-4

OLEACEAE (Olive Family)
*Fraxinus pensylvanica* Marsh (green ash). A dominant overstory species with *Quercus macrocarpa*. W-5

ONAGRACEAE (Evening Primrose Family)
*Epilobium coloratum* Biehler (purple-leaved willow-herb). An uncommon plant collected on the east side near the drainage area. R-2
*Gaura parviflora* Dougl. (velvety guara). Somewhat weedy; along the trail on the south and east sides. D-2
*Oenothera biennis* L. (common evening primrose) Scattered in sandy soil on the south side of the site. S-4
*Oenothera rhombipetala* Nutt. ex T. & G. (fourpoint evening primrose). Common on sandy sites along the trail on the east and southeast sides. S-3

OXALIDACEAE (Wood Sorrel Family)
*Oxalis dillenii* Jacq. (gray-green wood sorrel). A trailside plant most common on the east and south sides. D-3
*Oxalis violacea* L. (violet wood sorrel). A scarce understory plant in this area. W-2

*Oxalis stricta* L. (yellow wood sorrel). A typically common understory plant. W-3

PLANTAGINACEAE (Plantain Family)
*Plantago lanceolata* L. (buckhorn). Roadside/trailside species on the south and west sides. D-3
*Plantago patagonica* Jacq. var. *patagonica* (Patagonian plantain). A prominent species in the sand prairie. S-4
*Plantago rugelii* Dcne. (Rugel’s plantain). Growing in the road and along the trail on the east side. D-3

POACEAE (Grass Family)
*Agrostis stolonifera* L. (redtop). Scattered in stands of *Bromus inermis* on the west side of the site. D-3
*Andropogon hallii* Hack. (sand bluestem). Occasional in disturbed sandy sites; southeast side. S-3
*Andropogon gerardii* Vitmann (big bluestem). Scattered between the trail and Highway 11 on the west side. D-3
*Aristida basiramea* Engelm. ex Vasey (forktip three-awn). Infrequent clumps growing on sandy, disturbed sites. S-2
*Aristida oligantha* Michx. (prairie three-awn). Occasionally encountered in the sand prairie. S-3
*Bouteloua curtipendula* (Michx.) Torr. (sideoats grama). Uncommon here, perhaps due to the dry nature of the sand prairie. S-4
*Bouteloua gracilis* (H.K.B.) Lag. ex Steud. (blue grama). A very adaptable prairie grass found here in the sand prairie. S-3
*Bromus ciliatus* L. (fringed brome). Another understory species that tolerates moist, shaded habitats. W-2
*Bromus japonicus* Thunb. ex Murr. (Japanese brome). This species is one of the weedy invaders on the east side. It occasionally inhabits sandy, grassland sites. D-4
*Bromus latifolium* (Schribn. ex Shear) Hitchc. (ear-leaved brome). A native brome on shaded understory sites. W-2
*Bromus squarrosus* L. (square brome). Roadside species, east side. D-3
*Bromus tectorum* L. (downy brome). A rapidly spreading annual brome scattered along roadsides and along the trail. D-4
*Calamovilfa longifolia* (Hook.) Scribn. (prairie sandreed). Along the fence line on the east side and in the sand prairie. S-3; D-2
Cenchrus longispinus (Hack.) Fern. (sandbur). In sandy disturbances along the walking trail; southeast side of the site. D-2

*Chloris verticillata* Nutt. (windmill grass). Small "tumblegrass" that invades sandy sites. S-3

Dactylis glomerata L. (orchard grass). A roadside plant east of Highway 11 and an infrequent species along the trail. D-2

Dichanthelium oligosanthes (Sch.). Gould var. scribnerianum (Nash) Gould (Scribner dichanthelium). A low-growing species that is common in the sandy area on the west side. S-3

*Digitaria cognata* (Schult.) Pilg. (fall witchgrass). Scattered along the trail and in the sand prairie on the southeast side. S-3

*Digitaria sanguinalis* (L.) Scop. (hairy crabgrass). A roadside/trailside invader on the northeast side. D-3

Echinochloa crusgalli (L.) Beauv. (barnyard grass). Collected along the trail and near Highway 11 on the west side of the site. D-3

Echinochloa muricata (Beauv.) Fern. var. microstachya Wiegard (barnyard grass). A weedy invasive plant on the east side. D-3

*Eleusine indica* (L.) Gaertn. (goosegrass). Along the road in moist soil just south of the cemetery. D-3

*Eleusine indica* (L.) Gaertn. (goosegrass). Along the road in moist soil just south of the cemetery. D-3

Echinochloa crussgalli (L.) Beauv. (barnyard grass). Collected along the trail and near Highway 11 on the west side of the site. D-3

Echinochloa muricata (Beauv.) Fern. var. microstachya Wiegard (barnyard grass). A weedy invasive plant on the east side. D-3

*Elymus canadensis* L. (Canada wild rye). Common to low areas on the east side. R-3

*Elymus trachycaulus* (Link) Gould ex Shinners (slender wheatgrass). Although infrequent, this understory graminoid is widely distributed. W-2

*Elymus virginicus* L. var. virginicus (Virginia wildrye). Roadside plant on the west side. D-3

Elytrigia intermedia (Host.) Nevski (intermediate wheatgrass). Along Highway 11 and the walking trail on the west side of the site. D-3

Elytrigia repens (L.) Nevski. (quack grass). Near the trail and Highway 11 on the west side. D-3

*Eragrostis citianensis* (All.) E. Mosher (stinkgrass). Scattered in the cemetery road on the east side, this species tolerates several soil types. D-3

*Eragrostis hypnoides* (Lam.) B.S.P. (teal lovegrass). In gravel and sand along the cemetery road on the east side. D-4

*Eragrostis pectinacea* Michx. (Carolina lovegrass). Common along the trail and the road on the east side of the site. D-3


*Eragrostis trichodes* (Nutt.) Wood (sand lovegrass). Scattered within sandy sites on the southeast and south sides. S-3

*Festuca arundinacea* Schreb. (tall fescue). Roadside plant occurring with *Bromus inermis* and *Panicum virgatum*. D-3

*Hordeum jubatum* L. (foxtail barley). A roadside species along Highway 11. D-4

*Hordeum pusillum* Nutt. (little barley). Associated with *Lepidium* and *Thlaspi* on the south side of the trail. D-4

*Leersia virginica* Willd. (whitegrass). In semi-shaded low area on the east side; understory species on disturbed sites. R-3; W-4

*Leptochloa fascicularis* (Lam.) A. Gray (bearded sprangletop). Very adaptable to the dry, sandy soils on the south and east sides of the study area. D-2; S-3

*Lolium perenne* L. var. perenne (perennial ryegrass). Mixed with *Bromus inermis* and *Phleum pratense* within grassy openings. D-3

*Muhlenbergia frondosa* (Poir.) Fern. (wirestem muhly). Roadside near Highway 11 and growing in semishaded locations on the east side of the site. D-3

*Muhlenbergia mexicana* (L.) Trin. (Mexicana muhly). Common in the shaded, understory of the oldgrowth forest. W-3

*Muhlenbergia racemosa* (Michx.) B.S.P. (marsh muhly). This grass, found growing in clumps shaded by *Prunus pumila*, was collected in the sand prairie. S-2

*Panicum capillare* L. (witchgrass). A weedy plant along the trail (south side) in both sandy and clay soils. D-3.

*Panicum dichotomiflorum* Michx. (fall panicum). On disturbed sites along the cemetery road (East side) and the trail. D-3

*Panicum virgatum* L. (switchgrass). One of the more dominant species in the sand prairie. S-5

*Pascopyron smithii* (Rydb.) A. Love (western wheatgrass). Uniformly scattered prairie plant. S-4

*Paspalum setaceum* Michx. var. stramineum (Nash.) D. Banks (sand paspalum). A common annual grass on sandy soils. S-3

*Phalaris arundinacea* L. (reed canarygrass). This species has become established in a drainage area along Highway 11 on the southwest side of the site. R-4

*Phleum pratense* L. (timothy). Scattered along the highway and the trail. D-3

*Poa compressa* L. (Canada bluegrass). Shaded areas near the cemetery and along the road. D-2
Poa pratensis L. (Kentucky bluegrass). Along trails and in roadside ditches; occasional forest understory plant. D-4; W-2

*Setaria glauca* (L.) Beauv. (yellow foxtail). Most often encountered on the south side in sandy soils and sunny openings along the trail. D-3

*Setaria viridis* (L.) Beauv. (green foxtail). Trailside species on the south side and along the cemetary road. D-4

*Sorghastrum nutans* (L.) Nash (Indian grass). Scattered between the trail and Highway 11 on the west side. S-3

*Sporobolus cryptandrus* (Torr.) A. Gray (sand dropseed). This species is not extremely abundant here but is typical of disturbed sites and sandy soils. D-3; S-4

*Stipa spartea* Trin. (porcupine grass). Bunch grass common to the sand prairie. S-3


*Triplasis purpurea* (Walt.) Chapm. (sandgrass). Scattered along the trail and in the sand prairie on the southeast side. S-3

*Vulpia octoflora* Walt. (sixweeks fescue). Widely scattered in sandy soil, this species is often overlooked later in the growing season. S-4

**POLEMONIACEAE** (Polemonium Family)

*Phlox paniculata* L. (fall phlox). Uncommon understory species, often flowering in late summer or fall in this area. W-2

**POLYGONACEAE** (Buckwheat Family)

*Eriogonum anuum* Nutt. (annual eriogonum). Occasionally encountered in the sand prairie. S-3

*Polygonum aerastrum* Jord. ex Bor. (knotweed). Weedy plant on the south side of the site. D-3

*Polygonum coccinimum* Muhl. (water smartweed). Large patches of this species were found between the trail and Highway 11 on the west side. R-3

*Polygonum lapathifolium* L. (pale smartweed). In low, wet drainage area on the south side of the site. R-3

*Polygonum pensylvanicum* L. (Pennsylvania smartweed). Collected in low, wet areas on the west side of the site. R-2

*Polygonum scandens* L. (false buckwheat). Trailside plant on the southwest side and occasional in forest openings. W-2; D-3

*Rumex crispus* L. (curly dock). Along Highway 11 on the west side of the site. D-3


**PORTULACACEAE** (Purslane Family)

*Talinum parviflorum* Nutt. (prairie fameflower). Uncommon plant in the disturbed sand prairie on the west side of the site. S-2

**RANUNCULACEAE** (Buttercup Family)

*Clematis virginiana* L. (virgin's bower). In thickets of small shrubs and trees; uncommon. W-2

*Ranunculus abortivus* L. (early wood buttercup). Common understory herbaceous plant; best observed in spring. W-4

*Ranunculus sceleratus* L. var. *sceleratus* (cursed crowfoot). In low, wet drainage area on the south side of the site. R-3

**ROSACEAE** (Rose Family)

*Geum canadense* Jacq. (white avens). A common understory species. W-3

*Prunus americana* Marsh (wild plum). Common in bordering thickets and on disturbed sites. D-4; W-4

*Prunus pumila* L. var. *besseyi* (Bailey) GI. (sand cherry). Occasionally encountered in shrubby thickets. W-2

*Prunus virginiana* L. (choke cherry). Forming thickets with *Cornus drummondii* and *Prunus americana*. W-4

*Rosa arkansana* Porter (prairie wild rose). Quite common in the sand prairie. S-4

*Rubus occidentalis* L. (black raspberry). Understory species; roadside on the east side. W-3; D-3

**RUBIACEAE** (Madder Family)

*Galium aparine* Nutt. (catchweed bedstraw). Somewhat aggressive understory plant. W-3


*Galium triflorum* Michx. (sweet-scented bedstraw). Occasionally occurring understory species with *Carex leavenworthii*. W-2

**SALICACEAE** (Willow Family)

*Populus deltoides* Michx. ssp. *monilifera* (Ait.) Eckenw. (eastern cottonwood). Several trees occur near the roadside on the southwest side of the site. D-4

*Salix amygdaloides* Anderss. (peachleaf willow). Occasional examples occur on the south and west sides of the site. D-3

*Salix exigua* Nutt. subsp. *interior* (Rowlee) Cronq. (coyote willow). Scattered on low sites on the south and west sides and in sandy soil along the abandoned railroad line. D-3

*Eriogonum anuum* Nutt. (annual eriogonum). Occasionally encountered in the sand prairie. S-3
SCROPHULARIACEAE (Figwort Family)
*Penstemon grandiflorus* Nutt. (shell-leaf penstemon). Very common to sandy sites in this area; infrequent here. S-2

*Verbascum thapsus* L. (common mullein). Especially common on sandy sites south of the trail; south side. S-4

*Veronica arvensis* L. (corn speedwell). Near the trail on the south side. D-2

*Veronica perigrina* L. var *xalapensis* (H.K.B.) St.J. & War. (purslane speedwell). Weedy species in sandy soil and along the trail on the south side. D-3

SIMAROUBACEAE (Quassia Family)
*Ailanthus altissima* (P. Mill.) Swingle (tree of heaven). Along roadside near cemetery; disturbed drainage area. R-1

SMILACACEAE (the Catbrier Family)

SOLANACEAE (Nightshade Family)
*Physalis heterophylla* Nees (clammy ground cherry). Roadside plant on the west side and intermixed in the sand prairie to the southeast. D-3; S-4

*Solanum carolinense* L. (Carolina horse-nettle). Scattered between the trail and Highway 11 on the west side. D-2

*Solanum interius* Rydb. (plains black nightshade). Along the trail on the south side and occasional between the trail and Highway 11 on the west side. D-3

*Solanum ptycanthum* Dun. ex DC. (black nightshade). Collected along the cemetery road and in the sand prairie. D-3; S-3

TYPHACEAE (Cat-tail Family)

ULMACEAE (Elm Family)
*Celtis occidentalis* L. (hackberry). A common tree in Hannibal Woods but not a dominant species. W-3


*Ulmus pumila* L. (Siberian elm). This tree is occasionally encountered along the trail on the east side and is invasive on the west side. It is uncommon within the actual forest. D-3

ULMACEAE (Elm Family)
*Ulmus rubra* Muhl. (slippery elm). This species is uncommon in central and western Nebraska, but several thickets of slippery elm occur on the west side of Hannibal Woods. W-4

URTICACEAE (Nettle Family)

*Parietaria pensylvanica* Muhl. ex Willd. (Pennsylvania pellitory). A shade-tolerant understory species also found in openings along the trail. W-3; D-3

*Pilea pumila* (L.) A. Gray (clearweed). Uncommon in the low areas on the east side of the site. R-2

*Urtica dioica* L. (stinging nettle). Invasive species in shaded and semi-shaded areas along the trail. W-3

VERBENACEAE (Vervain Family)
*Phryma leptostachya* L. (lopseed). Typically inhabits shaded understory sites. W-2

*Verbena bracteata* Lag. & Rodr. (prostrate vervain). In sand soils on the south side of the site and along the road on the east side. D-3

*Verbena hastata* L. (blue vervain). Collected only from the semi-shaded drainage area on the east side of the site. D-2

*Verbena stricta* Vent. (hoary vervain). Common in the sandy area which encroaches along the south trail. S-4

*Verbena urticifolia* L. (nettle-leaved vervain). Collected along the trail on the west side of Hannibal Woods and also within the woodland. W-2

VIOLACEAE (Violet Family)
*Viola pratincola* Greene (blue prairie violet). Most noticeable in open areas along the trail and in the woodland understory. W-3

*Viola sororia* Willd. (downy blue violet). The common understory violet in this area. W-4

VITACEAE (Grape Family)
*Parthenocissus vitacea* (Knerr) Hitchc. (woodbine). In association with *Fraxinus pensylvanica* and *Ulmus spp.* along the trail on the west side. W-3

*Vitis riparia* Michx. (river-bank grape). A common vine in sunny and shaded locations. W-4
CONCLUSION

This project was initiated as part of a botanical survey that extended throughout the middle Loup River Valley. However, subsequent studies at the Hannibal Woods site indicate that its botanical value and natural beauty are very significant. A combination of soils, topography, and species interactions plus the prominence of Oak Creek, a permanent stream, have contributed to the formation of a diverse plant community that is atypical for this part of Nebraska. The resulting discovery of 86 new county records in such a small area (16 Ha) is extremely noteworthy (D. Sutherland et al. 2006 personal communication). Although the amount of interest and plant collecting intensity in Nebraska has increased in recent years, it is encouraging that many botanical discoveries have yet to be made. As future taxonomic studies are considered, Hannibal Woods deserves to be included among those unique natural sites that significantly enhance and contribute to the flora of the state.

ACKNOWLEDGEMENTS

The author wishes to thank the Nebraska Game and Parks Commission and the Office of Graduate Studies and Research at the University of Nebraska – Kearney for their support, Steve Rolfsmeier and Gerry Steinauer who were originally part of the Loup River Study and assisted with plant identification, Rick Simonson, graphics, Mrs. Ray (Shirley) Johnson for historical information, and the Howard County Register of Deeds Office for access to the original Land Survey of the area.

LITERATURE CITED


Churchill, S.P. 1979. A botanical survey of Cuming County: Part II, the Bryophytes; with additions to part I, the vascular plants. Transactions of the Nebraska Academy of Sciences 7:61-64.


FLORISTIC RECORDS IN THE PLATTE AND LOUP RIVER BOTTOMLANDS OF PLATTE COUNTY, NEBRASKA

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ABSTRACT

A recent inventory of vascular plants in the Loup and Platte riverbottoms in Platte County has greatly increased knowledge of the area’s flora. Of the 542 species of vascular plants now known to grow in the county, 289 were discovered after 1977, with more than 100 of those after 1990. 425 native and 117 naturalized species are known so far. Nearly 700 native and naturalized alien species are expected to occur in the county, based upon totals from nearby counties. Thus, almost 150 years after European settlement, more than 20% of the species remain unverified; of those, many are undoubtedly non-native. The riverbottoms of the county have the best-preserved native flora and are today much richer in species than the uplands, which are more heavily impacted by agriculture.

† † †

Ecology and Background

The area of union of the Loup River system with the Platte River basin near Columbus, Nebraska, provides a collective view of the plants found in both river systems. A comprehensive floristic determination for this area could be valuable for evaluation of future land-use impacts in those large watersheds. Growing threats of climate changes could have significant effects on local plant communities. Establishing accurate lists of species is important for detecting signs of change in our local flora.

With ninety-nine percent of the original tall-grass, mixed-grass and wetland prairies plowed for agriculture or used for grazing, populations of many once-common native species are now drastically reduced. Agriculture and urbanization have significantly altered the landscape for many species. As land-use disturbances continue at a rapid rate, bottomland floras are now more diverse, heterogeneous mixes of plants than in presettlement times. The absence of frequent prairie fires and the invasion of many exotics threaten remaining fragments of native prairie and original bottomland forests.

History of Plant Collecting in Nebraska and Platte County

Published reports of Nebraska's flora begin with explorers Lewis and Clark in 1803-6, Nuttall and Bradbury in 1808, James of the Long Expedition in 1820, the Fremont Expedition in the 1840s, and the Warren Expedition of 1857. Among the early attempts to list Nebraska’s complete flora are two catalogues, those of Samuel Aughey (1876) and H. J. Webber (1890). Local studies in the state have produced numerous floristic lists for counties and other areas. A detailed list of such publications from 1804 through 1985 is presented by Kantak and Churchill (1986); others are cited by Kaul et al. (2006). The state's vegetation was mapped at 1:1,000,000 by Kaul and Rolfsmeier (1993), and some detail was shown for Platte County. Satellite imagery is depicted at 30-meter resolution by the Nebraska Gap-Analysis Project (1993).

The earliest plant collections in Platte County were by Edwin James of the Long Expedition to the Rocky Mountains in 1820, who traveled the Platte Valley across Nebraska and made many original documentations of Nebraska plant life (Goodman and Lawson 1995). The plants James documented in what is now Platte County are Lithospermum incisum, fringed puccoon; Cirsium sp., a thistle; Vicia americana, American purple vetch (not on our list); Rhus glabra, smooth sumac; Asclepias speciosa, showy milkweed; Toxicodendron radicans, poison ivy;
Apocynum cannabinum, hemp dogbane; Helianthus petiolaris, plains sunflower; Amorpha fruticosa, wild-indigo; Gaura coccinea, scarlet gaura; Monarda pectinata, a mint not on our list; Potamogeton nodosus, floating-leaf pondweed; Rubus occidentalis, black raspberry; Sparganium eurycarpum, bur-reed; Callirhoe involucrata, purple poppy-mallow; Plantago patagonica, woolly plantain; and Anemone canadensis, meadow anemone.

The junction of the Loup and Platte rivers at Columbus was a landmark for Pawnee Indians in the 1820s (Ducey 2000). Warren (1875) noted that the valley of the Loup Fork was well wooded as far up as the Pawnee villages to the west of present-day Platte County. The Platte River at Columbus was described as having a sand bottom and many sandbars, and the floodplain was said to be from two to ten miles wide, as it is today. In 1844, Carleton reached the fork of the Loup and Platte Rivers and remarked:

The bed of the river is but one wide expanse of quicksand, which is formed in bars and these are continually changing and driving about. The channels are innumerable, but are usually only a foot or so deeper than the surrounding water. The river is filled with beautiful islands. They are all well wooded, but only here and there is there any timber growing upon the main bank. Sometimes we found the channels between the islands and the shore, entirely dry, presenting to the eye a wide extent of sand, which as the wind swept over it, was blown about in clouds, as one would notice on a barren coast of the ocean. The bottomlands are what would be called high river prairie (Carleton 1844-1846 (1983)).

Curry (1950) wrote that when the city of Columbus was founded, prior to 1870, the grass “blue-joint” grew thick and matted, was taller than a man’s head and common in the area. It was reported to grow between twelve and fifteen feet tall along the sloughs in the area and defied any attempts by primitive plows. (The plant called blue-joint today is Calamagrostis canadensis, which never grows that tall, and perhaps Curry was describing Phragmites australis, common reed, which reaches such height in moist habitats. Calamagrostis canadensis is not on our list of vouched species, but it is known from several adjacent counties and is undoubtedly in Platte County today.)

The Loup River drains much of the Sandhills, which are less disturbed than most areas of the state, but the substitution of cattle for bison has altered grazing patterns and affected native flora there. The Platte River originates in Colorado and has numerous diversions, with significant irrigation usage and storage along the entire watercourse. Row-crop agriculture dominates its borderlands.

METHODS

Our 12-year sampling period, 1996-2007, documents species within the Platte and Loup River bottoms after 150 years of settlement by Euro-Americans in these watersheds. For completeness and comparison, we list all species ever collected in Platte County, as documented by specimens deposited in various university herbaria, especially that of the University of Nebraska-Lincoln, which houses many specimens we collected. The list was assembled from Atlas of the Flora of the Great Plains (Great Plains Flora Association 1977), The Flora of Nebraska (Kaul et al. 2006), and our own observations and collecting. It consists almost entirely of plants collected in the bottomlands of Platte County, because very little collecting has been done in the much-disturbed, heavily agricultural uplands north of those bottomlands, most of whose species also occur in the bottomlands. This congregation of plants of river bottoms appears to be common in the lower reaches of the Platte River.
Figure 1

Platte County Map Showing Study Sites
Of Platte and Loup River Bottomlands
Figure 2. Aerial view of sites. Top: Witchey's Island Site, by the Platte River. North is at the top. The river was dry when the photograph was taken, and its braided bed is evident in the lower half of the picture. Bottom: Loup River Site. North is at the top, and Columbus is just out of range to the north. 1 inch = .17 mile
The focus for observations and collection were two primary sites on the Platte and Loup Rivers, where two of the largest watersheds in Nebraska unite (Fig. 1). The Platte River site is Witchey’s Island (Fig. 2), a heavily wooded area (but not now a true island) on the north bank of the Platte River, equidistant between Duncan and Columbus on a parcel of property almost a mile in length. Witchey’s Island has been grazed only minimally by livestock and natural deer populations, has not had fire for over 100 years, and has never been cultivated or farmed. It was homesteaded in 1864 by John Witchey, and according to historical record he maintained only a small garden and orchard. The Loup River site (Fig. 2) is on the south bank of the river and includes dense bottomland forest with open prairies, all on sandy soil.

The coordinates for most plants collected are as follows:

**Witchey’s Island-Platte River Site (Fig. 2 Top)**
- NW corner of site: Latitude 41.3809542, Longitude -97.445221
- NE corner of site: Latitude 41.3834823, Longitude -97.430938
- SW corner of site: Latitude 41.3765672, Longitude -97.444935
- SE corner of site: Latitude 41.3779800, Longitude -97.430747

**Loup River Site (Fig. 2 Bottom)**
- NW corner of the site: Latitude 41.4162131, Longitude -97.367379
- NE corner of site: Latitude 41.4139801, Longitude -97.354334
- SW corner of the site: Latitude 41.4079510, Longitude -97.366522
- SE corner of site: Latitude 41.4083231, Longitude -97.354334

Lake Babcock, three miles northwest of Columbus, was another sampling location, as was Buck Island on the Loup River southeast of the city. But most collecting was at the established Loup and Platte River study sites because of their ease of access and the intact nature of their flora. The sampling locations were walked during the spring, summer and fall growing seasons, typically on a weekly basis, to identify species not previously vouchered.

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<th></th>
<th>Trees</th>
<th>Shrubs</th>
<th>Lianas</th>
<th>Herbs</th>
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<td>20</td>
<td>7</td>
<td>385</td>
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<tr>
<td>Introduced</td>
<td>8</td>
<td>10</td>
<td>1</td>
<td>98</td>
<td>117</td>
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<tr>
<td><strong>totals</strong></td>
<td><strong>21</strong></td>
<td><strong>30</strong></td>
<td><strong>8</strong></td>
<td><strong>483</strong></td>
<td><strong>542</strong></td>
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</table>
RESULTS AND DISCUSSION

The native and naturalized species known so far are summarized in Table 1 above, and the full list of those species follows the text, as Table 2.

The Witchey's Island site is representative of an eastern Nebraska riparian forest with a mixed-hardwood community, where the tree canopy is Celtis occidentalis, hackberry; Fraxinus pennsylvanica, green ash; Morus alba, white mulberry; Quercus macrocarpa, bur oak; and Ulmus americana, American elm. Cottonwoods, Populus deltoides, are present, but not to the large size of those in the Loup River site. The representative shrubs for this community are Cornus drummondii, rough-leaved dogwood; Ribes missouriense, Missouri gooseberry; Symphoricarpos occidentalis and S. orbiculatus, wolfberry and coralberry; and Zanthoxylum americanum, prickly-ash. Abundant woody vines (lianas) form jungle-like tangles: Parthenocissus quinquefolia, Virginia creeper, and P. vitacea, woodbine; Smilax hispida, green brier; Toxicodendron radicans, poison ivy; Menispermum canadense, moonseed; and Vitis riparia, riverbank grape. The herbaceous plants in this community include Carex spp., sedges; Elymus canadensis, Canada wild rye; Ageratina altissima, white snakeroot; Muhlenbergia ssp., muhly grasses; Sanicula canadensis, Canada sanicle; and Viola sororia, sister violet. This community occurs in the floodplains of rivers and streams in the eastern fourth of the state and extends only slightly westward into central Nebraska, along the Loup and Platte River systems. Western wild rose, Rosa woodsii, is more typical of central and western Nebraska, but it is abundant and robust here.

The Loup River site is also representative of eastern Nebraska riparian woodland, where the tree canopy is represented by cottonwood, many of them 10-30 m in height. The subcanopy contains Acer negundo, boxelder; Gleditsia triacanthos, honey locust; Fraxinus pennsylvanica, green ash; Ulmus americana, American elm; and Morus alba, white mulberry — all common at this site. Shrubs include Cornus drummondii, Ribes missouriense, Sambucus canadensis (elderberry), and Symphoricarpos orbiculatus. Parthenocissus quinquefolia, Toxicodendron radicans and Vitis riparia are also common. Representative herbaceous plants include Ageratina altissima, white snakeroot; Galium aparine, bedstraw; Geum canadense, white avens; Poa pratensis, Kentucky bluegrass; Rudbeckia laciniata, cutleaf coneflower; and Viola sororia, sister violet—all common to abundant.

Recent intrusions of exotic, invasive species are evident: Lythrum salicaria, purple loosestrife; Euphorbia esula, leafy spurge; and introduced genotypes of Phragmites australis, common reed. We witnessed their rapid proliferation, but Tamarix ramosissima (salt-cedar) is not yet known in the study area, although it is rampant to the west, along the Platte. Some species apparently are moving upriver, east to west, such as Robinia pseudoacacia, black locust; Catalpa speciosa, northern catalpa; and Lonicera tatarica, Tatarian honeysuckle. The invasive exotics Amur honeysuckle (Lonicera maackii) and autumn-olive (Elaeagnus umbellata) were not present in or near our study sites, but their currently aggressive westward spread across Nebraska assures eventual arrival in Platte County.

The Loup River site has naturalized species such as Rhamnus cathartica, buckthorn; Convallaria majalis, lily-of-the-valley; and Lonicera tatarica, which are common there but not at the Witchey's Island site. The latter site harbors such natives as Hibiscus laevis, halberd-leaf rosemallow; Mimulus glabratatus, roundleaf monkey flower; Quercus macrocarpa, bur oak, and the introduced Lysimachia nummularia, moneywort — all rare or absent at the Loup River site. Prickly-ash, Zanthoxylum americanum, and rough-leaved dogwood, Cornus drummondii, both native to the area, are increasingly abundant in the understory at Witchey's Island, especially in heavily grazed places because livestock do not eat them. Black locust, Robinia pseudoacacia, and northern catalpa, Catalpa speciosa, both native to southeastern North America, are invading the forests near the confluence of the rivers. Siberian elm, Ulmus pumila, and white mulberry, Morus alba, both introduced to North America from Asia long ago, are established and abundant. A native invasive tree, red-cedar (Juniperus virginiana), is abundant in fields and even in deep forests, and here as almost everywhere across the state, it overwhelms native ecosystems.

Some species reach their western limits in or near these sites, e.g., Arisaema triphyllum (jack-in-the-pulpit), Zanthoxylum americanum (prickly-ash), Erythronium albidum (prairie fawnlily), Viola pubescens (smooth yellow violet), and Parthenocissus quinquefolia (Virginia creeper). Others reach their eastern limits in the same area, e.g., Opuntia fragilis, little prickly-pear.
Table 2. Platte County families and species of vascular plants documented. New records (boldface) are as compared to mapped records in *Atlas of the Flora of the Great Plains* (Great Plains Flora Assn. 1977). Some of these new records are mapped in *The Flora of Nebraska* (Kaul et al. 2006), whose nomenclature is used below. Introduced, naturalized species are indicated by an asterisk (*). Most of the vouchering specimens are in the Bessey Herbarium of the University of Nebraska State Museum, Lincoln.

<table>
<thead>
<tr>
<th>Family</th>
<th>Species</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACERACEAE</td>
<td><em>Acer ginnala</em>, Amur maple*</td>
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<td></td>
<td><em>Acer negundo</em>, boxelder</td>
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<td></td>
<td><em>Acer saccharinum</em>, silver maple, soft maple</td>
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<td>ADOXACEAE</td>
<td><em>Viburnum opulus</em>, highbush-cranberry*</td>
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<td>AGAVACEAE</td>
<td><em>Yucca glauca</em>, yucca</td>
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<tr>
<td>ALISMATACEAE</td>
<td><em>Sagittaria cuneata</em>, arrowhead, duck-potato</td>
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<td></td>
<td><em>Sagittaria latifolia</em>, arrowhead</td>
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<tr>
<td>AMARANTHACEAE</td>
<td><em>Amaranthus albus</em>, pale amaranth</td>
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<td><em>Amaranthus retroflexus</em>, redroot pigweed</td>
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<td><em>Amaranthus tuberculatus</em>, water-hemp</td>
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<td></td>
<td><em>Froelichia floridana</em>, snake-cotton</td>
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<td><em>Froelichia gracilis</em>, slender snake-cotton</td>
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<td><em>Rhus aromatica</em>, fragrant sumac*</td>
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<td><em>Rhus glabra</em>, smooth sumac</td>
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<td><em>Rhus typhina</em> &quot;Laciniata&quot;, staghorn sumac*</td>
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<td></td>
<td><em>Toxicodendron radicans negundo</em>, poison ivy</td>
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<td><em>Toxicodendron radicans rydbergii</em>, poison ivy</td>
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<td><em>Sanicula odorata</em>, cluster sanicle</td>
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<td><em>Spermolepis inermis</em>, scaleseed</td>
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<td><em>Asclepias speciosa x syriaca</em>, hybrid milkweed</td>
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<td><em>Asclepias viridiflora</em>, green milkweed</td>
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<td><em>Bidens connatus</em> (both varieties), beggarticks</td>
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<td><em>Bidens frondosus</em>, beggarticks</td>
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<td><em>Carduus nutans</em>, musk thistle*</td>
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<td></td>
<td><em>Cirsium altissimum</em>, tall thistle</td>
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**Eclipta prostrata**, yerba de tajo
**Erechtites hieraciifolia**, fireweed
**Erigeron annuus**, annual fleabane
**Erigeron philadelphicus**, marsh fleabane
**Erigeron strigosus**, daisy fleabane
**Eupatorium altissimum**, tall boneset
**Eupatorium maculatum v. brunerii**, spotted Joe Pye weed
**Eupatorium perfoliatum**, boneset
**Euthamia gymnocephalis**, goldentop
**Gnaphalium obtusifolium**, fragrant cudweed
**Grindelia squarrosa**, curly-cup gumweed
**Helenium autumnale**, sneezeweed
**Helianthrus annuus**, common sunflower
**Helianthus grosseserratus**, sawtooth sunflower
**Helianthus petiolaris**, plains sunflower
**Helianthus tuberosus**, Jerusalem artichoke
**Heliopsis helianthoides**, false sunflower
**Heterotheca latifolia**, camphor-weed
**Heterotheca villosa**, golden-aster
**Hydrophyllum tenuifolium**
**Iva annua**, marshelder
**Lactuca serriola**, prickly lettuce*
**Leucanthemum vulgare**, oxeye daisy*
**Liatris squarrosa**, gayfeather
**Liatris punctata**, gayfeather
**Matricaria matricarioides**, pineapple weed*
**Nothocalais cuspidata**, false dandelion
**Ratibida columnifera**, prairie coneflower
**Ratibida pinnata**, grayhead coneflower
**Rudbeckia hirta**, black-eyed Susan
**Rudbeckia laciniata**, cutleaf coneflower
**Senecio plattensis**, prairie ragwort
**Silphium integrifolium v. laeve**, rosinweed
**Silphium lacinatum**, compass plant
**Silphium perfoliatum**, cup plant
**Solidago canadensis**, Canada goldenrod
**Solidago gigantea**, tall goldenrod
**Solidago mollis**, soft goldenrod
**Solidago nemoralis**, gray goldenrod
**Taraxacum officinale**, dandelion*
**Thelesperma megapotamicum**, greenthread
**Tragopogon dubius**, goat's-beard*
**Vernonia baldwinii**, interior, western ironweed
**Xanthium strumarium**, spiny cocklebur

**BALSAMINACEAE**
**Impatiens capensis**, touch-me-not

**BERBERIDACEAE**
**Berberis vulgaris**, European barberry*

**BIGNONIACEAE**
**Catalpa speciosa**, northern catalpa*

**BORAGINACEAE**
**Hackelia virginiana**, stickseed
**Lithospermum caroliniense**, plains puccoon
**Lithospermum incisum**, fringed puccoon
**Onosmodium molle occidentale**, false gromwell

**BRASSICACEAE**
**Arabis hirsuta pycnocarpa**, rock cress
**Barbarea vulgaris**, winter cress*
**Capsella bursa-pastoris**, shepherd's-purse*
**Cardamine pensylvanica**, bitter cress
**Chorispora tenella**, blue mustard*
**Descurainia pinnata**, tansy mustard
**Descurainia sophia**, tansy mustard*
**Erysimum repanum**, bushy wallflower*
**Hesperis matronalis**, dame's rocket*
**Lepidium densiflorum**, pepper-grass
**Physaria ludoviciana**, bladderpod
**Rorippa palustris glabra**, bog yellow-cress
**Rorippa sessiliflora**, yellow-cress
**Sisymbrium loeselii**, tall hedge-mustard*
**Thlaspi arvense**, field penny-cress*

**CACTACEAE**
**Opuntia fragilis**, little prickly-pear
**Opuntia humifusa**, eastern prickly-pear

**CAESALPINIACEAE**
**Chamaecrista fasciculata**, showy partidge-pea
**Gleditsia triacanthos**, honey-locust
**Gymnocladus dioica**, Kentucky coffee tree

**CAPRIFOLIACEAE**
**Lobelia siphilitica**, great blue lobelia
**Lobelia spicata**, palespike lobelia
**Triodanis perfoliata**, Venus’s looking-glass

**CANNABACEAE**
**Cannabis sativa**, marijuana*
**Humulus lupulus**, hop

**CAPRIFOLIACEAE**
**Lonicera japonica**, Japanese honeysuckle*
Lonicera morrowii, Morrow's honeysuckle
Lonicera tatarica, Tatarian honeysuckle
Sambucus canadensis, elderberry
Symphoricarpos occidentalis, wolfberry
Symphoricarpos orbiculatus, coralberry

CARYOPHYLLACEAE
Agrostemma githago, corn-cockle
Arenaria serpyllifolia, thyme-leaf sandwort
Cerastium brachypodum, chickweed
Cerastium fontanum vulgare, chickweed
Dianthus armeria, Deptford pink
Holosteum umbellatum, jagged chickweed
Saponaria officinalis, soapweed, bouncing Bet
Stellaria media, common chickweed

CELASTRACEAE
Celastrus scandens, American bittersweet
Euonymus atropurpureus, wahoo

CELITIDACEAE
Celtis occidentalis, hackberry

CERATOPHYLLACEAE
Ceratophyllum demersum, coontail

CHENOPODIACEAE
Chenopodium glaucum, oakleaf goosefoot
Chenopodium simplex, maple-leaf goosefoot
Chenopodium standleyanum, Standley's goosefoot
Chenopodium strictum, goosefoot
Corispermum americanum, American bugseed
Cycloloma atriplicifolium, winged pigweed
Kochia scoparia kochia, summer cypress
Salsola tragus =S. iberica, Russian thistle

CISTACEAE
Lechea mucronata, pinweed

CLEOMACEAE
Polanisia jamesii, James's clammyweed

CLUSIACEAE
Hypericum perforatum, common St.John's-wort

COMMELINACEAE
Commelina communis, dayflower
Tradescantia occidentalis, spiderwort

CONVOLVLULACEAE
Calystegia macounii, Macoun's bindweed
Calystegia sepium angulata, hedge bindweed
Convolvulus arvensis, field bindweed
Ipomoea hederacea, ivyleaf morning-glory
Ipomoea purpurea, common morning-glory

CORNACEAE
Cornus drummondi, rough-leaf dogwood
Cornus sericea, red-osier dogwood

CRASSULACEAE
Penthorum sedoides, ditch stonecrop

CUCURBITACEAE
Echinocystis lobata, wild-cucumber
Sicyos angulatus, bur-cucumber

CUPRESSACEAE
Juniperus virginiana, eastern red-cedar

CYPERACEAE
Bolboschoenus fluviatilis, river bulrush
Carex bebbii, sedge
Carex blanda, sedge
Carex brevior, sedge
Carex comosa, sedge
Carex crawei, sedge
Carex davisii, sedge
Carex eleocharis, sedge
Carex emoryi, sedge
Carex granularis haleana, sedge
Carex gravida, sedge
Carex heliophila, sunsedge
Carex hystericina, sedge
Carex laeviconica, sedge
Carex meadii, sedge
Carex molesta, sedge
Carex pellita, sedge
Carex praegracilis, sedge
Carex sartwellii, sedge
Carex scoparia, sedge
Carex stipata, sedge
Carex tetanica, sedge
Carex vulpinoidea, sedge
Cyperus acuminatus, flatsedge
Cyperus bipartitus, brook flatsedge
Cyperus erythrorhizos, redroot flatsedge
Cyperus lupulinus lupulinus, flatsedge
Cyperus lupulinus x schweinitzii, flatsedge
Cyperus odoratus, rusty flatsedge
Cyperus schweinitzii, Schweinitz's flatsedge
Cyperus squarrosus, flatsedge
Cyperus strigosus, false nutsedge, umbrella sedge
Eleocharis compressa, spikerush
Eleocharis erythropoda, redstem spikerush
Schoenoplectus pungens, common threesquare
Schoenoplectus tabernaemontani, softstem bulrush
Scirpus pallidus, bulrush
Scirpus pendulus, bulrush

DRYOPTERIDACEAE
Onoclea sensibilis, sensitive fern

ELAEAGNACEAE
Elaeagnus angustifolia, Russian olive*

EQUISETACEAE
Equisetum arvense, field horsetail
Equisetum hyemale v. affine, scouring-rush
Equisetum laevigatum, scouring-rush

EUPHORBIACEAE
Acalypha rhomboidea, three-seeded mercury
Astragalus canadensis, Canadian milkvetch
Astragalus crassicarpus, ground-plum
Crotalaria sagittalis, rattlebox
Dalea leporina, hare's-foot dalea
Dalea purpurea purpurea, purple prairie-clover
Dalea villosa, silky prairie-clover
Desmodium glutinosum, large-flowered tick-clover
Glycyrrhiza lepidota, wild licorice
Lathyrus polymorphus, hoary vetch
Lespedeza capitata, round-head lespedeza
Lotus corniculatus, bird's-foot trefoil*
Lotus purshianus, prairie trefoil
Medicago lupulina, black medick*
Medicago sativa sativa, alfalfa*
Melilotus albus, white sweet-clover*
Melilotus officinalis, yellow sweet-clover*
Oxytropis lambertii, purple locoweed
Pediothelium argophyllum, silver-leaf scurfpea
Pediothelium digitatum, palmleaf scurfpea
Psoralidium lanceolatum, lemon scurfpea
Robinia pseudoacacia, black-locust*
Strophostyles helvula, wild bean
Strophostyles leiosperma, slickseed wild bean
Trifolium hybridum, Alsike clover*
Trifolium pratense, red clover*
Trifolium repens, white clover*
Vicia villosa, hairy vetch*

FAGACEAE
Quercus macrocarpa, bur oak

GENTIANACEAE
Gentiana andrewsii dakotica, bottle gentian
Gentiana puberulenta, downy gentian

GROSSULARIACEAE
Ribes missouriense, Missouri gooseberry

HYDROCHARITACEAE
Elodea nuttallii, elodea
Naias guadalupensis, naiad

HYDROPHYLLACEAE
Ellisia nyctelea, waterpod

IRIDACEAE
Belamcanda chinensis, blackberry lily*

FABACEAE
Amorpha canescens, leadplant
Amorpha fruticosa, wild-indigo
Apios americana, ground-nut
Iris germanica, bearded iris*
Iris pseudacorus, yellow iris, yellow flag*
Sisyrinchium campestre, blue-eyed grass
Sisyrinchium montanum, blue-eyed grass

JUGLANDACEAE
Juglans nigra, black walnut

JUNCACEAE
Juncus arcticus balticus, Baltic rush
Juncus brachyphyllus, shortleaf rush
Juncus dudleyi, Dudley's rush
Juncus interior, inland rush
Juncus torreyi, Torrey's rush

LAMIACEAE
Hedeoma hispida, rough false pennyroyal
Leonurus cardiaca, motherwort*
Lycopus americanus, American water-horehound
Lycopus asper, western water-horehound
Mentha arvensis, field mint
Monarda fistulosa, wild-bergamot
Monarda punctata occidentalis, horsemint*
Nepeta cataria, catnip*
Prunella vulgaris lanceolata, American heal-all
Prunella vulgaris vulgaris, European heal-all
Pycnanthemum virginianum, Virginia mountain-mint
Salvia reflexa, Rocky Mountain salvia
Scutellaria galericulata, marsh skullcap
Scutellaria lateriflora, mad-dog skullcap
Scutellaria parvula missouriensis, little skullcap
Teucrium canadense canadense, American germander
Teucrium canadense occidentale, American germander

LEMNACEAE
Lemna spp., duckweed
Spirodela polyrrhiza, greater duckweed
Wolffia columbiana, Columbian watermeal

LILIACEAE
Allium canadense canadense, wild onion
Allium canadense fraseri, wild onion
Allium canadense lavendulare, wild onion
Allium per dulce, fragrant onion

Asparagus officinalis, asparagus*
Convallaria majalis, lily-of-the-valley*
Erythronium albidum, prairie fawnlily
Hemerocallis fulva, daylily*
Hypoxis hirsuta, yellow star-grass
Polygonatum biflorum, Solomon's seal
Smilacina stellata, starry false Solomon's seal

LINACEAE
Linum rigidum simulans, stiff flax
Linum sulcatum, grooved flax

LYTHRACEAE
Ammannia robusta, toothcup
Lythrum alatum, winged loosestrife
Lythrum salicaria, purple loosestrife*

MALVACEAE
Abutilon theophrasti, velvet leaf*
Callirhoe alcaeoides, pink poppy-mallow
Callirhoe involucrata, purple poppy-mallow
Hibiscus laevis, halberd-leaf rose-mallow

MARSILEACEAE
Marsilea vestita, pepperwort, water-clover

MENISPERMACEAE
Menispermum canadense, moonseed

MIMOSACEAE
Desmanthus illinoensis, Illinois tick-clover

MOLLUGINACEAE
Mollugo verticillata, carpet-weed

MORACEAE
Morus alba, white mulberry*

NELUMBONACEAE
Nelumbo lutea, American lotus, chinkapin

NYCTAGINACEAE
Mirabilis hirsuta, hairy four-o'clock
Mirabilis nyctaginea, wild four-o'clock

NYMPHAECACEAE
Nymphaea odorata s.l., white waterlily

OLEACEAE
Fraxinus pennsylvanica, green ash
ONAGRACEAE
Calylophus serrulatus, plains evening-primrose
Gaura coccinea, scarlet gaura
Oenothera biennis, common evening-primrose
Oenothera rhombipetala, fourpoint evening-primrose

ORCHIDACEAE
Cypripedium candidum, white lady's-slipper

OXALIDACEAE
Oxalis dillenii, gray oxalis

PAPAVERACEAE
Argemone polyanthemos, prickly poppy

PHRYMACEAE
Phryma leptostachya, lopseed

PLANTAGINACEAE
Plantago lanceolata, English plantain*
Plantago patagonica patagonica, woolly plantain
Plantago rugelii, American plantain
Plantago virginica, plantain

POACEAE
Agropyron cristatum, crested wheatgrass*
Agrostis hysmalis, tinkle-grass
Agrostis stolonifera, redtop*
Andropogon gerardii Gerardii, big bluestem
Andropogon gerardii Hallii, sand bluestem
Aristida basiramea, forktip three-awn
Aristida oligantha, oldfield three-awn
Bouteloua curtipendula, sideoats grama
Bouteloua gracilis, blue grama
Bouteloua hirsuta, hairy grama
Bromus inermis, smooth brome*
Bromus japonicus, hairy chess, Japanese brome*
Bromus pubescens, Canada brome
Bromus tectorum, cheatgrass*
Buchloe dactyloides, buffalo grass
Calamovilfa longifolia, prairie sandreed
Cenchrus longispinus, sandbur
Chloris verticillata, windmill grass
Dactylis glomerata, orchard grass*
Digitaria cognata, fall wheatgrass
Digitaria ischaemum, smooth crabgrass*
Digitaria sanguinalis, hairy crabgrass*
Echinochloa crusgalli, barnyard grass*
Echinochloa muricata microstachya, barnyard grass
Eleusine indica, goosegrass*
Elymus canadensis, Canada wild rye
Elymus elongatus, tall wheatgrass*
Elymus hispidus, intermediate wheatgrass
Elymus repens, quackgrass*
Elymus smithii, western wheatgrass
Elymus trachycaulus trachycaulus, slender wheatgrass
Elymus villosus, hairy wild-rye
Elymus virginicus, Virginia wild-rye
Eragrostis cilianensis, stinkgrass*
Eragrostis pectinacea, Carolina lovegrass
Eragrostis spectabilis, purple lovegrass
Eragrostis trichodes, sand lovegrass
Eriochloa contracta, prairie cupgrass
Glyceria grandis, tall manna-grass
Glyceria striata, fowl manna-grass
Hordeum jubatum, foxtail barley
Hordeum pusillum, little barley
Koeleria macrantha, Junegrass
Leersia virginica, Virginian cutgrass
Lolium arundinaceum, tall-fescue
Lolium perenne, perennial ryegrass*
Miscanthus saccharifolius, silver grass, miscanthus*
Muhlenbergia frondosa, wirestem muhly
Muhlenbergia glomerata, muhly
Muhlenbergia mexicana, wirestem muhly
Muhlenbergia pungens, blowout
Muhlenbergia racemosa, marsh muhly
Panicum acuminatum, panic grass
Panicum capillare, common witchgrass
Panicum dichotomiflorum, fall panicum
Panicum leibergii, Leiberg panicum
Panicum oligosanthes scribnerianum, Scribner's panicum
Panicum virgatum, switchgrass
Paspalum setaceum stramineum, paspalum
Phalaris arundinacea, reed canary-grass*
Phleum pratense, timothy*
Phragmites australis, common reed
Poa annua, annual bluegrass*
Poa compressa, Canada bluegrass
Poa pratensis, Kentucky bluegrass (?)
Polypogon monspeliensis, rabbitfoot grass*
Redfieldia flexuosa, blowout grass
Schedonardus paniculatus, tumblegrass
Schizachyrium scoparium, little bluestem
Secale cereale, rye*
Setaria italica, foxtail millet*
Setaria pumila, yellow foxtail*
Setaria verticillata, bristly foxtail*
Setaria viridis, green foxtail*
Sorghastrum nutans, switchgrass
Sorghum bicolor, sorghum, milo*
Spartina pectinata, prairie cordgrass
Sphenopholis obtusata major, wedgegrass
Sphenopholis obtusata obtusata, wedgegrass
Sporobolus cryptandrus, sand dropseed
Sporobolus vaginiflorus, poverty grass
Stipa spartea, porcupine grass
Tridens flavus, purpletop grass
Tripsacum dactyloides, eastern gamagrass
Triticum aestivum, wheat*
Vulpia octoflora, six-weeks fescue
Zizania palustris interior, interior wildrice

POLEMONIACEAE

Phlox paniculata, summer phlox*

POLYGONACEAE

Eriogonum annuum, annual wildbuckwheat
Polygonum achoreum, knotweed
Polygonum aviculare, knotweed, wireweed*
Polygonum bicorne, pink smartweed
Polygonum coccineum, scarlet smartweed
Polygonum convolvulus, black-bindweed*
Polygonum lapathifolium, nodding smartweed
Polygonum pensylvanicum, Pennsylvania smartweed
Polygonum persicaria, smartweed*
Polygonum punctatum, water smartweed
Polygonum ramosissimum (all vars.), bushy knotweed
Polygonum scandens, climbing false-buckwheat
Polygonum tenue, slender knotweed
Rumex acetosella, sheep sorrel*
Rumex altissimus, pale dock, tall dock
Rumex patientia orientalis, patience dock*
Rumex stenophyllus, narrowleaf dock*

PONDEROSIACEAE

Heteranthera limosa, mud-plantain

PORTULACEAE

Phemeranthus parviflorus, prairie fameflower
Phemeranthus rugospermus, sand fameflower

POTAMOGETONACEAE

Potamogeton foliosus, leafy pondweed
Potamogeton illinoensis, Illinois pondweed
Potamogeton nodosus, floating-leaf pondweed
Potamogeton pectinatus, sago pondweed
Potamogeton pusillus, small pondweed

PRIMULACEAE

Androsace occidentalis, western rockjasmine
Lysimachia nummularia, moneywort*

RANUNCULACEAE

Anemone canadensis, meadow anemone
Anemone caroliniana, Carolina anemone
Aquilegia canadensis, columbine
Delphinium virescens, prairie larkspur
Ranunculus abortivus, kidney-leaf buttercup
Ranunculus flabellaris, yellow watercrowfoot
Ranunculus longirostris, white watercrowfoot
Ranunculus sceleratus, cursed crowfoot
Thalictrum dasycarpum, purple meadow-rue

RHAMNACEAE

Rhamnus cathartica, buckthorn*

ROSACEAE

Agrimonia gryposepala, agrimony
Geum canadense, white avens
Potentilla recta, sulfur cinquefoil
Prunus americana, American plum
Prunus pumila besseyi, sand cherry
Prunus tomentosa, Nanking cherry, bush cherry*
Prunus virginiana, chokecherry
Rosa arkansana, dwarf prairie-rose
Rosa multiflora, multiflora rose*
Rosa woodsii, western wild rose
Rubus occidentalis, black raspberry
**Rubiaceae**
- *Galium aparine*, cleavers
- *Galium circaezans*, woods bedstraw
- *Galium obtusum*, bluntleaf bedstraw

**Rutaceae**
- *Zanthoxylum americanum*, prickly-ash

**Salicaceae**
- *Populus alba*, silver poplar*
- *Populus deltoides occidentalis*, Plains cottonwood
- *Salix amygdaloides*, peach-leaf willow
- *Salix eriocephala famelica*, diamond willow
- *Salix exigua interior*, sandbar willow

**Santalaceae**
- *Comandra umbellata umbellata*, comandra, bastard toadflax

**Scrophulariaceae**
- *Agalinis tenuifolia parvifolia*, gerardia
- *Bacopa rotundifolia*, water-hyssop
- *Gratiola neglecta*, hedge-hyssop
- *Leucospora multifida*, leucospora
- *Lindernia dubia*, false pimpernel
- *Mimulus glabratus*, roundleaf monkeyflower
- *Mimulus ringens*, Allegheny monkeyflower
- *Penstemon albidus*, white beardtongue
- *Penstemon angustifolius angustifolius*, narrowleaf beardtongue
- *Penstemon buckleyi*, Buckley’s penstemon
- *Penstemon grandiflorus*, large beardtongue
- *Scrophularia marilandica*, eastern figwort
- *Verbascum blattaria*, moth mullein*
- *Verbascum thapsus*, common mullein*
- *Veronica anagallis-aquatica*, water speedwell*
- *Veronica catenata*, water speedwell*
- *Veronica peregrina peregrina*, purslane speedwell*
- *Veronica peregrina xalapensis*, purslane speedwell*
- *Veronica polita*, veronica*

**Simaroubaceae**
- *Ailanthus altissima*, tree-of-heaven*

**Smilacaceae**
- *Smilax hispida*, greenbriar, prickly catbriar

**Solanaceae**
- *Datura wrightii*, angel’s trumpet*
- *Physalis heterophylla*, ivyleaf groundcherry
- *Physalis longifolia*, common ground-cherry
- *Solanum carolinense*, horse-nettle
- *Solanum interius*, Plains black nightshade
- *Solanum ptycanthum*, black nightshade
- *Solanum rostratum*, buffalo bur

**Sparganiaceae**
- *Sparganium eurycarpum*, bur-reed

**Tylaceae**
- *Typha angustifolia*, narrowleaf cattail
- *Typha latifolia*, broadleaf cattail

**Ulmaceae**
- *Ulmus americana*, American elm
- *Ulmus pumila*, Siberian elm*
- *Ulmus rubra*, red elm, slippery elm

**Urticaceae**
- *Boehmeria cylindrica*, false nettle
- *Parietaria pensylvanica*, pellitory
- *Urtica dioica*, stinging nettle

**Verbeneae**
- *Lippia lanceolata*, northern fogfruit
- *Verbena bracteata*, prostrate vervain
- *Verbena hastata*, common vervain
- *Verbena stricta*, hoary vervain
- *Verbena urticifolia*, white vervain

**Violaceae**
- *Viola pubescens eriocarpa*, smooth yellow violet
- *Viola sororia*, sister violet

**Vitaceae**
- *Parthenocissus quinquefolia*, Virginia creeper
- *Parthenocissus vitacea*, woodbine
- *Vitis riparia*, riverbank grape

**Zannichelliaceae**
- *Zannichellia palustris*, horned pondweed

**Zygophyllaceae**
- *Tribulus terrestris*, puncture vine*
LITERATURE CITED


FIRST RECORD OF *PLAGIORCHUS MICRACANTHOS* (TREMATODA: PLAGIORCHIIDAE) FROM THE WESTERN SMALL-FOOTED MYOTIS, *MYOTIS CILIOLABRUM* (CHIROPTERA: VESPERTILIONIDAE)

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ABSTRACT

A western small-footed myotis (*Myotis ciliolabrum*) from South Dakota harbored 2 plagorchiid trematodes in its small intestine. Both trematodes were identified as *Plagiorchis micracanthos* Macy, 1931. This is the first report of *P. micracanthos* from *M. ciliolabrum*, and the first time this parasite has been reported in a bat from South Dakota. At least 10 other parasites are known to infect and/or infest *M. ciliolabrum* in North America.

† † †

The western small-footed myotis, *Myotis ciliolabrum* (Merriam 1886), is a small vespertilionid that occurs over much of western North America from central British Columbia, southern Alberta, and southwestern Saskatchewan, Canada, southward to Chihuahua, Coahuila, and Zacatecas, Mexico (Holloway and Barclay 2001). Two subspecies are recognized, *M. c. ciliolabrum* in the east and *M. c. melanorhinus* in the western part of the range (Hall 1981; van Zyll de Jong 1984).

Previous reports of parasites from this host include coccidia (Scott and Duszynski 1997; Scott et al. 1999), chiggers and mites (Krutzsch 1955; Bradshaw and Ross 1961; Jones et al. 1973), and nematodes (Measures 1994; Table 1). Herein, we document a new host and a new distributional record for a trematode parasite that is known to infect bats in North America.

METHODS

On 13 September 2006, an adult female *M. ciliolabrum* was collected by hand from the Prairie Wind Casino, located 16.1 km E Oglala in the Pine Ridge Indian Reservation, Shannon County, South Dakota (43°11.1'N, 102°59.3'W). We euthanized the bat by cervical dislocation and examined it for helminths by opening the gastrointestinal tract from the esophagus to anus. We then placed the GI tract in a Petri dish containing a 0.9% saline solution. We also examined feces for coccidial parasites following previously published methods (McAllister et al. 2004). The GI tract plus the liver, heart, reproductive tract, and urinary tract were examined using a stereomicroscope. Two trematodes were recovered in the small intestine, placed briefly in distilled water for egg ejection, and preserved in 70% ethanol. Trematodes were stained with Semichon's acetocarmine, dehydrated through a series of graded ethanol, cleared with xylene, and mounted in Canada Balsam.
A voucher specimen of the trematode was deposited in the United States National Parasite Collection (USNPC), Beltsville, Maryland (USNPC 99004). The *M. ciliolabrum* (skin and skull) was deposited in the Angelo State Natural History Collection (ASNHC), San Angelo, Texas (ASNHC 13038).

Table 1. Parasites reported from *M. ciliolabrum*.

<table>
<thead>
<tr>
<th>Parasite</th>
<th>Location</th>
<th>Prevalence</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Apicomplexa</em></td>
<td></td>
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<td></td>
</tr>
<tr>
<td><em>Eimeria pilarensis</em></td>
<td>NM</td>
<td>1/12 (8%)</td>
<td>Scott and Duszynski, 1997</td>
</tr>
<tr>
<td><em>Eimeria rioarribaensis</em></td>
<td>NM</td>
<td>4/22 (18%)</td>
<td>Scott et al., 1999</td>
</tr>
<tr>
<td><em>Trematoda</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Plagiorchis micracanthos</em></td>
<td>SD</td>
<td>1/1 (100%)</td>
<td>This study</td>
</tr>
<tr>
<td><em>Nematoda</em></td>
<td></td>
<td></td>
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</tr>
<tr>
<td><em>Longibucca lasiura</em></td>
<td>CANd</td>
<td>1/10 (10%)</td>
<td>Measures, 1994</td>
</tr>
<tr>
<td><em>Acari</em></td>
<td></td>
<td></td>
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<tr>
<td><em>Leptotrombidium myotis</em></td>
<td>SD</td>
<td>not stated</td>
<td>Turner and Jones, 1968</td>
</tr>
<tr>
<td><em>Macronyssidae</em> (nymphs)</td>
<td>CA</td>
<td>1/1 (100%)</td>
<td>Krutzsch, 1955</td>
</tr>
<tr>
<td><em>Macronyssus crosby</em></td>
<td>NM</td>
<td>1/1 (100%)</td>
<td>Ritzi et al., 2002</td>
</tr>
<tr>
<td><em>Ornithodoros sp.</em></td>
<td>AZ</td>
<td>not stated</td>
<td>Bradshaw and Ross, 1961</td>
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<tr>
<td><em>Spinturnix americanus</em></td>
<td>AZ</td>
<td>not stated</td>
<td>Bradshaw and Ross, 1961</td>
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<tr>
<td><em>Spinturnix carloshoffmanni</em></td>
<td>AZ</td>
<td>not stated</td>
<td>Bradshaw and Ross, 1961</td>
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<tr>
<td><em>Trombicula myotis</em></td>
<td>AZ</td>
<td>not stated</td>
<td>Bradshaw and Ross, 1961</td>
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<tr>
<td><em>Insecta</em></td>
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<tr>
<td><em>Cimex pilosellus</em></td>
<td>SD</td>
<td>not stated</td>
<td>Turner, 1974</td>
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</table>

- Prevalence = number infected/number examined (%).
- Baja California Norte and Sonora.
- Other *M. ciliolabrum* taken from near San Diego, California were uninfected; number not given.
- Alberta, Canada.

RESULTS AND DISCUSSION

No coccidia were found in the feces; however, the two trematodes found in the small intestine of *M. ciliolabrum* belonged to the family Plagorchiidae and were identified as *Plagiorchis micracanthos* Macy, 1931. This bat parasite has been previously reported from other vespertilionids including the little brown myotis (*Myotis lucifugus*) in New Mexico (Cain and Studier 1974) and Minnesota (Macy 1931), big brown bat (*Eptesicus fuscus*) in Minnesota (Macy 1931), gray myotis (*Myotis grisescens*) in Kansas (Ubelaker 1966), western pipistrelle (*Pipistrellus hesperus*) in Nevada, and eastern pipistrelle (*Pipistrellus [=Perimyotis] subflavus*) in Nebraska (Nickel and Hansen 1967). Interestingly, Manter and Debus (1945) reported this species of trematode from the California myotis (*Myotis californicus*) in Louisville, Cass County, Nebraska. However, the range of *Myotis californicus* is > 1,000 km to the west, so their host must be considered a misidentification (see Fig. 3 in Simpson 1993). Unfortunately, the identity of this bat will remain an enigma because a voucher specimen is not available.

A variety of parasites has been reported to infect/infest *Myotis californicus*, including 2 species of coccidia, 6 species of Acari, one insect, and a single species each of trematode and nematode in North America (Table 1). We have provided a new host and distributional record for *P. micracanthos*. Additional studies on helminths of bats of the northern Great Plains are warranted to further advance our knowledge of chiropteran parasites and their geographic distribution.
ACKNOWLEDGMENTS

We thank members of the Oglala Sioux Nation, Prairie Wind Casino for donating the bat to the senior author and the South Dakota Game, Fish and Parks for issuing our scientific collecting permit (No. 42). We also thank Drs. Loren Ammerman and Robert Dowler (ASNHC) for verifying the identity of the bat and Dale W. Sparks (Indiana St. University) and an anonymous reviewer for improving the ms.

LITERATURE CITED


ABSTRACT

Common carp (Cyprinus carpio) are a non-native fish in the United States. Due to their prolific nature, they may have detrimental effects on fish and waterfowl communities, including those of Nebraska Sandhill lakes. Information regarding population structure, age, and growth of common carp in Nebraska Sandhill lakes is lacking. We examined adult common carp populations from Marsh and Pelican lakes on the Valentine National Wildlife Refuge. We described size and age structure, growth, and recruitment patterns for these two populations. Age-frequency histograms revealed consistent recruitment of common carp through age 7 in Marsh Lake but inconsistent recruitment in Pelican Lake. Common carp growth was initially faster in Pelican Lake than in Marsh Lake, likely because of a less dense carp population in Pelican Lake. Pelican Lake contains northern pike (Esox lucius) and largemouth bass (Micropterus salmoides), top-level piscivores, while Marsh Lake contains no predatory fish species. The absence of top-level piscivores preying on age-0 common carp may have led to the denser population in Marsh Lake. Further research is recommended to understand fully the role of common carp in Sandhill lake communities.

† † †
for food and cover at various life stages (Forester and Lawrence 1978).

Because common carp can have substantial impacts on aquatic ecosystems, understanding basic population characteristics is a necessary first step to determine appropriate management strategies. This information, however, is lacking for populations in Nebraska Sandhill lakes. Therefore, our objective was to describe the size and age structure, growth, and recruitment patterns of common carp in Marsh and Pelican lakes, Nebraska.

**STUDY SITES**

Marsh Lake and Pelican Lake are located in Cherry County, Nebraska, on the Valentine National Wildlife Refuge. Marsh Lake has a surface area of 907 ha, and mean and maximum depths of 1.8 m and 2.6 m. Pelican Lake covers 332 ha, and has mean and maximum depths of 1.2 m and 1.9 m (Paukert and Willis 2000). Marsh Lake had lower aquatic macrophyte coverage (14% coverage of emergent and submergent vegetation), while Pelican Lake had moderate aquatic macrophyte coverage (37% total coverage; Paukert and Willis 2000). Both fish communities were simple but quite different -- Marsh Lake contained no top-level piscivores while Pelican Lake did. In addition to common carp, Marsh Lake primarily contained black bullhead (*Ameiurus melas*), golden shiner (*Notemigonus crysoleucas*), and yellow perch (*Perea flavescens*). Pelican Lake contained northern pike (*Esox lucius*), largemouth bass (*Micropterus salmoides*), yellow perch, bluegill (*Lepomis macrochirus*), and black bullhead.

**METHODS**

Common carp were sampled from Marsh Lake in April of 2006 using modified fyke nets (16-mm bar mesh, 1.1- by 1.5-m frames, and 22-m leads), while carp in Pelican Lake were collected with pulsed-DC (200-250 V, 3-6 A) boat electrofishing in July of 2006. Total length (mm) and weight (g) were recorded, and length-frequency histograms were generated to describe common carp population size structure in each lake. We then calculated proportional stock density (PSD; percentage of 28-cm and longer fish that also exceeded 41 cm) and relative stock density of preferred-length fish (RSD-P; the percentage of 28-cm and longer fish that also exceeded 53 cm) to quantify size structure (Gabelhouse 1984). The 95% confidence intervals (CI) for PSD and RSD-P were calculated as suggested by Gustafson (1988). Catch per unit effort (CPUE), an index of population abundance, was calculated as the mean number of fish ≥ stock length (i.e., 28 cm) captured per net night or per hour of electrofishing (Hubert 1996).

Asteriscus otoliths, the only validated aging structure for common carp (Brown et al. 2004), were removed from common carp to determine age and growth. Otoliths were mounted in epoxy and sectioned transversely through the nucleus using a low-speed Isomet saw. Two independent readers determined age in years with the aid of a microscope. Discrepancies in age assignments were resolved by examining the otoliths in unison. Age-frequency histograms were created to describe the age structure and assess recruitment patterns in both lakes. Growth was described as mean length by cohort at time of capture and von Bertalanffy growth parameters were determined for each population (Van Den Avyle and Hayward 1999).

Reproductive status and sex of pre-spawn common carp from Marsh Lake was recorded by determining sexual maturity through direct examination of gonads. We determined 50% maturity at length and age using probit analysis (Welch and Foucher 1988). Reproductive characteristics were not recorded from carp from Pelican Lake because they were sampled post-spawn (i.e., July).
Figure 1. Length frequency by 2-cm length groups for common carp sampled from Marsh and Pelican lakes, Nebraska in April and July of 2006, respectively.
Figure 2. Age frequency for common carp sampled from Marsh and Pelican lakes, Nebraska in April and July of 2006, respectively.
RESULTS

A total of 560 common carp was sampled from Marsh Lake and mean CPUE was 2.6 stock-length fish/trap net night. Total length ranged from 87 mm to 709 mm. The size structure was dominated by smaller individuals between 80 mm and 140 mm (Fig. 1). Proportional stock density was 51 (95% CI = ± 20) and RSD-P was 23 (95% CI = ± 16). Marsh Lake demonstrated relatively consistent recruitment through age 7 as no missing year classes were detected (Fig. 2). An abundant 2005 cohort dominated the sample (n=281). Growth of common carp in Marsh Lake was slow (Fig. 3). The von Bertalanffy growth coefficient \((K)\) was 0.173 and ultimate length \((L_{\infty})\) was 709 mm.

We observed 100 percent maturity for common carp of both sexes in Marsh Lake by 360 mm. The 50% total length at maturity (both sexes combined) was 312 mm (PROBIT, \(\chi^2 = 40.27, P < 0.0001\)) and the 50% age at maturity was 3.4 years (PROBIT, \(\chi^2 = 31.43, P < 0.0001\)). The smallest mature male was 171 mm while the smallest mature female was 348 mm.

A total of 63 common carp was collected from Pelican Lake and mean CPUE was 12.2 stock-length fish/hour electrofishing. Total length ranged from 90 mm to 865 mm. The size structure of common carp in Pelican Lake was dominated by individuals 600 mm and longer (Fig. 1). Proportional stock density for Pelican Lake was 98 (95% CI = ± 6) and RSD-P was 96 (95% CI = ± 7). The Pelican Lake population exhibited erratic recruitment with several missing year classes not included or not sampled. The population sample was dominated by the age-4 and -5 cohorts (2001 and 2002 year classes), with a maximum observed age of 16 years (Fig. 2). Growth was rapid up to age 4, where they reached asymptotic lengths (Fig. 3). The von Bertalanffy growth coefficient \((K)\) was 0.295 and \(L_{\infty}\) was 758 mm in Pelican Lake. Common carp exceeded 600 mm by age 4. We were unable to analyze maturity of common carp from Pelican Lake because they were collected after spawning.

DISCUSSION

Common carp population samples from our two study lakes were obtained with different gears and at different times of year, which may preclude direct comparisons between the two samples. However, while we suspect that length-related differences may occur between gears, the use of distinct gears does not explain the difference in recruitment patterns observed in the two lakes. The Pelican Lake population demonstrated erratic recruitment while common carp in Marsh Lake showed consistent recruitment, suggesting that carp recruitment patterns in Nebraska Sandhill lakes may be influenced by factors specific to individual lakes. Phelps (2006) found that common carp recruitment patterns in 18 eastern South Dakota lakes exhibited highly synchronous, erratic recruitment, presumably due to large-scale climatic factors.

We did not determine population abundance for common carp in our two study lakes. However, Pelican Lake likely had only a moderate population abundance based on the mean CPUE of 12.2 stock-length fish/hour electrofishing.
length fish/hour of electrofishing. Paukert and Willis (2000) collected common carp by electrofishing in nine Sandhill lakes, and four had a mean CPUE that exceeded the value for Pelican Lake, maximum CPUE was 77.1 stock-length fish/hr at Home Valley Lake. We had no comparison data for trap-net CPUE, so we cannot assess population abundance of common carp in Marsh Lake based on that index.

Pelican Lake had a 71-cm (28-in) maximum length limit for northern pike in an attempt to increase the abundance of large piscivores and reduce common carp abundance. Sammons et al. (1994) found that northern pike preyed on common carp in midsummer and winter in a South Dakota glacial lake and DeBates (2003) found that pike in Pelican Lake preyed upon age-0 carp in September and October. Furthermore, Pelican Lake has a 38-cm (15-in) minimum length limit for largemouth bass, another piscivore. The common carp population in Pelican Lake was characterized by larger, older, and faster-growing individuals than that of Marsh Lake, which lacked top-level piscivores. A lower overall population abundance in a predator-dominated fish community likely explains the faster growth of common carp in Pelican Lake. In contrast, the common carp in Marsh Lake had no predators; thus, the slower growth rate suggests a population with density-dependent growth.

Population characteristics differed in the two populations examined during this study; therefore, common carp recruitment patterns and factors influencing recruitment patterns in Nebraska Sandhill lakes may need to be assessed on a lake-by-lake basis. Given the substantial influence that this organism can have on entire aquatic ecosystems, we recommend further research to better understand population characteristics of common carp.

ACKNOWLEDGMENTS

We thank J. Klammer (Nebraska Game and Parks Commission) for assistance with the common carp electrofishing survey. D. Hartman and the Valentine State Fish Hatchery provided housing and logistic support. M. Lindvall and Valentine National Wildlife Refuge provided access to study lakes. C. Hoagstrom, E. Lorenzen, J. Rydell, and C. Symens provided field and laboratory assistance. Partial funding for this project was provided by the Nebraska Game and Parks Commission through Federal Aid in Sport Fish Restoration Project F-118-R.

LITERATURE CITED


NORTHERN PIKE (ESOX LUCIUS) POPULATION CHARACTERISTICS AND RELATIONS TO RECRUITMENT IN HACKBERRY LAKE, NEBRASKA

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ABSTRACT

Knowledge of the population structure of northern pike (Esox lucius), an important recreational and top-level piscivore, is essential to Nebraska Sandhill lakes management. We collected a sample of adult northern pike from Hackberry Lake in June and July of 2004. Proportional stock density (PSD) was 98 (95% CI = ± 3) and relative stock density of preferred-length fish (RSD-P) was 40 (95% CI = ± 9). Northern pike were aged using sagittal otoliths, and fish from the 1993 to the 2002 year classes were present in our population sample. Age-frequency histograms revealed relatively consistent recruitment of northern pike, as no missing year classes were detected, but year-class strength was variable among years. Examination of mean length at age suggested that growth was rapid in the first two years and slowed thereafter but was faster than populations in other locations, perhaps because this population is near the edge of the geographical range for this species. Year-to-year climatic variability may affect lake habitats, and slow growth and reduced size structure can result in lakes with high recruitment rates (Diana 1987).
The goal of this study was to describe northern pike population characteristics in Hackberry Lake, Nebraska. Specific objectives were to quantify size and age structure, growth rates, and recruitment patterns. We also explored potential climatological influences on year-class strength by examining relationships with temperature, precipitation, wind speed, and winter severity.

**STUDY SITE**

Northern pike were obtained from Hackberry Lake, a Nebraska Sandhill lake located in Cherry County in north-central Nebraska. This lake is large (275 ha), shallow (1.5 m mean depth, 2.1 m maximum depth), and moderately vegetated (38% coverage, Paukert and Willis 2000). The fish community consisted primarily of common carp (Cyprinus carpio), largemouth bass (Micropterus salmoides), bluegill (Lepomis macrochirus), yellow perch (Perea flavescens), northern pike, and black bullhead (Ameiurus melas). A complete description of the lake physicochemical characteristics can be found in Paukert and Willis (2000).

Angling regulations for northern pike included a three fish daily bag limit and maximum size limit of 71 cm (i.e. all fish ≥ 71 cm must immediately be returned to the lake), which has been in place since 1993. Finally, the lake was chemically renovated (e.g. rotenone) following this study (in September 2004) to remove an abundant common carp population.

**METHODS**

Northern pike were collected using four overnight experimental gill net sets in June and July of 2004. Experimental gill nets were of two different sizes. One net size was 36-m long with five 7.6-m panels of 1.9-, 2.5-, 3.8-, 5.1-, and 6.4-cm bar mesh. The other net used was 43-m long with six 7.6-m panels of 1.9-, 2.5-, 3.8-, 5.1-, 6.4-, and 7.6-cm bar mesh. Collected fish were placed on ice and returned to the laboratory for further processing.

Total length (TL; mm) and weight (g) were recorded from each specimen prior to removal of sagittal otoliths for aging. Some northern pike were damaged due to predation by snapping turtles (Chelydra serpentina) while in the gill nets; lengths and/or weights were not recorded from these individuals although otoliths were removed when possible. Although scales and cleithra have been used in the past to age northern pike (Casselman 1990, Laine et al. 1991), the use of otoliths has gained recent favor over many other bony structures to age fish (Secor et al. 1995, Casselman 1987). Sagittal otoliths were removed, polished, and dried. Otoliths were mounted in epoxy and sectioned through the focus using an Isomet low-speed saw. Several sections were mounted on a slide to ensure that annuli were not missed. Annuli were counted by two independent readers and disagreements were resolved by reading in concert.

Length- and age-frequency histograms were generated to describe size and age structure of northern pike. Size structure was further indexed using proportional stock density (PSD; the percentage of 35 cm and larger fish that also exceeded 53 cm) and relative stock density of preferred-length fish (RSD-P; the percentage of 35 cm and larger fish that also exceeded 71 cm; Gabelhouse 1984). Northern pike growth was described as mean length by cohort at time of capture.

A catch-curve analysis (Ricker 1975) was computed by regressing the log of number-at-age as a function of age for ages 2-11. Residuals produced from the catch-curve analysis were used to index year-class strength (Maceina 1997). Positive residuals represented relative strong year classes while negative residuals represented relative weak year classes. Bi-variate relationships between year-class strength (i.e. residual) and selected climatological variables (i.e. temperature, precipitation, wind, and winter severity) that corresponded with key time periods in northern pike spawning, larval, and juvenile stages were explored by conducting correlation analyses. Climatological data were obtained from the National Oceanic and Atmospheric Administration weather station in Valentine, Nebraska, located approximately 32 km from Hackberry Lake and operated by the National Weather Service. Climate variables examined were mean daily air temperature (°C), cumulative daily precipitation, mean daily wind speed (km/h), and winter severity (cumulative number of days where temperature was ≤ 0° C) in the first winter for an age-0 northern pike. Statistical analyses were conducted using the Statistical Analysis System (SAS 2000). Statistical significance was set a priori at α = 0.10 because this was an exploratory study with a low number of observation (i.e. year-classes).
Figure 1. Length frequency for northern pike sampled from Hackberry Lake, Nebraska in June and July 2004.

Figure 2. Age frequency for northern pike sampled from Hackberry Lake, Nebraska in July 2004.
Figure 3. Mean observed total length (± SE) at time of capture by cohort for northern pike in Hackberry Lake, Nebraska in 2004.

Figure 4. Plot of mean cumulative wind speed (km/h) for April, May, and June as a function of year-class strength (i.e., residual) for northern pike from Hackberry Lake, Nebraska.
RESULTS

A total of 139 northern pike was collected from Hackberry Lake between 16 June and 16 July 2004. Total length ranged from 490 mm to 860 mm with a mean of 679 mm (Fig. 1). Proportional stock density was 98 (95% CI = ± 3) and RSD-P was 40 (95% CI = ± 9) indicating a population dominated by larger individuals. One memorable-length (TL ≥ 86 cm) and no trophy-length (TL ≥ 112 cm; Gabelhouse 1984) northern pike were collected.

Ages ranged from 2 to 11, years corresponding to the 2002-1993 year classes (Fig. 2). Age-1 northern pike (2003 year class) were absent from our sample; however, those may not have been sampled effectively with our gill nets. Northern pike exhibited relatively consistent recruitment from 1993 to 2002, as no missing year-classes were detected. However, year class strength was variable as indicated by the erratic pattern in the age-frequency histogram (Fig. 2). The 2000-2002 year classes were weaker than expected in comparison with the more abundant, older age groups.

Growth was rapid through the first two years but slowed thereafter (Fig. 3). The mean length for age-3 fish (i.e., approximately 3.5 years of age) was 644 mm (SE = ± 10) while the mean length was 677 mm (SE = ± 12) for age-6 fish.

Mean combined wind speed for April, May, and June was negatively correlated with northern pike year-class strength (r = -0.57, P = 0.09; Fig. 4) while various measures of annual precipitation were not correlated with year-class strength. Combined March, April, and May mean daily air temperature and year-class strength were curvilinearly related (r = 0.81, P = 0.02; Fig. 5). Winter severity (cumulative number of days ≤ 0° C) was not significantly correlated with year-class strength (r = -0.40, P = 0.26).

DISCUSSION

The Hackberry Lake northern pike population had faster early growth rates (ages 2-4) than most populations in North America and Europe (Willis 1989; Neumann et al. 1994; Margenau et al. 1998). Paukert and Willis (2003) reported similar growth of northern pike in a study of 30 Sandhill lakes. Out of the 139 northern pike sampled in Hackberry Lake, only one memorable length and no trophy length fish were collected, suggesting that northern pike at the southern boundary of their natural geographic range may not attain large sizes due to physiological environmental limitations. Neumann et al. (1994) found that northern pike growth in Lake Thompson, South Dakota, was restricted during the high water temperature periods of summer.

The high observed PSD and RSD-P are indicative of a northern pike population dominated by larger individuals. The maximum size limit (71 cm) for anglers likely contributed to the observed size structure. The angling restrictions were established to protect larger northern pike that may control common carp recruitment through predation, Sammons et al. (1994) found that northern pike in a
South Dakota lake preyed on common carp in midsummer and winter. Our gill net sizes may not have captured smaller (i.e. age 1) northern pike effectively, as no substock size (TL < 350 mm; Gabelhouse 1984) fish were captured. Neumann and Willis (1994) caught no northern pike <340 mm in a South Dakota lake in a 25-mm (bar measure) gill net; the smallest gill net mesh size used in our study was 19 mm. Thus, we likely did not catch small (i.e., TL < 350 mm) northern pike because fish were not fully recruited to the gear. The Hackberry northern pike population exhibited relatively consistent but still variable recruitment. Paukert and Willis (2003) also reported variable northern pike recruitment, but missing year classes were rare. They suggested that among-lake variability in recruitment patterns might be attributable to lake-specific factors.

Northern pike year-class strength was curvilinearly related to mean combined March, April, and May air temperature, corresponding to the time period when northern pike are spawning, hatching, and entering their juvenile life stages. Because northern pike in our study lake are near the southwestern edge of their natural geographical range (Crossman 1996), warmer years may depress recruitment. Previous research has found positive relationships between temperature and recruitment but most of these studies occurred at more northerly latitudes (Kipling and Frost 1970; Casselman and Lewis 1996). Although water levels have been cited as important for spawning and nursery habitats (Casselman and Lewis 1996), thereby potentially affecting year class strength, precipitation was not related to year-class strength in Hackberry Lake over the range of years in our study. We suspect that the abundance of aquatic vegetation for spawning habitat in Sandhill lakes provided adequate resources for northern pike recruitment in most lakes. Mean combined wind speed for April, May, and June was weakly correlated with northern pike year-class strength. Wind has been reported to affect recruitment of other fishes through physical destruction of eggs, transport of eggs to unfavorable locations, and sedimentation on eggs. Hassler (1970) reported that higher mortality was associated with wind-induced siltation of embryos. Some combination of wind-related factors is likely to detrimentally affect northern pike recruitment in Hackberry Lake.

Finally, although winter severity has been implicated in high overwinter mortality of other fishes (Oliver et al. 1979; Adams et al. 1982; Miranda and Hubbard 1994), we found no evidence that recruitment of northern pike in Hackberry Lake was affected by severity of winter.

This research provides detailed information on a northern pike population in one Sandhill lake. However, we recommend further research in other lakes to fully understand the recruitment patterns of northern pike in Nebraska Sandhill lakes.

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EXERCISE AND DIABETES INFLUENCE ANTIOXIDANT ACTIVITY AND GENE EXPRESSION IN FEMALE RATS

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ABSTRACT

The goal of this study was to examine the influence of exercise training and type I diabetes on the activity of aconitase and superoxide dismutase (SOD), on levels of reduced glutathione (GSH), on the expression of genes responsible for glutathione synthesis (Gclc, g-glutamylcysteine synthase; Gss, glutathione synthetase), and on the expression of genes responsible for the formation of two potassium channels (Kcnd2, Ito; KCNQ1, IKs) in cardiac muscle. Forty female Sprague-Dawley rats were divided into four groups: sedentary controls, sedentary diabetics, trained controls, and trained diabetics. Diabetes was induced via streptozotocin injection, and training consisted of swimming up to 2 hours per day for 11 weeks. Aconitase activity and GSH levels were unchanged, but SOD activity was significantly elevated in trained diabetic rats compared with sedentary diabetic rats. Gss expression was significantly downregulated in diabetic rats compared with control rats. Kcnd2 expression was significantly downregulated in trained diabetic rats compared with sedentary diabetic rats, and KCNQ1 expression was consistently downregulated in trained rats compared with sedentary rats and in diabetic rats compared with control rats. These results suggest training alone or combined with diabetes increases antioxidant mechanisms and downregulates the expression of genes related to K⁺ ion channel activity.

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Ventricular arrhythmias are a leading contributor to sudden death in chronic disease states that are characterized by cardiac remodeling, including congestive heart failure, myocardial infarction, and diabetes mellitus (Kaprielian et al. 2002, Li et al. 2005, Oudit et al. 2001, Tsuchida and Watajima 1997). Potassium channels are of particular importance because they contribute to the repolarization and duration of the action potential characteristic of cardiac muscle. Recent work has demonstrated that reactive oxygen species (ROS), including superoxide, hydrogen peroxide, and hydroxyl radical, play an important role in the electrophysiological changes seen in chronic cardiac disease states. Mitochondrial aconitase, which irreversibly converts citrate to isocitrate in the citric acid cycle, is inactivated by superoxide and hydrogen peroxide (Bulteau et al. 2003), so its activity may be used to evaluate the level of oxidative stress. Superoxide also induces apoptosis via numerous mechanisms, including lipid peroxidation and protein denaturation, and is degraded to H₂O₂ by superoxide dismutase (SOD). Reduced glutathione (GSH), a major free radical scavenger produced by all cells, protects the heart against damage from H₂O₂ (Li et al. 2003), and its levels reflect the degree of oxidative challenge placed upon the tissue. g-glutamylcysteine synthase is responsible for catalyzing the synthesis of g-glutamylcysteine from glutamic acid and cysteine, and glutathione synthetase then catalyzes the synthesis of GSH from g-glutamylcysteine and glycine; the second reaction is ATP-dependent (Huang et al. 2000, Rozanski and Xu 2002). The ratio of GSH to its oxidized form, GSSG, is often used to evaluate the ability of the tissue to withstand oxidative stress. Moreover, GSH homeostasis appears to be influenced by glucose metabolism (Rozanski and Xu 2002). In diabetic rat hearts, the production of ROS is increased, and GSH depletion is responsible for the cell death that leads to cardiac disease (Ghosh et al. 2005, Shen et al. 2004). In both the failing heart
(Chen et al. 2005) and the diabetic heart (Ferreira et al. 2003, Fitzl et al. 2001), oxidative stress causes increased production of superoxide in the mitochondria, altering the expression of mitochondrial proteins (Shen et al. 2004). Oxidative stress has been suggested as the cause of elevated expression of redox-sensitive transcription factors in the cardiac tissue of diabetic rats as evidenced by increased activity of nuclear factor-κB and activating protein-1 (Nishio et al. 1998). In addition, overexpression of manganese SOD has been shown to reduce cardiomyopathy in a mouse model of type 1 diabetes mellitus (Shen et al. 2006).

While the benefits of exercise on overall health are well established, exercise is also associated with the production of ROS, potentially causing oxidative damage to cardiac muscle tissue (Ji 1999). In rodents, regular exercise has been shown to increase median lifespan (Hollofsy 1993) and to upregulate antioxidant defense mechanisms in rodent skeletal muscle, heart, and liver (Bronikowski et al. 2003, Ji 1999, Ji et al. 1998). In mice, voluntary exercise has been shown to attenuate age-related changes in cardiac gene expression, particularly by minimizing changes in genes associated with inflammation and responses to stress (Bronikowski et al. 2003, Jin et al. 2000). In rats, a distinct difference in cardiac gene expression has been reported between animals subjected to a physiological load (exercise training) and those subjected to a pathological load (myocardial infarction, congestive heart failure) (Jin et al. 2000), although physiological hypertrophy, a classic adaptation to chronic exercise training, has inconsistent effects on GSH levels in cardiac tissue in rodents (Dhalla and Singal 1994, Kanter et al. 1985, Lennon et al. 2004). However, as mentioned previously, GSH is influenced by glucose metabolism, and exercise training has been shown to influence both glucose metabolism and insulin sensitivity. Trained rats have increased cardiac glucose uptake at rest and during acute exercise compared with sedentary rats (Kainulainen et al. 1989). While the GLUT4 isoform of the glucose transporter is increased in skeletal muscle in response to exercise training (Hollofsy 1993), the GLUT1 isoform seems to play a more important role in cardiac muscle (Laybutt et al. 1997).

Potassium channels represent the largest and most diverse group of ion channels (Rasmussen et al. 2004, Roden and George 1997). At least nine different K+ currents have been identified and may be categorized into three groups: the calcium-independent voltage-gated (Kv) transient outward currents (I_{to1}, I_{to2}), the delayed outwardly rectifier currents (I_{Kr}, I_{Kr}, I_{Kur}), and the rapidly activating currents (I_{K1}, I_{KACH}, I_{KAPT}, I_{Kp}) (Nerbonne 2000, Roden and George 1997). These currents vary in density, voltage-dependent properties, and time-dependent properties, and in the heart the distribution of these channels affects the duration of the action potential (Viswanathan et al. 1999). Studies suggest that I_{to} density is decreased in heart failure (Li et al. 2002), as evidenced by decreases in mRNA expression and channel proteins for Kv (Huang et al. 2000, Yao et al. 1999). Increased extracellular levels of GSH upregulate I_{to} in isolated myocytes, possibly by increasing cellular uptake of cysteine, from rats with chronic myocardial infarction (Leopold and Loscalzo 2000, Rozanski and Xu 2002). This upregulation is also dependent upon glucose utilization (Rozanski and Xu 2002, Xu et al. 1996, Xu et al. 2002), and I_{to} current density has been shown to be decreased in the myocytes of animal models of altered glucose metabolism, including streptozotocin (STZ)-induced diabetic rats (Xu et al. 1996), genetically diabetic rats (Tsuchida and Watajima 1997), and insulin-resistant animal models (Shimoni et al. 2000). In rodents, I_{to} is the major determinant of action potential duration (Wang et al. 1994). Kv4.2, also known as Kcnd2, is the most abundant member of the Kv4 family of Kva subunits and encodes I_{to} in rats. All members of the Kv4 family are characterized by fast activation and inactivation (Nerbonne 2000). Unlike other transcripts, Kcnd2 is expressed in a steep gradient from the epicardium to the papillary muscles (Dixon and McKinnon 1994). Decreases in Kcnd2 mRNA have been measured in ventricular tissue from rats with STZ-induced diabetes (Nishiyama et al. 2001) and rabbits with heart failure (Rose et al. 2005). KCNQ1, also known as K_{LQT1}, is one of 5 members of the Kva subunit family for the K_{Va} current (Kubisch et al 1999, Wang et al. 1996, Yang et al. 1997). All members of this family are characterized by very slow activation and very, very slow inactivation (Nerbonne 2000). In the heart KCNQ1 combines with KCNE1 from the b subunit family to form I_{to} (Barhanin et al. 1996, Sanguinetti et al. 1996). KCNQ1 is widely distributed between individual cardiac cells (Rasmussen et al. 2004), and mutations of this component are responsible for a condition known as long QT syndrome (Wattanasirichaiagoon and Beggs 1998, Yang et al. 1997).

The major goal of this study was to examine the influence of exercise training and type 1 diabetes mellitus on the activity of aconitase and SOD and on the ratio of GSH/GSSG in cardiac tissue and to determine if exercise training and type 1 diabetes mellitus alter the expression of the genes responsible for...
for the synthesis of GSH, Gclc (g-glutamylcysteine synthase) and/or Gss (glutathione synthetase). A second goal was to determine if exercise training and type 1 diabetes mellitus alter the expression of genes responsible for two different K+ channels, Kcnd2 and KCNQ1. Our results suggest exercise training, alone or combined with diabetes, has little to no phenotypic effect on antioxidant mechanisms but downregulates the expression of KCNQ1. In addition, our results suggest exercise training may attenuate increases in blood glucose over time in insulin-deficient rats.

MATERIALS AND METHODS

Animals

All methods were consistent with the Guide for the Use and Care of Laboratory Animals published by the U.S. National Institutes of Health (NIH Publication No. 85-23, revised 1985), and were approved by the University of Nebraska at Kearney Institutional Animal Care and Use Committee (IACUC #91003-A). Forty female Sprague-Dawley rats (age 3 weeks) were obtained from Harlan Industries (Indianapolis, IN) and housed in the Bruner Hall of Science Animal Care Facility on the campus of the University of Nebraska at Kearney. Rats were kept under a 12:12 hour light-dark cycle (light from 0700 to 1900) and provided standard rat chow and water ad libitum. At age 4 weeks, type 1 diabetes mellitus (D) was induced in half the rats (n=20) via ip injection of STZ (65 mg/kg in 0.1 M citrate buffer, pH = 4.5). The remaining 20 control (C) rats received vehicle injection. Diabetic status was confirmed by measuring blood glucose levels 24 hours later using a tail-clip method and a glucometer (Roche Diagnostics Corp., Indianapolis, IN). The next week half the rats in each group (10 D rats, 10 C rats) began a daily swim-training regime in 30-35°C water. Exercise-trained (ET) rats began with 15 minutes of swimming on the first exposure, and swim time was progressively increased 15 minutes each week until rats were training 2 hours per day, 5 days per week. Sedentary non-trained (NT) cage mates (n=20) were handled daily and placed in shoulder-deep 30~35°C water weekly to experience similar stresses. All rats were sacrificed at age 16 weeks using an overdose of sodium pentobarbital (150 mg/kg ip). Prior to sacrifice blood glucose levels were measured in all diabetic animals as described previously. Left ventricle, right ventricle, and septum tissue from all groups of rats were collected, washed, snap frozen in liquid nitrogen, and stored at -80°C.

Antioxidant enzyme activity

One tissue sample from each region of the heart from each rat was used to evaluate the activity of aconitase and SOD using kits purchased from Oxis Research™ (Portland, OR; catalog numbers 21041 and 21010, respectively). Samples were read on a Multiskan® MCC plate reader with Ascent® software (Thermo Electron Corporation, Vantaa, Finland). A total protein assay was performed on the same homogenate using a bicinchoninic acid (BCA™) protein assay kit purchased from Pierce (Rockford, IL; catalog number 23225). Activity was expressed in Units/mg protein.

GSH/GSSG ratio

One tissue sample from each region of the heart from each rat was used to evaluate the ratio of reduced to oxidized glutathione using a kit purchased from Oxis Research™ (catalog number 21040). Unfortunately, the measurement of GSSG failed; therefore, GSH levels (nmol/mg tissue) only are reported in the results.

Gene expression

Cardiac muscle tissue samples were thawed, homogenized in Trizol® reagent, and centrifuged at 4°C for 20 minutes at 12,000 rpm. RNA isolation was performed on the homogenate using a RiboPure™ kit purchased from Ambion, Inc. (Austin, TX). Spectrophotometry and agarose gel electrophoresis analyses were done to verify the quantity and quality of the isolated RNA. Once sufficient RNA (at least 2 mg/ml) was isolated from each region of the heart from 3 rats in each of the 4 groups, the expression of Kcnd2, KCNQ1, Gclc, and Gss were analyzed in triplicate using a 7500 Real Time PCR System (Applied Biosystems Incorp., Foster City, CA). Primers for Kcnd2 (Rn00589141), KCNQ1 (Rn00583375), Gclc (Rn00563101), and Gss (Rn00564188), as well as the endogenous control glyceraldehyde 3-phosphate dehydrogenase (GAPDH; Rn4352338E), were purchased from Applied Biosystems. Each well on the 96 well plate contained 25 ml TaqMan® 2x Universal PCR MasterMix No AmpErase® UNG (Applied Biosystems, kit 4309169), 1.25 ml 40x MultiScribe™ and RNase Inhibitor Mix (Applied Biosystems, kit 4309169), 2 ml sample (concentrated to 2 mg RNA per ml), 2.5 ml primer and total GSH analysis were simply snap frozen. All samples were stored at -80°C. Skeletal muscle tissue samples from the biceps femoris were also collected, washed, snap frozen in liquid nitrogen, and stored at -80°C.
mix, and 19.25 ml DNAse-, RNAse-free distilled water (Invitrogen Corp., Grand Island, NY). Samples were analyzed using the Applied Biosystems universal cycling conditions for TaqMan® gene expression assays of 30 minutes at 48°C followed by 10 minutes at 95°C and then 40 cycles of 15 seconds at 95°C followed by 60 seconds at 60°C. The difference in threshold cycle (Ct) was used to calculate the quantitative fold change between groups, and fold changes were then normalized relative to GAPDH transcript levels.

Citrate synthase activity
To evaluate the effectiveness of the training program, citrate synthase activity was measured from tissue samples from the biceps femoris as described by Srere (1969). Briefly, samples were diluted 1:10 in ice-cold 0.1 M Tris buffer (pH 8.0) and homogenized. Following centrifugation for 1 minute at 2,000 rpm and 4 minutes at 4,000 rpm, samples were analyzed in a 96 well plate with each well containing 120 ml 0.1 M Tris buffer, 20 ml 3.0 mM acetyl coenzyme A, 20 ml 1.0 mM dithio-bis-2-nitrobenzoic acid (DTNB), and 20 ml sample. Following a 7 minute incubation at room temperature, the change in absorbance at 414 nm was recorded every 30 seconds for 2 minutes. Next, 20 ml 5.0 mM oxaloacetate was added to each well, and the change in absorbance at 414 nm every 30 seconds for 3 minutes was recorded. The average activity (DOD) per minute before adding oxaloacetate was subtracted from the average activity per minute after adding oxaloacetate. Citrate synthase activity was then calculated by using the extinction coefficient for DTNB (13.6 mmol⁻¹ cm⁻¹) and by taking into account the dilution of the original tissue (1/100) as follows: (net DOD per minute) / ((13.6 mmol) (0.01 g)) = activity in mmol/g/min.

Statistical analysis
All data were analyzed using analysis of variance (ANOVA) and Student’s t-test (two-tailed). Significance was ascribed for p<0.05. Initial statistical analysis indicated no regional differences (results not shown), so data from all three regions of the heart were combined for further analysis.

RESULTS
Diabetic rats had significantly higher (p<0.001) blood glucose compared with C rats (D 452 ± 96 mg/dl; C 137 ± 9 mg/dl) 24 hours following STZ injection, and blood glucose levels were still elevated in D rats at the time of sacrifice (519 ± 136 mg/dl). Blood glucose levels were not significantly different between NTD and ETD rats 24 hours following STZ injection (NTD 457 ± 93 mg/dl; ETD 441 ± 107 mg/dl) or at sacrifice (NTD 565 ± 87; ETD 460 ± 167 mg/dl), although the increase in blood glucose within NTD over time was significant. ET rats had significantly higher (p<0.01) citrate synthase activity compared with NT rats (ET 23.4 ±11.4 mmol/g/min; NT 11.5 ± 9.2 mmol/g/min). There were no significant differences in body weight between groups (ET 243 ± 24 g; NT 236 ± 24 g; D 232 ± 27 g; C 248 ± 17 g).

ANOVA indicated significant differences in SOD activity, but not in aconitase activity or GSH levels, between groups (Table 1). SOD activity was significantly elevated in ETD rats compared with NTD rats (Table 1). ANOVA also indicated significant differences in Gss and KCNQ1, but not Gclc or Kcnd2, expression between groups (Figure 1). KCNQ1 was consistently downregulated in D and ET rats compared with C and NT rats, and Kcnd2 expression was significantly downregulated in ETD rats compared with ETC rats (Figure 1).
Antioxidants and gene expression in rats 55

Figure 1. Fold changes in Gclc, Gss, Kcnd2, and KCNQ1 in cardiac muscle tissue comparing groups of female rats. The difference in threshold cycle (C₇) was used to calculate the quantitative fold change between groups, and fold changes were then normalized relative to glyceraldehyde 3-phosphate dehydrogenase (GAPDH) transcript levels. n = 3 for each group. NTC, non-trained control; NTD, non-trained diabetic; ETC, exercise-trained control; ETD, exercise-trained diabetic. * t-test indicates significant difference (p < 0.05). # ANOVA indicates significant differences (p < 0.05).

Table 1. Aconitase activity (Units/mg protein), superoxide dismutase activity (Units/mg protein) and reduced glutathione (nmol/mg tissue) in cardiac muscle tissue of female rats. NTC, non-trained control; NTD, non-trained diabetic; ETC, exercise-trained control; ETD, exercise-trained diabetic. Values are mean ± SD. * t-test indicates significant difference compared with NTD (p < 0.05). # ANOVA indicates significant difference between groups (p < 0.05).

<table>
<thead>
<tr>
<th>Group</th>
<th>Aconitase</th>
<th>Superoxide dismutase</th>
<th>Reduced glutathione</th>
</tr>
</thead>
<tbody>
<tr>
<td>NTC (n=10)</td>
<td>7.28 ± 4.50</td>
<td>0.19 ± 0.11</td>
<td>1.50 ± 0.37</td>
</tr>
<tr>
<td>NTD (n=10)</td>
<td>6.95 ± 3.88</td>
<td>0.22 ± 0.12</td>
<td>1.64 ± 0.39</td>
</tr>
<tr>
<td>ETC (n=10)</td>
<td>8.30 ± 4.22</td>
<td>0.24 ± 0.17</td>
<td>1.44 ± 0.52</td>
</tr>
<tr>
<td>ETD (n=10)</td>
<td>9.08 ± 5.78</td>
<td>0.35 ± 0.22*</td>
<td>1.91 ± 0.59</td>
</tr>
</tbody>
</table>
DISCUSSION

Exercise and diabetes are both known to increase the formation of ROS that can inactivate enzymes and must be degraded by a series of enzyme-controlled reactions in order to minimize the harmful effects of oxidative stress. SOD degrades O$_2$$^-\cdot$ to H$_2$O$_2$, and GSH is then oxidized to GSSH as H$_2$O$_2$ is reduced to H$_2$O. Our observation of significant differences in SOD activity, but not in aconitase activity or GSH levels, suggests a significant increase in O$_2$$^-\cdot$ production with ET combined with D, which is consistent with the observation of increased O$_2$$^-\cdot$ production by both myocardial mitochondria and coronary arteries in the diseased heart (Chen et al. 2005). γ-glutamylcysteine synthase is generally regarded as the rate-limiting enzyme in the formation of GSH (Jung and Thomas 1996). Our results show no differences in Gclc expression, but a general downregulation of Gss was observed in ET and/or D rats compared with NTC rats. Downregulation will not necessarily result in decreased enzyme activity or activity, of course, because mRNA and resultant protein levels are affected by many factors. Similarly, upregulation of a gene will not necessarily result in increased quantity of that protein because mRNA levels may not predict protein levels or levels of enzyme activity. Without data for GSSG and the ability to calculate the GSH/GSSG ratio, we can only speculate as to whether the differences in expression of Gss are expressed phenotypically as differences in GSH. However, if more ROS are produced and no differences in GSH are observed, it follows that adequate amounts of GSH were produced and subsequently oxidized into GSSG since GSH levels are all within the typical range reported for rat myocardium (Leeuwenburgh et al. 1997).

Our results suggest a downregulation in Kcnd2 expression in ETD rats compared with ETC rats and a general downregulation of KCNQ1 expression in ET rats compared with NT rats. Again, without GSSG data, we can only speculate that these differences may be due to altered GSH. Insulin has been shown to have an electrophysiological effect on myocytes of diabetic rats through its effects on glutathione metabolism (Xu et al. 1996). Recent evidence, however, suggests that the remodeling of I$_{Na}$ in the diabetic rat heart may not be due to changes in the glutaredoxin system but more likely due to changes in the thioredoxin system, particularly due to decreased thioredoxin reductase (Li et al. 2005). Both the thioredoxin and glutaredoxin systems are members of the thiol-disulfide oxidoreductase superfamily that act to reduce protein disulfides and protein-mixed disulfides, respectively (Fernandes and Holmgren 2004, Jurado et al. 2003, Paget and Buttner 2003, Yamawaki et al. 2003). The lack of insulin in diabetic individuals may decrease the availability of NADPH required by the thioredoxin and glutaredoxin systems to reduce the proteins that control I$_{Na}$ density (Li et al. 2003). In addition, while the duration of the cardiac action potential in normal hearts is influenced by the activation of I$_{Ks}$ and I$_{Kr}$, evidence suggests that the increased length of the action potential in diabetic hearts may be due in part to a decrease in I$_{Ks}$ (Casas et al. 2000, Xu et al. 1996). This could explain the difference in Kcnd2 expression observed between ETD and ETC rats. Left ventricular hypertrophy is a classic adaptation to ET (Scheuer and Tipton 1997), and hypertrophied hearts also display a prolonged action potential (Lebeche et al. 2006). Alone, KCNQ1 produces rapidly activating K+ currents, and the slowly activating K+ current I$_{Ks}$ is produced when KCNQ1 combines with minK (Barhanin et al. 1996, Sanguinetti et al. 1996). While the lack of GSSG data make any connection between GSH and KCNQ1 speculative, the observations that mutations in KCNQ1 are associated with increased action potential duration (Wattanasirichaigoon and Beggs 1998, Yang et al. 1997) and that hypertrophied hearts have longer action potentials may explain the decreased expression of KCNQ1 in cardiac tissue of ET rats relative to NT rats.

Our observation that exercise training attenuated any further increase in blood glucose levels is consistent with the observations of Dall'Aglio et al. (1983), who suggested this attenuation was due to enhanced insulin action. An increase in the sensitivity of glucose transporters during exercise was first observed by Richter et al. (1982), and a subsequent study demonstrated that the enhanced glucose uptake continues in skeletal muscles following cessation of exercise and is caused first by insulin independent mechanisms and then by insulin dependent mechanisms (Garetto et al. 1984). In control settings, most of the GLUT4 isofrom transporters are stored intracellularly, and GLUT4 translocation to the cell surface is stimulated by insulin, muscular contractions, and hypoxia (Cartee et al. 1991, Douen et al. 1990, Holloszy and Hansen 1996, Kawanaka et al. 1999). Endurance exercise training appears to cause an adaptive increased in the GLUT4 transporter in skeletal muscles (Friedman et al. 1990, Holloszy 2005, Ploug et al. 1990, Rodnick et al. 1990). These mechanisms may explain the attenuated long-term increase in blood glucose levels in the ETD rats compared with NTD rats.
The influence of gender on our observations must not be overlooked because gender is known to influence the development of disease states. In a transgenic mouse model of hypertrophic cardiomyopathy, for example, female mice with LV hypertrophy continue to display concentric hypertrophy when male mice of the same age display LV dilation (Olsson et al. 2001). In STZ-induced diabetic rats, males exhibit more severe cardiomyopathy (Brown, Anthony et al. 2001, Brown, Walsh et al. 2001) and consistently have attenuated K⁺ currents compared to female counterparts (Shimoni and Liu 2003a, Shimoni and Liu 2003b). Shimoni and Liu (2003b) observed no change in $I_{\text{peak}}$ controlled by Kcnd2, in diabetic female rats while $I_{\text{peak}}$ was significantly reduced in diabetic male rats. Our results indicate significant downregulation of Kcnd2 expression in ETD female rats compared with ETC female rats, and a trend toward downregulation of Kcnd2 expression in ETD female rats compared with NTD female rats ($P = 0.08$). Therefore, gender-specific differences in the regulation of K⁺ channels must be taken into consideration.

ACKNOWLEDGEMENTS

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LITERATURE CITED


EFFECTS OF BLUEBERRIES ON MORTALITY RATES AND INDY GENE EXPRESSION IN

DROSOPHILA MELANOGASTER

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ABSTRACT

Aging may involve free radical accumulation, which causes cell damage. Foods with antioxidant properties, such as blueberries, have been implicated as being able to extend the longevity of an organism. In addition to environmental factors, genetics also plays a role in aging and death. In Drosophila melanogaster, one of the genes involved in longevity is Indy (I'm not dead yet). Mutations to this gene have demonstrated the ability to increase lifespan. The objective of this experiment was to determine if blueberries added to instant fly food affects mortality rates and Indy gene expression profiles of female D. melanogaster. To do this, D. melanogaster were cultured on media with or without blueberries, mortality curves were tallied, fruit flies were collected for RNA extraction, and analysis of Indy gene expression was conducted by quantitative real time reverse transcriptase polymerase chain reaction (qRT-PCR). Survivorship curves showed that females cultured on blueberry containing media lived significantly longer than those on control medium. qRT-PCR analyses revealed multiple differential expression patterns of Indy between treatments and time points. One comparison to note is that at day 25, Indy expression was significantly down-regulated in females cultured on blueberry medium compared to females cultured on control medium. This suggests a possible relationship between gene regulation and lifespan in D. melanogaster females cultured on blueberry containing medium.

† † †

Aging is a natural process of a series of changes over time, often involving an increase in disease and death. Several theories regarding the components that affect aging and how to slow down the process have been proposed (Harman 1956, McCord and Fridovich 1969, Harman 1972, Oliver et al. 1987, reviewed in Madvedev 1990, Landis et al. 2004). One of the most prevalent aging theories involves the effects of free radicals as a causative agent of aging. The “free radical theory” states that free radical production due to normal metabolism damages cellular macromolecules and thereby determines lifespan (Harman 1956). In addition to normal metabolism, free radical production also occurs when there is exposure to ionizing radiation, typically from photosynthesis, and through the reduction of oxygen (Harman 1981). Damage incurred includes alterations in the membranes of mitochondria and lysosomes (Harman 1972), or fatal changes to DNA, proteins, and lipids (Golden et al. 2002). One hypothesis suggested to minimize these effects involves supplementation with antioxidants, which are chemicals that naturally reduce the rates of oxidative reactions (Hagen 2003).

Antioxidants can be obtained from the diet, including green tea, berries, carrots, spinach, tomatoes, and red grapes. Adding antioxidants to the diet has been proposed to decrease the amount of oxidative damage to the body, thus reducing the degree of oxidative stress, which has been correlated to lifespan limitation (Golden et al. 2002). Supplemeting the diet with fruit and vegetable extracts containing elevated levels of antioxidants in rats was correlated with the slowing and reversal of some age-related cognitive defects (Joseph et al. 1998). Blueberry, spinach, and strawberry extracts were also given to older animals, effectively reducing oxidative stress and resulting in a reversal in cognitive decline (Joseph et al. 1999).

In addition to obtaining antioxidants from the environment, antioxidant and metabolic enzymes are encoded in the genome. A model genetic organism used to study the effects of free radical production and
antioxidant defense as it relates to aging is *Drosophila melanogaster*. The genome of *D. melanogaster*, as well as many other organisms, encodes multiple antioxidant and metabolic enzymes. One of the genes used to study the relationship between longevity extension and gene regulation in *D. melanogaster* is *Indy* (*I'm not dead yet*). *Indy* has been proposed to influence absorption of metabolites and metabolism (Rogina et al. 2000). P-insertional mutations of *Indy* have been found to increase the average lifespan of *D. melanogaster* by approximately 90% (Bulgakova et al. 2004). This lifespan extension was associated with reductions in both *Indy* mRNA and INDY protein levels, and with a decrease in the slope of the mortality curve. These results imply that the *Indy* mutation lowers the demographic rate of aging, in turn affecting the normal aging process (Marden et al. 2003). Our goals for this project were two-fold. The first was to determine if supplementing the diet with a food high in antioxidants, blueberries, would affect the life span of mated female *D. melanogaster*. The second goal was to determine if blueberry supplementation affected the metabolism of these females by regulating *Indy* expression. The overall goal was to determine if there was a relationship between antioxidant supplementation, metabolic gene regulation, and lifespan.

![Figure 1. Mortality curve for control and blueberry cultured females.](image)

**METHODS**

**Culture of *D. melanogaster***

The *D. melanogaster* population used in this study is an outbred population. It had been kept at large numbers (approximately 15,000) for about 16 months in the laboratory using an overlapping generation regime (i.e. only 20% of the food bottles are replaced each week). This population was initiated from 10 lines that were inbred after flies were collected from a natural population originating from North Carolina. The populations are maintained at the University of Nebraska-Lincoln by Dr. Lawrence Harshman.

Flies were initially cultured on control food for 48 hours in a 25°C incubator with a diurnal light cycle. After 48 hours, equal numbers of males and females were transferred to new control and blueberry food by light ether anesthesia. Males and females were cultured on either control or blueberry media for three
Effects of blueberries on D. melanogaster mortality

separate trials (50 pairs per bottle for 5 bottles). Approximately 15 g of control food (Carolina Biological, Burlington, NC) was measured into each 250 mL bottle and 60 ml of nanopure water was added and mixed. For preparation of blueberry food, 15 g of control food was added to 20 g (dry weight) of pureed blueberries.

For Trials 1-3, flies were transferred to new food every five days, and death occurrences and sex of the dead fruit flies were noted. Trial 1 was run to determine sampling time points for RNA analysis by constructing a mortality curve (Fig. 1). In Trial 2, samples of females and males were collected by light ether anesthesia and frozen separately according to sex for RNA extraction on days 0, 10, 20, 25, and 30. Trial 3 was run to supplement flies collected from Trial 2. Samples ranging from one to five flies were collected and frozen on days 20, 25, and 30. A survivorship curve was constructed after all trials had been completed (Fig. 2).

Figure 2. Survivorship curves for blueberry and control cultured females. The females cultured on control media lived to 55 days, while the blueberry cultured females lived to 85 days. The average life span for the control cultured females was 20.9 days and 24.9 days for blueberry cultured females. A Wilcoxon test revealed a significant increase in longevity in blueberry cultured females versus controls ($p = 0.0067$).

RNA Analysis

Samples were extracted using the TRIzol RNA extraction method according to manufacturer’s instructions (Invitrogen, Carlsbad, CA). Thirty-six samples of females were extracted, quantitated spectrophotometrically, and integrity assessed by gel electrophoresis. qRT-PCR was performed using Taqman Gene Expression Assay® kits and the 7500 Real Time PCR® system (Applied Biosystems, Foster City, CA) according to manufacturer’s instructions. The FAM labeled primer and probe sets used were Indy (assay #Dm01793740_g1) and Rp49 (endogenous control; assay # Dm02151827_g1). The primer and probe sets were pre-designed and tested by Applied Biosystems to span an exon-exon boundary to eliminate detection of genomic DNA and to ensure target specificity. In addition, these sets are proprietary information owned by Applied Biosystems and are not available to be published. Reactions were carried out in triplicate and performed in a 50 μl volume utilizing 200 ng total RNA sample and TaqMan® One-Step RT-PCR Mix (Applied Biosystems) according to manufacturer’s instructions. Negative controls without RNA or RT were also run. The reaction parameters were 48°C for 30 min; 95°C for 10 min; (95°C for 15 sec, 60°C for 1 min) 40 cycles;

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The PCR products were analyzed in the linear range for amplification with *Rp49* utilizing the 7500 Real Time PCR System Sequence Detection Software (Applied Biosystems). The relative quantitative results were used to determine changes in *Indy* gene expression between flies cultured on control and those cultured on blueberry food.

### Statistical Analysis
Results from the mortality data were analyzed using the Kaplan-Meier time-failure analysis in JMP 6.0 software (SAS Institute, Cary, NC). Survival curves were compared using the Wilcoxon and Log Rank tests with an alpha level of 0.05. Wilcoxon P values are reported (Log-Rank P values were always smaller). Fold change on a log₂ scale for *Indy* expression was determined utilizing the ΔΔCt method and statistical significance between treatments was determined using a one-tailed Student’s *t*-test for unpaired data with an alpha level of 0.05.

![Figure 3. qRT-PCR of Indy up-regulation in blueberry cultured females versus control cultured females. Average fold change is the log₂ ratio of blueberry cultured to control cultured females. At 10 days old, females cultured on blueberry or control media are not different in *Indy* expression levels. At 25 and 30 days old, *Indy* expression levels become significantly down-regulated versus the day 20 comparison (*p* < 0.05). Experiments were performed in triplicate and error bars represent standard error of the mean.](image-url)

### RESULTS

#### Survivorship Experiment
Females cultured on control food lived as long as 55 days, whereas those cultured on blueberry food lived as long as 85 days. The average lifespan of control cultured flies was 20.9 days. In comparison, the average lifespan of blueberry cultured flies was 24.9 days (Fig. 2). A comparison of the Kaplan-Meier survivorship curves between control and blueberry cultured flies using a Wilcoxon test revealed a significant increase in lifespan for the blueberry cultured flies compared to the control flies (*p* = 0.0067).

#### RNA Analysis
qRT-PCR was used to determine the average fold change on a log₂ scale of the ratio of *Indy* expression between blueberry and control cultured females. For all qRT-PCR analyses, both negative controls (no-RNA and no-RT) did not amplify above the threshold within 35 cycles. The ratios for each time point were
compared to each other. No significant difference in expression of *Indy* was determined on day 10 compared to any other day. However, there was a significant down-regulation of *Indy* expression levels on days 25 and 30 when compared to the expression level on day 20 ($p < 0.05$) (Fig. 3).

qRT-PCR was also used to determine the average fold change on a log2 scale of the ratio of *Indy* expression between the control time point (day 0) versus all other time points for blueberry and control cultured females. In control samples at day 25, *Indy* expression was significantly up-regulated compared to days 10 and 20, respectively ($p < 0.004$). Blueberry samples on day 20 showed *Indy* was significantly up-regulated compared to day 10 ($p = 0.009$). Samples from day 20 compared to day 25 for blueberry showed a significant decrease in *Indy* expression ($p < 0.004$). When comparing days 25 and 30 for control samples, *Indy* was down-regulated, whereas it was up-regulated in blueberry samples ($p < 0.037$). The only time point in which *Indy* expression was significantly different between blueberry and control was day 25 ($p = 0.0002$), in which the *Indy* was significantly down-regulated in the blueberry cultured females (Fig. 4).

![Figure 4: qRT-PCR of Indy expression blueberry and control cultured females over time.](image)

Figure 4. qRT-PCR of *Indy* expression blueberry and control cultured females over time. Average fold change is the ratio of the day in bottle to the control time point (day 0). $*$ = day 10 vs 25 for control females ($p = 0.003$); $\dagger$ = day 10 vs 20 for blueberry females ($p = 0.009$); $\ddagger$ = day 20 vs 25 for either treatment ($p < 0.004$); $\sharp$ = day 25 vs 30 for either treatment ($p < 0.037$); £ = blueberry vs. control cultured females at 25 days old ($p = 0.0002$). Experiments were performed in triplicate and error bars represent standard error of the mean.
DISCUSSION

Data from this experiment show that blueberry cultured females have a significantly increased lifespan over those cultured on control food (Fig. 2). The only difference between the groups was the food medium they were cultured upon. Therefore, it would seem the presence of antioxidants or some other factor in the blueberry food may be related to the increased lifespan. The significant differences found between levels of Indy gene expression in control and blueberry cultured females at different time points may be attributed to differences in reproductive bursts. Expression levels of Indy have also been implicated in lethality during early embryogenesis. During lifespan, expression of Indy may fluctuate, affecting viability of offspring of *D. melanogaster* (Bulgakova et al. 2004). As a result, expression may be down-regulated at a later time period in the longer-lived blueberry flies than in control flies because bursts in reproduction occur differently.

The significant down-regulation of Indy expression in blueberry cultured versus control cultured females at day 25 may indicate that a component in the blueberries may be responsible for differential gene regulation as well, thus affecting average lifespan (Fig. 4). Mutations to Indy increase life span of *D. melanogaster* and cause a decrease in its level of expression. In *D. melanogaster*, Indy is expressed in the fat body, midgut, and oenocytes. These sites are most likely the primary area of intermediary metabolism, absorption, and further metabolic storage, thus Indy has been proposed to be directly involved with metabolism. Indy protein is similar to the dicarboxylate co-transporters in mammalian species that play a role in glucose metabolism (Bulgakova et al. 2004). Mutations that cause a decrease in protein production may also be correlated with a decrease in the effectiveness of such proteins in both *D. melanogaster* and mammalian species at absorbing metabolites and assisting in optimal intermediary metabolism. A decrease in the effectiveness of normal metabolism may be correlated to conditions similar to caloric restriction (Rogina et al. 2000).

Further research involving diet and Indy gene expression should also focus on other characteristics of *D. melanogaster*, such as flight and fecundity. It would be beneficial to study differences in lifespan and Indy expression between mated and virgin females and males. In females, reproductive processes introduce a component of stress, which may also play a role in lifespan and subsequent gene expression. Analyzing genetic expression of other genes such as catalase and superoxide dismutase in mated and virgin females and males may also provide insight into the effects of differences between diets. The current study demonstrated that lifespan extension with antioxidant promoting supplements may have an effect on differential gene regulation. Future research may provide insight into effects of diet and changes in gene expression, thus ultimately providing greater understanding of the process of aging.

ACKNOWLEDGEMENTS

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LITERATURE CITED


INTELLIGENT MODULAR TOOL FOR EMERGENCY SURGICAL TREATMENT DURING PAYLOAD-CRITICAL MISSIONS

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ABSTRACT

During any extended mission to an extreme environment (i.e. the International Space Station, a lunar base or a manned mission to Mars) the chances of an otherwise minor injury becoming life threatening grow to be significant. In order to address these concerns, equipment must be provided to diagnose and treat a wide range of possible afflictions while direct contact with Earth-based physicians is impossible. Minimally invasive surgery (MIS) is an excellent treatment option due to its history of decreasing trauma in patients and speeding recovery. In an effort to provide the maximum functionality for any given MIS procedure, an intelligent modular surgical system has been designed and is being further refined to assist surgeons and other practitioners during medical procedures without necessitating the inclusion of many different instruments. The overall design approach was to identify the functions of existing technology and then to design a device that combined functionalities whenever possible to minimize the overall complexity of the design. The intelligence in the design is intended to make finding instruments easier for the individual performing the surgical procedure rather than replace humans in the operating theater. This paper presents analysis quantifying the payload reduction achieved by the new modular design as it pertains to extended missions to extreme environments. In addition to assisting surgeons, this system will take approximately 25% less space than the current equivalent MIS tools.

† † †

With the continuing mission of the International Space Station (ISS), the proposed lunar base and manned missions to Mars (O'Brien and King 2004, Watson and Benedetto 2004) comes a corresponding increase in time away from Earth. Along with this increase in time comes an increase in risk: if an astronaut suffers some otherwise minor injury or illness during time off-planet, the chances of mortality increase greatly. Since it takes 24 hours to return an astronaut from the ISS, 7 days to return from the Moon and 9-12 months to return from Mars (Agha 2005), definitive care by a terrestrial physician is far from certain in any emergency situation.

According to a recent publication, on a 2.4-year trip to Mars, a 7-member crew can expect to experience one emergency given an emergency incidence rate of 0.06 events/person-year for the general populace (Summers et al. 2005). The emergency incidence rate for astronauts is likely to be lower due to the intense training and ultra-selective medical screening they undergo; however, unforeseeable illness or accidents can happen at any time, and the loss of even one crewmember is unacceptable.

In a 1993 study, Houtchens divided a list of possible injuries and illnesses into three classes based
on severity of symptoms. Class 1 impairments are not usually life-threatening and will resolve themselves with minor prescription or nonprescription medications; examples of Class 1 injuries are headaches, mild ulcers, sinusitis and urinary tract infections. Class 2 impairments include air embolism, chemical burns, open or closed chest injuries, uncomplicated heart attacks, and appendicitis; these require immediate stabilization or treatment to provide in-flight recovery or evacuation. The final class of impairments, Class 3, includes explosive decompression, massive crushing injuries or open brain injuries and would require prompt evacuation after resuscitation if possible (Houtchens 1993). Since Class 1 impairments would not normally require invasive treatment and Class 3 impairments would most likely be fatal, the major focus of emergency treatment in-flight should be concentrated on the Class 2 type of impairment.

Due to the wide range of possible injuries or illnesses that might require treatment over a 2 ½ year voyage to Mars or extended Lunar stay, the surgical system designed must be able to accommodate a wide range of functions. Since the volume of a spacecraft is limited and therefore storage space is at a premium, the living quarters, workspace or experiment bays of a given craft will most likely need to double as emergency surgical bays, as investigated in the NASA Extreme Environment Mission Operations (NEEMO) habitat, Aquarius (Anvari et al. 2007, Rentschler et al. 2007). Due to this multitasking of rooms and work surfaces, and considering the safety of the patients and operators, the surgical solution used must contain fluids and tissues released during the surgical procedure in order to prevent contamination of work surfaces or infection of other personnel.

Previous investigations have determined that both open surgery and minimally invasive surgery (MIS) are viable in microgravity (Campbell et al. 1993, Campbell et al. 1996, Campbell et al. 2001, Link et al. 2001, Panait et al. 2004). Open surgery is what most people think of as “surgery”: a large incision allowing the surgeon direct access to the patient’s affected area. As its name suggests, MIS is much less invasive than traditional surgery, is applicable to a wide range of procedures, decreases trauma to patients, and helps decrease fluid loss and infection risk to patients, which is of major concern in a space vehicle, due to the high concentration of particulates in microgravity (Campbell et al. 1996, Campbell et al. 2001). In MIS, only 3-5 incisions, each measuring approximately 1 cm in length, are made to give surgeons indirect access to the affected area (Hunter and Sackier 1993, Richardson and Hunter 2000). The abdominal cavity is inflated with an inert gas (usually CO₂), creating a work space within the patient. Long slender instruments, a camera and light source are then inserted into the inflated cavity through plastic tubes, called trocars, allowing the surgeon to perform the operation without coming into direct contact with the patient’s internal tissues.

The purpose of this study was to evaluate the impact of a new modular surgical system (which was designed for a wide range of treatments) on reducing payload requirements for extended missions to extreme environments, as well as to demonstrate the usefulness of an overall approach to the design of tools for a specific set of goals.

MATERIALS AND METHODS

Surgical System

In order for an MIS surgical system to provide the widest range of procedures design criteria were solicited from an MIS surgeon at the University of Nebraska Medical Center (Nelson et al. 2007). A multifunction surgical system (shown in Figure 1) was designed using Functional Decomposition techniques and other established design methodologies (Dieter 2000) to interface with current MIS surgical equipment while combining repeated functions within single design parameters or features; therefore it has a hollow tool shaft less than 10 mm in diameter, allowing it to be used with commercially available trocars. Also, to further decrease the total volume of surgical equipment necessary on board, the system was designed for multiple uses, so initial sterility and the ability to sterilize multiple times were also considered. The unit was designed to be as small and light as possible, while still requiring minimal power, to lower reliance on potentially limited power reserves during an emergency procedure.

Though MIS reduces the trauma caused to a patient compared to traditional surgery, it has been shown that the removal and reinsertion of MIS instruments can cause unnecessary trauma to a patient during the surgery (Vallancien et al. 2002). The surgical system shown in Figure 1 was designed to accommodate up to six functional tool tips within a rotary chamber contained within the tool. The combination of multiple functionalities within one housing was a direct consequence of using Functional Decomposition techniques (Dieter 2000) in the design process; positioning and actuation of each tool tip is accomplished with the same tool shaft, reducing the overall complexity of the MIS task. The result is that a procedure can be performed without having to
remove the tool's shaft from the patient, decreasing the trauma from tool insertion and removal and lowering the infection risk to the patient. This multi-functionality also helps reduce the total number (therefore volume and weight) of surgical tools necessary to complete a procedure.

The tool is powered and occasionally controlled using software installed on a PC. This means that minimal special equipment will be required to run the instrument – only software that can be installed on any computer currently onboard. Though certain functions of the tool, specifically the indexing of the multiple tool tips, are electronically controlled for speed and accuracy, the tool is operated manually during a procedure. This not only limits the amount of power required to operate the tool, but also ensures that the tool will not fail due to power loss during the procedure. Since a highly trained surgeon who is accustomed to the tools necessary might not be available, the tool was also designed ergonomically. The handle is sized to accommodate a wide range of hand sizes and strengths, all the buttons are located for accessibility and the forces involved in the mechanisms are designed for easy actuation.

Finally, with the inclusion of multiple functional tips within the same tool comes an increase in the complexity of the instrument. Because of the aforementioned possibility of a non-surgeon having to use the surgical tool (a tele-mentored situation), a small measure of artificial intelligence was designed into the tool to help streamline the procedure and reduce the cognitive load on the operator. It has been shown that this intelligence helps decrease the amount of time required to perform a surgery (Miller et al. 2007), which will help reduce the cognitive load on the crewmember performing the operation.

Figure 1. The modular minimally invasive surgical tool was developed to be interfaced with commercially available MIS trocars, will house up to six MIS tool tips, is sterilizable, low-volume, low-power and manually actuated, lending itself well to deployment aboard a spacecraft in an emergency.
Volume & Weight Determination

In an effort to compare the volumes and weights of traditional MIS tools and the modular tool under development, a comparison was made between commercially available sterile tools and the computer (CAD) model of the tool under development. The modular tool was designed to accommodate up to six functional tips, so video of 22 surgical procedures performed at the University of Nebraska Medical Center was analyzed to determine the six tools to include in this study. The video indicated that several mechanical tools were represented in a majority of procedures. Commonly available analogues include: ENDOSTATIC™, ENDO DISSECT™, ENDO SHEARS™, ENDO CLINCH II™, ENDO BABCOCK™ & ROTICULATOR ENDO DISSECT™ (Covidien AG. http://www.covidien.com. Mansfield, MA). Of course, more tools were used during the procedure to provide cautery, suction, irrigation, suturing and stapling; however, these tools were not included in the current version of the modular tool due to their size or complexity, so they were not considered in the volume/weight analysis.

Five of the six tools mentioned above were weighed with and without their sterile packaging, and the packaging was measured to determine the total occupied volume. Through the measurement of these tools, a relationship was found between the size of the tool and the volume and weight of the packaging. A CAD model of the sixth tool, the ENDO BABCOCK™, was used for analysis since an actual tool was not available, so certain assumptions needed to be made, as discussed further in the “Results & Discussion” section. Paired t-tests were run to compare the length, width, height and weight of the packaging as measured to respective calculated package dimensions, which were then used to find the size of the package for the ENDO BABCOCK™. The weights of all packaging and MIS tools were summed to find the total shipping weight of the six traditional MIS tools.

Since the modular tool is currently under development, the volume and weight measurements were based solely on the CAD model developed using SolidWorks® (SolidWorks Corporation. http://www.solidworks.com. Concord, MA). The same proportionality used to extrapolate the volume and weight of the ENDO BABCOCK™ packaging was used to estimate the volume and weight of the modular tool’s packaging.

<table>
<thead>
<tr>
<th>Table 1. Dimensions of commercially available MIS tools and their sterile packaging. Values were used to determine the ratio of package dimension to tool dimension. Column 1 is the tool dimension, column 2 represents the package dimension as measured, column 3 is the difference between the measured tool and package dimensions and column 4 is the calculated estimate of the package dimensions.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tool</strong></td>
</tr>
<tr>
<td><strong>Tool</strong></td>
</tr>
</tbody>
</table>
RESULTS & DISCUSSION

Volume Determination

Table 1 shows the dimensions of the tools and packaging as measured. The measured differences between length, width and height of a tool and its packaging were averaged over all of the tools, resulting in a length difference of 82.23 mm, a width difference of 45.72 mm and a height difference of 6.82 mm. These averages were then added to the respective tool dimensions to obtain the calculated package dimensions, shown in the fourth column of Table 1. A Kolmogorov-Smirnov (K-S) test of normality, performed using MINITAB (Minitab, Inc., State College, PA), verified that the data were normally distributed (all $p > 0.15$). These calculated package dimensions were then compared to the measured package dimensions using a paired t-test in MINITAB. It was found that the calculated dimensions were not significantly different from the measured dimensions ($p_L = 0.999$, $p_w = 1.000$, $p_H = 1.000$), indicating a strong correlation between tool dimensions and package dimensions.

Since the calculated package dimensions correlated with the measured dimensions, package dimensions were then calculated for the ENDO BABCOCK (for which packaging was unavailable; see "Materials & Methods" section) and for the modular tool. The overall dimensions of the BABCOCK and modular tool packaging are shown in Table 2. The calculated volume of the modular tool is $0.011 \text{ m}^3$ and the calculated volume of the six modular tools is $0.015 \text{ m}^3$. The modular tool takes up 25.3% less space than the six tools it replaces. This will reduce the total amount of space required for emergency medical equipment onboard, resulting in either a smaller craft or the inclusion of other equipment in the payload.

Table 2. Calculated size requirements for packaging of tools based on CAD models.

<table>
<thead>
<tr>
<th>Tool Package</th>
<th>Dimensions</th>
<th>Tool Dimensions</th>
<th>Package Dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENDO L</td>
<td>510.000</td>
<td>592.233</td>
<td></td>
</tr>
<tr>
<td>BABCOCK W</td>
<td>100.000</td>
<td>145.720</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>25.000</td>
<td>31.820</td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>553.390</td>
<td>635.622</td>
<td></td>
</tr>
<tr>
<td>Modular Tool W</td>
<td>190.678</td>
<td>236.398</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>66.523</td>
<td>73.343</td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Measured and calculated weights (in grams) of traditional MIS tools based on physical samples, CAD models and calculated parameters. Columns 1-3 are measured values; column 4 is a weight as calculated using a CAD package; column 5 is the corrected weight based on the SolidWorks model; columns 6 & 7 are adjusted weights of tools and packaging using multipliers and additions, respectively, as discussed in the "Weight Determination" section.

<table>
<thead>
<tr>
<th>Tool + Packaging (g)</th>
<th>Packaging (g)</th>
<th>Tool (g)</th>
<th>SolidWorks Weight (g)</th>
<th>Tool Weight (calc) (g)</th>
<th>Total Weight (*) (g)</th>
<th>Total Weight (+) (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENDO DISSECT</td>
<td>138.7</td>
<td>84</td>
<td>54.7</td>
<td>*</td>
<td>126.96</td>
<td>149.86</td>
</tr>
<tr>
<td>ROTTICULATOR</td>
<td>217.3</td>
<td>112.5</td>
<td>104.8</td>
<td>77.27</td>
<td>98.74</td>
<td>243.24</td>
</tr>
<tr>
<td>ENDO DISSECT</td>
<td>175.5</td>
<td>97.4</td>
<td>78.1</td>
<td>61.39</td>
<td>78.45</td>
<td>181.27</td>
</tr>
<tr>
<td>ENDO GRASP</td>
<td>175.4</td>
<td>98.4</td>
<td>77.4</td>
<td>61.72</td>
<td>78.87</td>
<td>179.65</td>
</tr>
<tr>
<td>ENDO SHEARS</td>
<td>137.4</td>
<td>83.5</td>
<td>53.9</td>
<td>43.63</td>
<td>55.75</td>
<td>125.10</td>
</tr>
<tr>
<td>ENDO CLINCH II</td>
<td>175.8</td>
<td>98.4</td>
<td>77.4</td>
<td>61.72</td>
<td>78.87</td>
<td>179.65</td>
</tr>
</tbody>
</table>
Weight Determination

The measured masses of the five tools and available packaging are shown in Table 3. CAD models were developed based on measurements of actual tools; however, despite the care with which the measurements were taken, a small amount of measurement error was introduced, and no information about the precise material properties of the existing tools was available. These factors led to the need for a more theoretical approach to weight determination. The ratio of the weight calculated by SolidWorks to the measured weight was calculated for each of the four tools with SolidWorks models and averaged. This factor was then used to calculate the "actual" weight of each tool. This calculated weight was then compared to the measured weight using a paired t-test in MINITAB. Again, there was no statistical difference between the measured and calculated weights (p = 0.869) and data were normally distributed (p = 0.094), so the average factor was used to calculate the weight of the BABCOCK (139.58 g) and modular (1454.11 g) tools based on the SolidWorks models.

Since no packaging was available for the BABCOCK tool, the weight of its packaging as well as that of the modular tool needed to be estimated. Two methods were attempted: multiplicative and additive. To find the multiplier, the measured weight of each tool was divided by the measured weight of the tool and its packaging. To find the additive factor, the weights of the five available packages were averaged. These results of the multiplication and addition methods are shown in the 6th and 7th columns of Table 3, respectively, all of which are normally distributed (p > 0.15). Paired t-tests were again conducted in MINITAB to compare the results to the actual measured total weights, and it was found that the additive method provided a closer total weight (difference = -0.16 g, p = 0.978) than the multiplicative method (difference = -2.30 g, p = 0.759).

Using the additive method, the weight of the BABCOCK tool and its packaging was calculated as 234.74 g; therefore the weight of all six traditional tools and their packaging was calculated to be 1079.44 g. The same technique applied to the modular tool resulted in a calculated weight of 1549.27 g. Based on these calculations, the modular tool and packaging is approximately 44% heavier than the six equivalent traditional tools. At first glance, this seems like an unacceptable increase, due to the aforementioned weight requirement on spacecraft, however there are other factors that affect the outcome.

The traditional tools are only rated as single-use instruments, so multiples will need to be packed onboard to plan for additional casualties. Granted, the calculations in Summers et al. (2005) state that only one emergency is to be expected on the Mars mission, but using the modular tool, that fact is irrelevant: the modular tool was designed for multiple uses, meaning that it can be sterilized multiple times and reused so that if another emergency occurs, it can be dealt with by astronauts without needing to pack extra tools. If one extra emergency were planned for using the traditional tools, that brings the total weight of MIS tools up to 2158.88 g, 28% more than the one modular tool required, and the weight increase from using the modular tool would be justified.

Extension of Methodology

The analysis described in this paper has demonstrated that task- and/or environment-based criteria can be used to guide designers towards more efficient solutions to optimization problems, specifically payload minimization in this case. This process of moving from a set of goals through a redesign phase and towards an optimized design can be generalized in the following steps:

1) Identify key functional requirements and decompose into sub-functions;
2) Correlate functional domain (design requirements) to physical domain (design parameters) of current design;
3) Identify areas of redundancy or unnecessary complexity in functional/physical correlation;
4) Redesign to eliminate redundancy/complexity;
5) Evaluate new design against original functional requirements;
6) Iterate through steps (2-5) if necessary.

The process of breaking down and analyzing the desired function of a system, device, or process (Steps 1 & 2) is called Functional Decomposition (Dieter 2000); what was decomposed in this case was the process of minimally invasive surgery (Nelson et al. 2007) with special attention being paid to the goal of space savings. The output of functional decomposition can be a diagram, an outline, or any other breakdown representing what the system, device, or process should do or accomplish.

Correlating the elements of the functional decomposition to physical objects, components, or design features is the translation to how the desired functions are accomplished. In this case, the iterative process above exposed a multiple-tool surgical paradigm in which the individual components (tools) shared common functional (tool positioning and actuation) and physical (individual tool shafts) elements. Based on the functional constraints of
payload (space and weight), the optimization goal was to simplify the paradigm by incorporating as few elements as possible. Therefore, the simplification of the functional decomposition of the surgical task led to the multifunction tool design shown in Figure 1 (Nelson et al. 2007). The evaluation of this new design against the functional (space) constraints is the main focus of this paper; however, generalizing this process using the steps outlined above illustrates how a systematic design methodology can be applied to space and/or weight optimization problems encountered in many disciplines, and it gives a more complete sense of the potential applications of the work presented in this paper.

CONCLUSIONS

It has been shown that a modular surgical tool will meet most of the requirements necessary to perform minimally invasive surgical procedures aboard a spacecraft. This modular tool, while increasing the weight required for a single set of surgical instruments, will decrease the total weight required to provide multiple surgical interventions, should they arise. It also takes up significantly less space on board, allowing more equipment to be stored which could possibly save the lives of astronauts. The fact that the tool is multi-use and multi-function results in fewer instruments to keep sterile and requires less valuable storage space on board a craft dedicated to this type of equipment.

The uses of this surgical system are not limited to space travel. Any application where volume or weight is of concern could benefit from the use of this tool, such as deep sea submarine missions, other naval uses at sea, missions to the Antarctic, use in battlefields or even rural communities. With the increase in data infrastructure, the possibility for surgeons to tele-mentor non-surgeons giving emergency medical treatment is increasing by leaps and bounds, and this tool would facilitate this development by allowing surgeons to impact directly how instruments are deployed anywhere in the world. The functional design techniques discussed in the previous section provide a valid approach to designing tools for these applications.

Although it looks promising, the development of the surgical tool is not complete. Currently, the investigators are finalizing a prototype of the device based on the CAD models and beginning to validate the functionality of the tool and verify the weight and size requirements for the packaging. Having a physical prototype will enable the investigators to analyze the stresses (both mechanical and physiological) present during the tool’s use. This can potentially allow designers to eliminate even more weight from the tool through optimization, creating an even more efficient use of weight in payload-critical applications such as spaceflight, as well as to assess the possible ergonomic impact of the tool on surgeon performance.

The device was originally intended to be sterilized using a specific method (STERRAD; Advanced Sterilization Products. http://www.sterrad.com. Irvine, CA), but this method might not be the method of choice on board a spacecraft. The materials and motors in the device must be tested further to ensure sterility using a range of methods.

Finally, the device as designed is intended for manual use, but its potential applications to robotic telesurgery are obvious. The only commercially available telesurgery system currently on the market is the da Vinci Surgical System (Intuitive Surgical, Inc. http://www.intuitivesurgical.com. Sunnyvale, CA). It is likely that a multi-function tool such as this one will increase the efficiency of robotic surgery, leading to its widespread use and acceptance.

ACKNOWLEDGMENTS

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LITERATURE CITED


MULTIPLE PATHS TO CRITICAL REFLECTION:
A FLEXIBLE MODEL OF TEACHER LEARNING AND ITS IMPACT ON STUDENT ACHIEVEMENT

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ABSTRACT

This research evaluated impact of the Omaha Public Schools' Urban Systemic Program professional development model on mathematics and science teacher change and student achievement. The model offered various participation pathways, focused teachers' learning in three areas (beliefs, content, and pedagogy) and required teacher reflection during classroom strategy implementation. To determine teacher change, observations, interviews, action research, pre-post perception profiles, retrospective pre-post surveys (beliefs and understandings), and exit surveys were completed. Participants' action research determined impact on students' understandings. Criterion Referenced Tests, as well as leadership pre- and post- surveys, action research and interviews determined school change. To evaluate program impact, participant and non-participant AYP (Annual Yearly Progress) data were compared. Pathway comparisons used mean AYP Science Scores and Average Standards Mastered. Data indicate that changing beliefs and critical reflection were essential to change. Participants showed mean increases in scores, though none were significantly larger than non-participants and impact varied by path. However, with the commitment of leadership and 70% of teachers, schools significantly impacted achievement. Research implications include 1) the importance of the school as the unit of change to impact achievement and 2) the necessity of reflection and work-embedded professional development to impact teacher change and student achievement.

† † †

The most important factor determining student achievement is teacher quality (Darling-Hammond 1999, Darling-Hammond 2000, National Commission on Mathematics and Science Teaching for the 21st Century 2000). It is essential to provide quality teachers in the classroom, with teacher quality based on research that outlines what is meant by effective teaching.

In addition, during the past two decades research has advanced understanding of how people learn. The National Research Council (1999) defined important next steps in the research agenda. Research indicated that student learning is promoted when there is focus on learning for understanding, building on pre-existing knowledge and facilitating active learning. Later NRC work outlined what the culture of learning might look like in mathematics and science classrooms (National Research Council 2005) and stressed the importance of providing learner-centered, knowledge-centered, assessment-centered and community-centered environments.

Understanding of quality professional development as it impacts teacher change has advanced. Yet enduring challenges of professional development remain, including: 1) raising the performance of all students in mathematics and science while reducing achievement gaps, 2) enhancing the goals of student learning from
formulaic to promoting understanding, 3) promoting better teaching, and 4) developing new organizations that are flexible, organized for improvement and focused on student achievement results (Loucks-Horsely et al 2003). This research addresses these challenges and particularly focuses on the implementation of a professional development model and its effectiveness at teacher and school change as well as its impact on student learning.

**Prior Work: The Foundation for Change**

The state of mathematics and science teaching and learning in the Omaha Public Schools (OPS) has changed dramatically over the past ten years of National Science Foundation support. When the Urban Systemic Program (Banneker 2000: CEMS) began in Omaha, the district had successfully completed a five-year, National Science Foundation-funded Comprehensive Partnership for Math and Science Achievement (CPMSA) award. Key achievements during the CPMSA built a foundation for work during the USP; foundational work included the following:

1. Prior to the CPMSA, attention was paid to mathematics at the elementary level, but science instruction was often lacking. By the end of the CPMSA, elementary teachers were paying more attention to science instruction but still lacked the confidence and conceptual knowledge that would help them teach science more effectively.
2. District graduation requirements included only two years of mathematics and two years of science and accepted many non-core courses. The CPMSA was successful in eliminating courses that did not position students to take advanced courses in high school and be competitive at the post-secondary level; it also laid the foundation for a policy change to establish three-year graduation requirements in mathematics and science that expected core-course completion by all students in the district.
3. Enrollment and achievement of underrepresented students in mathematics and science was positively impacted, but achievement remained an issue.
4. Effective means to increase student enrollment and success in these courses were established:
   - Working with parents to better understand importance
   - Providing meaningful support to students – tutoring and enrichment.
5. CPMSA-funded, action research informed aspects of portfolio expectations and goals central to USP professional development.

By the transition year between the CPMSA and the USP, significant progress had been made on policies, convergence of resources, and standards. At the end of the CPMSA it was evident that teachers needed support to work with students for whom they had never been responsible; as a result, USP professional development targeted teacher belief systems and expectations, content and instructional pedagogy. The five years of USP work focused on continued change in policy, convergence of resources, standards-based curriculum and instruction, partnerships, and teacher professional learning to support educators more effectively as they worked to increase student achievement.

**Theoretical Frameworks: The Basis for Current Work**

To meet the expectations of policy changes and new standards successfully, a professional learning environment was required that would not only enhance teacher learning but also impact school change. Implementing the standards successfully required teacher and school change, a complex process since it strikes at teachers' beliefs and philosophies. The theoretical framework used to design this unique, flexible professional development model built on adult learning theory (Knowles et al. 1998), change processes (Fullan and Stiegelbauer 1991, Hargreaves and Fullan 1998, Lortie 1975), student-centered instruction (McCombs and Whisler 1997, National Research Council, 1999), and previous research on action research during the CPMSA (Koba et al. 2000, Koba and Clarke 2002).

**The Professional Development Model**

To translate this research into practice, the OPS specifically designed and implemented a professional development model during the USP, Banneker 2000: Community of Excellence in Mathematics and Science (CEMS). Rather than establish a traditional trainer-of-trainers model where only alpha teachers further their learning, the USP focused on the school as a unit of change to establish professional learning communities that engaged a critical mass of teachers focused on student learning (see Figure 1). As shown in the figure, all schools in the district were required to establish professional development plans for mathematics and science and were considered Planning Schools in the CEMS model. For a school to
receive financial and intellectual support from CEMS, the principal was required to involve, within a three-year period, 70% of their 4th – 9th grade teachers in the USP-designed, intensive professional development. The school was identified then as a Developing School, and teachers and leadership chose the professional development options best suited to them. Once the school reached its 70% teacher participation goal and impacted student achievement consistently, the school was named an Exemplary School and now serves as a model site in the OPS.

CEMS professional development was designed around the National Science Education Standards (National Research Council 1996) and included an emphasis on standards-based practices, with specific focus on inquiry and the nature of science, coupled with content learning. Participants committed to work-embedded learning and demonstrated their learning through a portfolio with four sections: 1) beliefs and philosophy, 2) content, 3) curriculum and instruction, and 4) action research. Understanding the complexity of change, we defined the parts of the portfolio with examination of beliefs and philosophy at the core. Beliefs were the focus of Part I but were also explicit in the teachers' reflective action research (Part IV), requiring teachers to be intellectual, reflective practitioners and to inquire into teaching and learning methods. Portfolio completion also required demonstration of content learning (Part II) and enhanced pedagogy (Part III: Curriculum and Instruction), expecting teachers to integrate theory and practice in the school setting. They demonstrated their learning in units of study they developed, implemented, videotaped and reflected upon. Data were collected between rounds of implementation, analyzed, and used to facilitate changed instruction, integrating theory and practice in the school setting. Finally, their research results were included in a database of resources available to teachers, honoring participants as producers of knowledge about teaching.

To assure flexibility in the program concurrently, a variety of approaches to the experience were available (see Figure 2). Teachers following the Individual Path chose to complete their learning through 18 hours of graduate work at the University of Nebraska Omaha or opted to work with the support of a CEMS Professional Development Specialist (PDS). Following the Team Path, teams of two to four members collaborated to learn and compile a portfolio; their learning plan was based on composite team needs. Finally, the School Wide Path resulted in school portfolios based on school needs, but not at the expense of teacher needs. In all cases, participation was voluntary.

Each approach had the participant develop and implement a learning plan, resulting in a variety of professional development activities. These plans were based on personal learning needs, school improvement goals and student achievement needs. To determine the participants' learning needs, we worked with McREL (Mid-continent Research for Education and Learning) to develop an online Profiler, a set of Likert scale statements to which participants responded. This online instrument clustered teachers' responses around categories (i.e., inquiry, equity, motivation, etc.) and compared results to exemplars. Discrepancies were identified and used by participants to develop learning goals, and databases of linked standards and research-based practices helped participants find learning resources. They completed an online plan to which their PDS responded. As these long-term plans were implemented, participants completed their online portfolio, supported electronically by the PDS in an interactive manner.

In summary, salient features central to the CEMS professional development model included:

1) Involvement of a "critical mass" (70%) of teachers at each school;
2) The active involvement of the leadership at each school;
3) Intensive study, based on teacher and student needs and focused on beliefs and philosophy, content, and instructional pedagogy;
4) Ongoing (12-18 months), consistent, and naturally embedded work with each teacher; and
5) A process for teachers' critical reflection regarding their beliefs and practices (action research).
METHODS

This study was established both to evaluate Banneker 2000: CEMS and to add to the research base. The focus of the study was to determine the impact of the CEMS model (standards-based professional development with flexible options for teacher engagement and focused on the school as the unit of change) on teacher and school change and on student achievement. To further define the research, the following questions were identified.

Research Questions
1. How does a flexible but intensive and ongoing professional development program promote teacher change?
2. How does teacher learning during this program impact student achievement and understanding in that teacher’s classroom?
3. How do commitments of and participation by school leadership and a critical mass of teachers in the school impact school change and school-wide student achievement?
4. Which professional development approach/pathway in the CEMS model was most effective for teacher change and student achievement?
**Individual Paths**

- Complete Profile and Plan

  - Complete university modules and meet quarterly for portfolio checks

  - Meet at least monthly to facilitate learning & portfolio progress

  - Work at own pace and meet for quarterly portfolio checks

Submit Individual Portfolio in 18 months

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**Group Paths**

- Complete Individual Profiles
- Develop Composite Results
- Work with Group to Plan

**Grade-Level**

- Meet at least monthly to facilitate learning and portfolio progress

Submit Team/School Portfolio in 12-18 Months

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**Discipline-Based**

- Meet six days scattered throughout the year to work as a group and complete individual implementation and reflection between meetings. Facilitates learning and portfolio progress.

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**Figure 2. Individual and group learning path options for CEMS participants.**

**Teacher Change**

To respond to the first question on the impact of the model on teacher change, data were gathered through the use of pre- and post-profiles of teacher perceptions, and pre- and post-retrospective surveys of teachers' beliefs and understandings, observations, and interviews.

*Pre- and post-profiler:* The Profiler, previously described, was administered to all CEMS participants. Data were collected online at the beginning of the program and as participants completed work (pre- and post-profiler). These data were used by teachers to reflect on their growth and by the USP to determine change in teachers' perceptions in three categories: beliefs, content and pedagogy. Though data were collected on those three categories, the data reported here are the beliefs data, since teacher beliefs were a core area of focus during the USP and essential to the change process. A series of questions was asked to which teachers responded, scores for questions related to various beliefs categories were clustered, and composite scores were reported. The clusters include general pedagogical approaches (constructivism), expectations for students (expectations/equity), and pedagogical content knowledge (inquiry/problem solving). Change in the composite scores between the pre- and post-Profiler for each of the three categories was determined for a sample of teachers (n=25). This sample included participants that varied across grade level, professional development path, cohort, and discipline (mathematics and science).
Directions: Read each of the statements in the first column and rank yourself in the second column (shaded gray) by thinking back to your understanding BEFORE your participation in Banneker 2000: CEMS. Next, think about your level of understanding about each statement AFTER your participation in Banneker and indicate that understanding (i.e., NOW) in the third column. Circle the appropriate numbers using the following key:

1 = no understanding  2 = very low level  3 = moderate level  4 = high level  5 = very high level

<table>
<thead>
<tr>
<th>How would you describe your level of understanding of or ability in the following:</th>
<th>My Level of Understanding or Ability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BEFORE BANNEKER</td>
</tr>
<tr>
<td>1. Teacher research to promote change requiring personal growth in attitudes and skills.</td>
<td>None</td>
</tr>
<tr>
<td>2. Teacher research to successfully implement learned teaching strategies.</td>
<td>None</td>
</tr>
<tr>
<td>3. Critical reflection on instruction to encourage student success in math or science.</td>
<td>None</td>
</tr>
<tr>
<td>4. Implementation of specific teaching strategies to support student inquiry.</td>
<td>None</td>
</tr>
<tr>
<td>5. Teaching big ideas and concepts as well as facts.</td>
<td>None</td>
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<tr>
<td>6. Instruction to elicit and address students’ prior knowledge, as supported by research.</td>
<td>None</td>
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<tr>
<td>7. Instruction to develop students’ conceptual understanding, as supported by research.</td>
<td>None</td>
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<tr>
<td>8. Instruction to help students think about and take control of their own learning, as supported by research.</td>
<td>None</td>
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<tr>
<td>9. Formative assessment strategies to promote inquiry and student understanding.</td>
<td>None</td>
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<tr>
<td>10. Ability to map units of study by unpacking standards to improve instruction.</td>
<td>None</td>
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<tr>
<td>11. Ability to analyze and enhance lessons to promote inquiry and student understanding</td>
<td>None</td>
</tr>
<tr>
<td>12. Ability to engage all students in learning math and/or science.</td>
<td>None</td>
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</table>

Figure 3. Sample retrospective pre- and post-survey instrument to evaluate participants’ understandings and abilities.
Observations and Interviews: Observations and interviews were conducted to determine fidelity of learning as it translated into practice and to identify the “determiners” of exemplary teachers. Among respondents to the retrospective pre- and post-survey, participants were identified that represented various cohorts, learning paths, grade levels and disciplines. Twelve teachers were identified to interview and observe; full data for nine teachers were collected and included in the analysis. These teachers represented various cohorts, both mathematics and science, and each grade band (primary, intermediate, middle school and high school).

Two observations of each participant were conducted between January and May of 2006. Observation methods included: 1) global scans to establish general classroom atmosphere and 2) pre-selected rubrics (Llewellyn 2001) to discern implementation fidelity of CEMS-taught inquiry based practices. Specific rubrics included lesson presentation, communication, student engagement, classroom organization, and questioning skills. Various indicators in each area scored a teacher as using teaching approaches that ranged from traditional to practicing inquiry. Rubrics were scored to deliver a composite score in each category to determine where in this range teachers were positioned (traditional, exploring inquiry, transitioning to inquiry or practicing inquiry). The boundary between “traditional approach” and “exploring inquiry” was rated a “1.” The boundary between “exploring inquiry” and “transitioning to inquiry” scored a “2,” while the boundary between “transitioning” to “practicing inquiry” ranked a “3.” A perfect “practicing inquiry” score was a “4.” In addition, scores were examined to determine in which areas teachers had most fully implemented inquiry.

Interviews were completed with each participant after all observations of that teacher were completed. The first interview question (How do you now see yourself as a teacher in the classroom?) related to teacher change. Interviews were coded for common themes and used to determine impact of learning on teacher change.

Student Achievement and Understanding
To respond to the second research question, “How does teacher learning during this program impact student achievement and understanding in that teacher’s classroom?” data were gathered from three primary sources: 1) participant vs. non-participant classroom CRT (Criterion Reference Tests) results, 2) teacher action research during strategy implementation to determine impact on student achievement and 3) teacher interviews to explore teachers’ perceptions and knowledge of both student understanding and the impact of teacher learning on student understanding.

Participant vs. non-participant assessment results: A cohort of Banneker teachers who completed a portfolio was compared to a group of non-participant teachers with similar school demographics. Participants included 68 Pre-Kindergarten through 7th grade Math and Science teachers, 34 of whom completed a portfolio in 2003-2004 and 34 of which did not participate in the program. All participants in the CEMS sample were pursuing one of the individual learning paths (CEMS, independent, team or university); no teams or school-wide participants were part of the sample. Inclusion in the treatment and sample was limited to those teachers that had student CRT scores in 2002-2003, the baseline year, and who
had taught in the same school, at the same grade level and in the same grade/discipline for the three consecutive years for which data were collected. These three years included the year prior to participation, the year during participation, and the year after participation. Control (non-Banneker) participants were matched to treatment (Banneker) participants according to school demographics, specifically the percent of minority students present in a school and the percent of free/reduced lunch students in a school.

Student CRT scores in Math and Science were used to tabulate the Average AYP (Adequate Yearly Progress) Score, Average Number of Standards Mastered, and Success Rate for each teacher. These same scores were tabulated in Math and Science for the years of 2002-2003, 2003-2004, and 2004-2005. Success rate was calculated by dividing the sum of the AYP scores by the sum of the AYP test parts.

**Action Research:** Teachers' reflective action research required that they implement strategies/approaches in the classroom that they learned during their personal program and reflect on student impact during implementation. Teachers gathered achievement data on both district criterion referenced measures and classroom measures of understanding. Summaries of sample action research results for each cohort were compiled to demonstrate impact.

**Interviews:** The second interview question (If someone were to look at your classroom now what would they observe?) was designed to elicit teacher feedback on both classroom atmosphere and student learning. Teacher interview responses were coded for common themes.

**Leadership and Critical Mass**

Data for the final research question were drawn from leadership action research, Exemplary School CRTs, principals' retrospective pre- and post-surveys, and teacher interviews.

**Leadership action research:** Principals and other instructional leaders in each developing school were given the opportunity to complete the portfolio process themselves, individually or as a team. These action research summaries served as qualitative and quantitative data for school level impact on teacher and student learning.

**Exemplary School CRT data:** As a school fulfilled its commitment to include 70% of the teachers in CEMS professional development, the school's CRT results were analyzed, comparing that year's results with the previous year. If consistent increases in CRT results across grade levels were demonstrated, the school was named Exemplary. These data served as the primary measure of impact of teacher learning on student achievement at the school level.

The first Exemplary School was named during the first year of CRT implementation so their designation was based on California Achievement Test (CAT) results and on differences between school and district CRT results. Three years of CRT data are available for the next nine schools gaining exemplary status, and two years of data are available for the remaining schools, named during the last year of CEMS. Samples of these data are printed below.

**Leadership retrospective pre- and post-surveys:** A ten-item, retrospective survey of leadership understandings was administered. Respondents were asked to think about the issues addressed in each question and to what degree it represented their understanding before and after participation in Banneker. Response categories included the following: 1) None, 2) Very Low, 3) Moderate, 4) High, and 5) Very High. At the close of the initiative, surveys were mailed to principals in all Developing and Exemplary Schools (n=58). A 28% return on surveys (n=16) provided data used in this analysis. Respondents included principals from eight Developing Schools and eight Exemplary Schools. Data were compiled for all respondents and analyzed for differences in response between principals in Developing and Exemplary Schools.

**Teacher interviews:** The final interview question (What are your professional relationships with teachers both in your school and outside the school and district?) provided qualitative data to inform the impact of leadership and critical mass on school change and student achievement. Teacher interview responses were coded for common themes.

**Path Effectiveness**

Multiple data sources were used to determine which professional development approach in the CEMS model was most effective for teacher change and student achievement. These sources included: 1) retrospective pre- and post survey results by path, 2) CRT results by path, 3) program completion rates by path, 4) teacher interviews, and 5) exit questionnaires.

**Retrospective pre- and post survey results by path:** The retrospective pre- and post-survey was previously described. A One-Way ANOVA was used to identify differences in reported understandings and beliefs according to teachers' Banneker pathway.

**CRT results by path:** These data were gathered as described in the "Student Achievement" section. In the sample used for this evaluation only CEMS (N=8) and Team (N=14) pathways had a large enough
sample to allow a comparison, due to the rigorous requirements for inclusion in the sample. Paired sample t-tests were used to assess whether either group exhibited a significant mean increase from baseline to one year after program instruction.

Program completion rate by path: A program "completer" was defined as an individual who submitted a portfolio at the end of their program. The definition of "participant" was an individual who committed to participation, completed the initial profiler and began program work. It excluded individuals that committed to involvement, only to drop out prior to initiation of work. The total "completer" number by path was determined, numbers were compared to the total number of original participants by path, and percent completion was determined.

Teacher interviews and exit questionnaires: As described previously, teacher interviews were conducted with a sample group. Since references to pathway experiences emerged during the interviews, transcripts were included as qualitative data. Exit questionnaires were administered to all Banneker participants, both completers and drops. Responses to these open-ended questions were coded, along with teacher interview results, for themes. These themes served as qualitative data to inform our understandings of path effectiveness.

RESULTS AND DISCUSSION

Teacher Change

Pre- and post-profiler: The beliefs component of the Profiler included question clusters that focused on general pedagogical approaches (constructivism), expectations for students (expectations/equity), and pedagogical content knowledge (inquiry/problem solving). Positive impacts on beliefs were apparent in all three categories (Figure 4). It is interesting to note that participants were expected to focus on only one of these areas during their program but often showed growth in all three areas. However, there were participants who measured declines in scores; many felt these declines were due to learning more about what they previously did not know and felt that their original responses were inflated. As stated earlier, the retrospective pre- and post-survey was included as a data source as a result of these responses.

Retrospective pre- and post-surveys: Figures 5 and 6 share these data and the questions on which these data were based. The paired sample t-tests indicated a significant change in beliefs for each individual question and for composite before and after scores (t(45)= 11.12, p< .05). Consistent positive impact was demonstrated on teachers' beliefs (Figure 5), in this case about their teaching. The highlighted questions showed the greatest change and indicate the importance of collaborative, teacher reflection in the context of their work (curriculum, strategies and materials). Figure 6 shares similar data for teachers' understandings. Paired sample t-tests indicated a significant gain in understanding for each individual question and for composite before and after scores (t(45)= 18.91, p<.05). While consistent and positive changes are demonstrated, the greatest increase was on questions related to teachers' own reflective practice, specifically the ability to implement research-based strategies, reflect during implementation and help students take more control of their inquiry-based learning.
Questions—Rank your level of agreement with each statement:

(Note: This was on a scale of 1-5, with 5 being the most positive. The number in parentheses after the question is the change in mean response for the question)

1. All students can learn science and mathematics subject matter through inquiry and/or problem solving. (+0.9)
2. Personal and critical reflection on my own instruction is essential to improved student understanding and achievement. (+1.3)
3. Assessing each student’s understanding of concepts is essential if all students are to master mathematics and science. (+1.0)
4. The way in which I teach impacts the success of all my students. (+0.8)
5. The role of high quality instructional materials is to support both what is taught and how it is taught. (+0.9)
6. Mapping instructional units helps me develop an understanding of how concepts are developed. (+1.4)
7. Mapping units of study by unpacking standards clarifies and prioritizes content and develops lessons that promote student understanding. (+1.5)
8. Modifying instructional materials should involve reflecting on research about how people learn (my own research and that of others). (+1.4)
9. Developing instructional materials in collaboration with others enhances unit and lesson quality and promotes teacher learning. (+1.2)
10. Conducive learning environments are created when positive students attitudes about learning science and mathematics are developed. (+0.9)

Creating a classroom environment conducive for learning includes recognizing a student’s progress and effort. (+0.8)

Figure 5. Results from the teacher participants’ “beliefs” retrospective pre- and post-survey and associated questions (n=45). Highlighted questions showed greatest change.
Questions - Rank your level of understanding of:

(Note: This was on a scale of 1-5, with 5 being the most positive. The number in parentheses after the question is the change in mean response for the question)

1. Teacher research to promote change requiring personal growth in attitudes and skills. (+1.41)
2. Teacher research to successfully implement learned teaching strategies. (+1.44)
3. Critical reflection on instruction to encourage student success in math or science. (+1.33)
4. Implementation of specific teaching strategies to support student inquiry. (+1.47)
5. Teaching big ideas and concepts as well as facts. (+1.13)
6. Instruction to elicit and address students’ prior knowledge, as supported by research. (+1.35)
7. Instruction to develop students’ conceptual understanding, as supported by research. (+1.31)
8. Instruction to help students think about and take control of their own learning, as supported by research. (+1.55)
9. Formative assessment strategies to promote inquiry and student understanding. (+1.33)
10. Ability to map units of study by unpacking standards to improve instruction. (+1.37)
11. Ability to analyze and enhance lessons to promote inquiry and student understanding. (+1.5)
12. Ability to engage all students in learning math and/or science. (+1.18)

Figure 6. Results from the teacher participants’ “understandings and abilities” retrospective pre- and post-survey and associated questions (n=45). Highlighted questions showed greatest change.

Interviews: Interview data (see Table 1) support results of pre- and post-profile data and retrospective pre-post survey data, and provide teachers’ rationales for changes in understandings and beliefs. Themes evident in the interviews include the importance of required reflection and use of research to their professional growth, enabling them to “discover” their own learning and translate that into classroom practice. A strong message of increased teacher efficacy and willingness to try new things emerged, and participants often related this to their changed beliefs – most strongly those beliefs about the role of inquiry in the classroom and the release of teacher control to allow student decisions and inquiry in the classroom.

Observations: Observation data showed learning environments in which students were engaged in lessons and teachers facilitated the learning. All participants attempted to allow student ownership of learning by releasing some control and providing inquiry opportunities. Degree of inquiry implementation varied, but all made steps toward an inquiry-based classroom.
Table 1. Teacher change themes and supporting participant quotes drawn from teacher interview data.

<table>
<thead>
<tr>
<th>Theme</th>
<th>Teacher Comments</th>
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| Required reflection             | • Nowhere do you have to look so closely. Wouldn’t have done it without Banneker.  
• I’ve always reflected, but I didn’t really know what to reflect on or about. I’m more targeted now – styles of teaching, who I’m teaching.  
• Ability to reflect and modify instruction  
• Confidence to try things  
• I have confidence to do my job.  
• More willing to try non-traditional lessons. I have control and confidence in decisions and judgments about it (cooperative learning).  
• I am a much better teacher today because of Banneker. Before Banneker I just did not teach science. I was afraid to teach it because I felt that I didn’t understand it. I avoided scheduling science or placed it at the end of the day. Many times we just didn’t get to it.  
• I am more confident in my science teaching and more willing to take risks when planning investigations. I welcome the many questions that my students ask.  
• I feel more comfortable doing science with my students now.  
• I have always loved science. I just needed more work on understanding science concepts and delivery of science...I am more turned on to science now than ever before because of Banneker and the NASA work.  
• Learned to determine the value of something before trying it and during implementation – from action research – not just because it was a trend.  
• Reading the research pushed me to do more group work  
• My teaching wouldn’t be where it is. I wouldn’t be reading research. I was in survival mode. Now I can sort research and determine what’s valid.  
• Science literacy and inquiry - Doing science, not just learning about it  
• Banneker definitely caused me to focus on thinking – inquiry – not just doing but thinking – “What are you thinking?” “Explain yourself.” “Tell me more.”  
• Teaching for understanding – not for the test.  
• My classroom has changed over the years. Today I am including more hands-on science than I did when I first started at Skinner. I have moved from just reading science to science investigations.  
• More inquiry, freedom, choices – less rote  
• I was a lot more rigid before. Thought there was a correct way and a wrong way – with little in between. Now no one way – with every group of kids I must change because they’re different and respond differently.  
• I was too quick to help students...Before, I felt confident in content and felt I had materials to use in the classroom...but letting go of control – that’s all Banneker.  
• Strengthened my ability to engage students in science; Less teacher-directed  
• Students as active participants instead of just bystanders - Know what they’re doing and why they’re doing it – more on task – fewer discipline problems  
• Discovering my own learning again  
• Know more about how kids learn and how to use that to build lessons  
• Increased content & pedagogical content knowledge, especially nature of science |
Rubric scores confirmed these patterns (see Table 2). With the exception of one teacher in one category, all were at least transitioning to inquiry, as evidenced by scores of two or greater in all categories. Lesson presentation, communication and engagement of students scored the highest, each with composite scores between 2.8 and 3.0 (strongly within the transitioning to inquiry category and close to practicing inquiry). The lesson presentation rubric evaluated teachers’ practices that reflect the role of teacher as facilitator and implementation of inquiry in the classroom, as well as use of whole-group, small-group and individual instruction, flexing their approach when unexpected results occur. The communication rubric defines the teacher as “practicing inquiry” when she clearly defines expectations, expects student-to-student as well as student-to-teacher dialogue, and facilitates that communication by movement through the room, monitoring discussions and making eye contact. The student engagement rubric defines practicing inquiry as classrooms where the teacher engages students in discussion, investigation and reflection, there is frequent self-engagement by students, students are consistently active in hands-on and minds-on activities, and the teacher frequently and effectively solicits information from students. Scores in each of these categories provide evidence that the observed teachers are strongly transitioning to inquiry (and in half the cases practicing inquiry). Slightly lower composite scores occurred for classroom organization and questioning skills, but all but one teacher scored at least as transitioning to inquiry. In some cases, classroom organization was fixed with no flexibility on the teachers’ part, often resulting in a lower score on that rubric. Overall, the observation data confirm that teachers involved in this research were clearly transitioning to inquiry and, in three cases, consistently practicing inquiry in the classroom.

**Student Achievement**

Math T-test Analyses: T-tests to compare the Average AYP intercepts for Math at baseline were found to be non-significant. The control and treatment groups did not have significantly different starting points in terms of their students AYP scores.

A Paired sample t-test indicated no significant difference from Average Math AYP Scores at baseline to Average Math AYP Scores at the third measurement for either participants or non-participants. Neither group showed evidence of increased success as measured by Average AYP math scores.

A Paired sample t-test indicated a significant difference from Average Math Standards Mastered at baseline to Average Math Standards Mastered at the third measurement for participants of Banneker (t(25)= -2.55, p<.05). No significant increase for Non-participants was found when examining Average Standards Mastered at time 1 and Average Standards Mastered at time 3. The participant group showed evidence of increased success as measured by Average Standards mastered in Math.
Science T-test Analyses: A Paired sample t-test indicated a significant increase for participants (t(25) = -2.11, p<.05) and non-participants (t(24) = -2.25, p<.05) when examining the difference from baseline to third measurement of Average AYP Scores in science. Non-participants showed a slightly larger mean increase in student's average AYP score than participants in the Banneker program.

Paired sample t-tests indicated a significant difference from Average Science Standards Mastered at baseline to Average Science Standards Mastered at the third measurement for both participants (t(25) = -4.866, p<.05) and non-participants (t(25) = -3.14, p<.05). (See Figure 7). Participating teachers of Banneker exhibited a slightly larger mean increase in the average number of standards mastered by their students than teachers that did not participate in the program.

Figure 7. Change in Science Standards Mastered for participants and non-participants between 2002 and 2005.

Discussion of T-test Results: Banneker trained teachers showed significant mean increases in Math Standards Mastered, Math Success Rate, Average AYP Science Scores, Science Standards Mastered, and Science Success Rates from the years 2002-2003 to 2004-2005. None of these increases were significantly larger than the increases demonstrated by Non-Banneker trained teachers. The absence of a significant difference between these two groups suggests the possibility of variables other than Banneker participation accounting for student achievement increases in the three years examined for this study. While classroom and school factors, such as percent of minority and free/reduced lunch students, have been controlled for through control/treatment matching, factors such as teacher motivation, expertise, and experience have not been measured or controlled. Also not accounted for are professional development hours taken by Non-Banneker teachers that may have affected classroom behavior or effectiveness. Finally, the range restriction of the five-point CRT scale makes this metric difficult to use when demonstrating change or differences due to variables. Fewer individuals score at the extremes and group means tend toward the center of the range, making it difficult to discern significant differences and/or changes in scores. As a result, these data must be interpreted in the context of additional information.

Action Research: Over 85% of teachers' action research projects detailed enhanced achievement and understanding of their students, as measured by Criterion Referenced Tests and/or teacher assessments. Table 3 shows results for a sample drawn from the same cohort year previously reported in the science and math t-test results. Common teacher research results across action research projects included 1) consistent and positive impact on California Achievement Test (CAT) scores, Criterion Referenced Tests (CRT's) and/or classroom assessments, 2) increased demonstration of student understanding in journals, student work and dialogue, 3) enhanced problem-solving and questioning, and 4) other positive impact on attitudes and behaviors that increased student opportunity to learn. As teachers completed their required teacher reflection, gathering data and focusing on what students did and said, they reported looking more
Table 3. Sample action research results drawn from 2003-2004 cohort.

<table>
<thead>
<tr>
<th>Grade and Discipline</th>
<th>Research Focus</th>
<th>Achievement Impact</th>
<th>Other Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st, Math</td>
<td>Problem-based Learning</td>
<td>Using PBL – 95% Advanced on CRT vs. no PBL - 50% Advanced, 48% Proficient and 2% Progressing.</td>
<td>Increased self-direction in problem-solving; improved perceptions of students and parents; increased confidence in problem-solving</td>
</tr>
<tr>
<td>1st, Science</td>
<td>Graphic organizers</td>
<td>Increased performance on CRT's</td>
<td>Enhanced abilities to communicate understanding</td>
</tr>
<tr>
<td>1st, Math</td>
<td>Cooperative Learning</td>
<td>Higher success rate on CRT's than previous year</td>
<td>Increased student discussion of work; positive perceptions.</td>
</tr>
<tr>
<td>1st, Math</td>
<td>Manipulatives to scaffold learning</td>
<td>Increased performance on CRT's over previous years</td>
<td>Better understanding of mathematical concepts; moved away from dependence on manipulatives</td>
</tr>
<tr>
<td>2nd, Science</td>
<td>Journals to process hands-on science</td>
<td>100% Advanced on all CRT's</td>
<td>Improved participation in science; student-reported increase in concept understanding</td>
</tr>
<tr>
<td>3rd, Science</td>
<td>Literacy centers – science vocabulary and concept growth</td>
<td>Not reported</td>
<td>Increased median scores on classroom assessments; improved understanding of science concepts; increase in self-directed learners</td>
</tr>
<tr>
<td>3rd, Science</td>
<td>Cooperative learning</td>
<td>Increased performance on CRT's</td>
<td>Improved cooperation</td>
</tr>
<tr>
<td>4th, Science</td>
<td>Learning cycle</td>
<td>CRT Round 1 (4-04) - 64% Proficient or Advanced; CRT Round 2 (4-03) - 90% Proficient or Advanced; Round 3 (4-03 Form B) - 95% Proficient or Advanced.</td>
<td>Increased student confidence and risk-taking; more detailed and mature journal answers; more engaged students with more positive behaviors</td>
</tr>
<tr>
<td>5th, Science</td>
<td>Performance-based assessment</td>
<td>% of students Proficient or Advanced increased from 77% to 95%</td>
<td>Improved work habits and engagement; increased confidence to answer questions, discuss and interact.</td>
</tr>
<tr>
<td>5th/6th, Math</td>
<td>Problem-solving in Science</td>
<td>CRT success (Proficient or Advanced) 1st CRT - 42%; 2nd CRT - 59%; 3rd CRT - 71%</td>
<td>Increased student engagement</td>
</tr>
<tr>
<td>6th, Science</td>
<td>Science journals to enhance conceptual understanding</td>
<td>Not reported</td>
<td>Better science writers; journals indicated increased understanding; increased engagement and enthusiasm</td>
</tr>
<tr>
<td>7th, Science</td>
<td>Inquiry and self-direction</td>
<td>Increased performance on CRT's</td>
<td>Increased engagement and time on task; improved self-direction.</td>
</tr>
</tbody>
</table>
Table 4. Student understanding themes and supporting participant quotes drawn from teacher interview data.

<table>
<thead>
<tr>
<th>Themes</th>
<th>Teacher Comments</th>
</tr>
</thead>
</table>
| Working together to question and explain | • Students doing more of the questioning and thinking  
• Questioning. Kids are using white boards, doing research, working together to answer their own questions, explaining to each other.  
• Kids are more likely to and free to ask questions. They respect other people's thoughts even if wrong, and let them explain. |
| Responsibility for thinking   | • Their understandings were deeper because they had to struggle through the thinking aspects (i.e., through inquiry).  
• Not all regurgitation. Great to know facts, but it's more important to explain.  
• Kids are the ones thinking rather than me pouring things in their heads.  
• My students are independent learners and work effectively individually and in groups.  
• My students understand their roles. |
| Changing environment          | • Through CEMS I learned tools to aide the teacher in facilitating that type (i.e., inquiry) of environment for students, leading to deeper understanding  
• Considering changes last year (departmentalization), our 4th graders are now 5th graders - I believe their CRT's are 100% for every student. Such a difference in knowledge they bring to the curriculum compared to past 5th graders. |

Table 5. Pre- and Post-Survey results from a leadership team's action research at the first Exemplary School, Pinewood Elementary.

<table>
<thead>
<tr>
<th>Focus of Survey Question</th>
<th>Initial Survey % Response</th>
<th>Final Survey % Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teacher level of comfort with inquiry-based science</td>
<td>15%</td>
<td>76%</td>
</tr>
<tr>
<td>Teacher love of teaching inquiry-based science</td>
<td>5%</td>
<td>72%</td>
</tr>
<tr>
<td>Student's level of &quot;liking&quot; science</td>
<td>55%</td>
<td>90%</td>
</tr>
<tr>
<td>Student response - whether their teacher liked teaching science</td>
<td>40%</td>
<td>89%</td>
</tr>
<tr>
<td>Students thought they would pass their CRT</td>
<td>30%</td>
<td>80%</td>
</tr>
</tbody>
</table>

closely at individual students and what each student understood, rather than looking at class averages. This usually led to modifications of instruction for the entire class and/or individual students, further enhancing understanding. Inconsistencies in CRT reporting between action research and t-test results may be due to individual teachers sampled, as well as the action research focusing on one year as compared to three years' scores from three cohorts measured in the t-tests.

Interviews: Themes that emerged from interview coding indicated that student understanding was deeper and more conceptual and that their abilities to engage in this type of thinking were enhanced (see Table 4). Teachers felt their students understood more and that, while CRT scores improved (in these particular classrooms), the more important results were student ownership of learning, collaborative efforts, and more questioning and thinking on the students' parts.

Leadership and Critical Mass

Leadership Action Research: One example of a site with both leadership commitment and a critical mass
of teachers (all teachers) was Pinewood Elementary. Pinewood’s effectiveness can be attributed to these two important aspects since the principal and instructional facilitator completed a leadership portfolio. During their work, they learned more about inquiry and facilitated professional development for their entire staff and also supported the purchase and use of classroom materials. Table 5 shows results drawn from their leadership action research. These results from a survey of all Pinewood teacher participants indicate that teachers’ level of comfort with inquiry-based science increased significantly. Not only did the comfort level increase but also the teachers’ love of teaching inquiry based science increased.

In addition, all students of participating teachers were surveyed. At the end of the professional development period, a majority of the students liked science. It was also clear from the student data that they perceived that their teachers liked science teaching. More than seventy-five percent of the students felt that they would pass their CRT.

Every school in which a principal or other instructional leader completed a leadership portfolio achieved Exemplary status. Recall that this required 70% teacher participation and positive impact on CRTs. Not all schools that met participation requirements were named Exemplary, but all schools where leaders were involved gained this status.

Exemplary School CRT Data: During the life of the USP, 17 Exemplary Schools were named. Data from 10 Exemplary Schools reported here. With the exception of the single high school named exemplary, these schools serve populations with high percentages of lower socioeconomic status students, English as a second language learners, and students of color. Six of these schools were named Exemplary in the summer of 2004, based on consistently improved CRT results between 2003 and 2004. Data from 2005 are included for these schools; while some scores continued to increase, some declined. Results from four schools named Exemplary in 2005 includes only two years of data, 2004 and 2005.

Central Park Elementary (Figures 8 and 9) shows an increase each year in grades one, two, four and six. Grades three and five showed an increase in science CRT results between years one and two and a decline during year three. Central Park showed increased mathematics success on the CRT during years one through three for grades one, two, four, five and six. There was a decrease in the mathematics CRT for grade four. The principal was supportive from the beginning of the initiative both in terms of personal participation in leadership meetings and in supporting teachers in their efforts.

Liberty Elementary (Figure 10) was involved in a school-wide professional development. The principal was instrumental in leading teachers to this point. She bought into the idea of school-wide professional development and helped, in conjunction with the instructional facilitator, to orchestrate implementation of the work. As a result, Liberty was successful in science CRT’s in grades one, two, and five across all three years, though decreases in CRT success occurred during the third year at the third, fifth and sixth grade levels.

Lothrop Spanish, Science, and Technology Magnet School had increased CRT success over the three years in grades one and four (Figure 11). There were increases in grades two and three the first year but a slight dip between years two and three. The school leadership at Lothrop was very supportive and involved with the partnership from the beginning of the grant.

Figure 8. Science Criterion Referenced Test results for Central Park Elementary, named Exemplary based on consistent increases in CRT results between 2002-2003 and 2003-2004.
Figure 9. Mathematics Criterion Referenced Test results for Central Park Elementary, named Exemplary based on consistent increases in CRT results between 2002-2003 and 2003-2004.

Figure 10. Science Criterion Referenced Test results for Liberty Elementary, named Exemplary in science based on consistent increases in CRT results between 2002-2003 and 2003-2004.

Figure 11. Science Criterion Referenced Test results for Lothrop Magnet School, named Exemplary in science based on consistent increases in CRT results between 2002-2003 and 2003-2004.
Figure 12. Science Criterion Referenced Test results for Minne Lusa Elementary, named Exemplary in science based on consistent increases in CRT results between 2002-2003 and 2003-2004.

Figure 13. Science Criterion Referenced Test results for Saratoga Elementary, named Exemplary in science based on consistent increases in CRT results between 2002-2003 and 2003-2004.

Figure 14. Science Criterion Referenced Test results for Burke High School, named Exemplary in science based on consistent increases in CRT results between 2002-2003 and 2003-2004.
Figure 15. Mathematics and Science Criterion Referenced Test results for Franklin Elementary, named Exemplary based on consistent increases in CRT results between 2003-2004 and 2004-2005.

Figure 16. Mathematics and Science Criterion Referenced Test results for King Science and Technology Magnet School, named Exemplary based on consistent increases in CRT results between 2003-2004 and 2004-2005.
Figure 17. Mathematics Criterion Referenced Test results for Bryan Middle School, named Exemplary in mathematics based on consistent increases in CRT results between 2003-2004 and 2004-2005.

Figure 18. Mathematics Criterion Referenced Test results for Hale Middle School, named Exemplary in mathematics based on consistent increases in CRT results between 2003-2004 and 2004-2005.
Questions - Rank your level of understanding of:

1. Science and math standards
2. Science inquiry as it is conducted in the classroom
3. Problem-solving strategies
4. Best practices in science and math
5. Effective science and math leadership
6. Monitoring science and math achievement
7. Analysis and use of science and math achievement data
8. Identifying effective science and math materials
9. Developing teacher leaders in math and science
10. Leadership's role in effecting change in math and science

Figure 19. Results from the principals’ “understandings and abilities” retrospective pre- and post-survey and associated questions (n=16). Highlighted questions showed greatest change.

Minne Lusa Elementary (Figure 12), like Liberty, joined the partnership as a school-wide project. The principal engaged grade level teams to complete the professional development. Time during the school day was allocated for teams to work together, and the resulting CRT success rate was very positive. In general, each year all grade levels except grades one and four increased the CRT scores. However, there was just a slight decrease in the Science CRT scores in grade one from year two to three. Grade four showed the largest dip in CRT scores during years two and three.

Another Exemplary School, Saratoga Elementary, showed significant increases in CRT success each of the three years in grades two, four and six (Figure 13). All grade levels increased in CRT success from year one to two, but grades one, three and five showed a decrease in success between years two and three.

Burke High School (Figure 14) was the lone Exemplary high school in this study. Students at Burke increased CRT success each year in biology and chemistry. Physics success increased between years one and two but slipped slightly between the second and third years.

Franklin Elementary (Figure 15) was named Exemplary and distinguished itself in both mathematics and science. There was an increase in mathematics CRT success each year. The science
CRT success also increased across all grade levels except for a slight decrease for 5th grade.

King Science Center (Figure 16), a middle school magnet center, showed progress in mathematics and science CRT's each year in mathematics (algebra, geometry, pre-algebra and math 5-7). The CRT science success rate increased each year in 7th and 8th grade and Biology but showed a slight decrease from year one to two in grades five and six.

Bryan Middle School (Figure 17) was successful each year in mathematics (Math 7, Algebra, Geometry and Pre-Algebra). Another Exemplary middle school, Hale (Figure 18) showed success each year in math 7, geometry, and pre-algebra. There was a decrease in CRT success in algebra.

Table 6. Leadership development themes and supporting participant quotes drawn from teacher interview data.

<table>
<thead>
<tr>
<th>Theme</th>
<th>Teacher Comments</th>
</tr>
</thead>
</table>
| The importance of networking               | • Greatly opened a network I didn't know was there before – of teachers so passionate and excited about science; The community challenged a lot of us beyond our comfort zone – almost like a sorority – dedicated to teaching.  
• Network of people to communicate with; common base knowledge to communicate with.  
• My professional relationships with teachers in my building are minimal relative to science. Many of them are not teaching science. The other Banneker teacher and I do talk about what is going on during science lessons. I have more communication with teachers in the district who have had Banneker classes with me and those who have been in Banneker workshops. We share information and ideas frequently.  
• My relationship (professional) is with another teacher in my building who was also a part of the Banneker program. Other colleagues that I communicate are those who were in the Banneker classes.  
• I sometimes discuss what I am doing with other Banneker teachers in my building. |
| Took on a leadership role                   | • Gave me more confidence in what I was doing. I took on more leadership...wanted to share and take the next step  
• Want to share; feel a responsibility to do so. |
| Did more than I expected of myself         | • I've done so many things I never expected to do...anything is possible  
• I didn't know what I was getting into. It totally exceeded my expectations. The Banneker process took me way further than I ever dreamed of. I had career goals, but never thought they'd be happening this early.  
• I don't know if Teresa and I would have pushed departmentalization without CEMS. |

Leadership retrospective pre-post surveys: Figure 19 shows the results from the USP principals' retrospective pre- and post-survey of understandings. The highlighted questions are those that showed the greatest change for “all” respondents though there were positive changes in all cases. It is interesting to note the questions on which Exemplary School principals showed greatest growth (questions 1, 2, 8, 9 and 10). These questions relate to understanding science curriculum and instruction at the classroom level and the role of leadership in effecting change. Most of the remaining questions address areas of understanding common to other disciplines required of all leaders in the OPS, especially monitoring data. One might infer that the more intimate understanding of science standards, inquiry and materials, as well as leadership capacity to affect change in math and science, were essential to the schools' Exemplary status. Further research in this area is warranted.

Teacher interviews: Data emerged during teacher interviews indicating the importance of expanded networks and how the networks enhanced participants' leadership capacity (Table 6). Though teacher leadership development was not the focus of this work (i.e., not a trainer-of-trainers model or leadership development effort), teacher leaders emerged. Principals often partnered with them and recognized their growth. Many became formal or informal leaders in their school, enhancing the work of the collaborative community, and several took on leadership roles at the district level.
Path Effectiveness

Retrospective pre- and post survey results: The One-Way ANOVA analysis showed that on only one question did teachers identified by path show a significant difference in their level of understanding after participation in Banneker. On question seven of the survey, instruction to develop students' conceptual understanding, as supported by research, University path teachers reported a significantly higher level of understanding after Banneker participation than Team path teachers. Composite scores on the beliefs instrument after participation showed no significant differences when comparing path.

CRT results by path: Pathway comparisons appeared to show that CEMS-supported teachers outperformed Team instructed teachers on all measures of science achievement. While these differences were not significant, CEMS-supported teachers exhibited increases in student achievement more often than Team instructed teachers. Pathway comparisons for other paths are not possible due to the rigorous criteria for inclusion in the study sample.

Program completion rate by path: Completion rates varied by path. Rates by path were: CEMS-supported (50%), University (52%), Independent (59%), Team (63%), School-wide (93%) and Workshop participants (96%). Completion was high for the school-wide path since the principal committed support systems to assure this. Reasons for ceasing participation in other paths was often reported in exit questionnaires as due to constraints in participants' personal lives rather than from the experience itself.

Teacher interviews and exit questionnaires: While completion rate was low for CEMS-supported and University paths, teacher feedback from interviews and exit questionnaires indicated a deeper level of change and commitment on the part of these teachers. Specific examples include extensive, positive feedback on experiences of the university cohorts, including confidence in content understanding, models for classroom application and the strong network of colleagues established during their 18 months of study together. They also spoke highly of university professors and the attention provided to them by faculty. This same type of personal experience was cited as a positive aspect of the CEMS path, especially when working with certain professional development specialists. The opportunity to work with their PDS both inside and outside the classroom made application of theory to practice much easier for this group. Coupled with significantly greater CRT success as compared with Team pathway participants, this indicates that personal interactions with the PDS mentor allowed greater translation of participant learning into effective classroom practice.

While some respondents spoke positively of team and school-wide experiences, it was not uncommon to hear that some team members carried more of the burden of work and, as a result, often learned more in the process. While every school that chose the school-wide option reached exemplary status, there was more resistance from some teachers when the principal required participation. Exemplary Schools that had the least resistance were those where the principals encouraged participation, allowed various paths to completion of participation, and provided support for teachers work (pay and/or release time).

The strengths of the individual pathways (university and CEMS-supported) and the team pathways (small teams and school-wide teams) vary. Individual paths had lower retention rates but deeper learning while team paths allowed greater participation and retention, but increased resistance and, in some cases, produced only cursory learning. Exit questionnaires consistently included statements that stressed the importance of pathway choice for completion of work and successful teacher learning.

CONCLUSIONS AND RECOMMENDATIONS

This research evaluated the impact of the Banneker 2000: CEMS professional development model on teacher and school change and determined the degree of impact on student achievement. Extensive qualitative data and initial quantitative data were used to evaluate and summarize the initiative's impact. The results were based heavily on the qualitative data and further organization and analysis of our quantitative data is warranted. However, the intent of this work is to summarize general impacts using the data already available. One area of concern is the low return rate of on-program completion surveys. This rate is likely due to teacher receipt of surveys in the summer, a time at which responsiveness might be limited. In the future, return rate might be enhanced by administration before the school year ends.

Research results on teacher change include evidence that teachers were able to change their previous belief systems about how students learn, who can learn and how to support student learning through inquiry-based approaches. All data sources (pre- and post-profile results, retrospective pre-post surveys and teacher interviews) provide evidence that the program served as an effective change intervention. Teachers' action research into inquiry-based (standards) instruction over an extended time.
proved central to this experience in which teachers acted as researchers and reflective practitioners. Their action research experiences required that they look at individual students' understandings and disaggregate data in their classroom rather than focus on mean results. Their required, reflective research forced teachers to listen to students, and listening opened doors to changed practice.

Letting students take center stage during inquiry experiences meant challenging teachers' previous beliefs and practices. Data consistently confirm that relaxing rigid control in the classroom allowed students to take center stage and teachers to understand students' understandings and abilities more fully – understandings that often exceeded the teachers' original expectations. This increased both student and teacher efficacy since student engagement and understanding improved using this approach.

Another essential factor that promoted teacher change, as reported by teachers during interviews and confirmed by the retrospective pre-post survey, was exposure to and training in the use of research, both their own action research and our research. Teachers learned to select research-based strategies for classroom use and to modify instruction based on their ongoing action research.

Finally, enhanced content and pedagogical content (especially inquiry) understandings made teachers more confident as they implemented new strategies. Elementary teachers often avoided science instruction because they lacked science content background, but this changed as they learned more content and strategies to teach that content effectively. Secondary teacher participants most often credited enhanced efficacy to improved pedagogical content knowledge.

Independent work by the program external evaluator supported our findings. Her case study results found the initiative was successful at promoting teacher change due to four factors.

1. It taught inquiry through inquiry (action research).
2. It examined teacher beliefs about teaching and learning.
3. It helped teachers establish professional development goals that were attainable.
4. It provided teachers with a positive self-efficacy (showed teachers they can make a difference in student learning).

This research also demonstrated that teacher change translates in some degree to student achievement. Full implementation of new policies and practices takes many years, and even when support systems are in place teacher implementation takes several years (Bybee 1997). Though participating teachers outperformed non-participating teachers on some district CRT measures, none of these differences were significant. However, the researchers felt that the five point CRT scale and inability to control all variables influenced these results. In addition, CRT results through the years were for different student cohorts. This, coupled with the length of time it takes to fully implement new learning, would encourage further research in the classrooms of these teachers in the future.

The impact on student understanding was more evident in teacher action research and researcher observations. Action research results consistently showed deeper conceptual understanding by students as evidenced in formative and summative classroom assessments not always assessed in the CRTs. Classroom observations during this research found classrooms with students at the center engaged in questioning, explanation and dialogue, grappling with ideas and searching for understanding.

Program impact was most evident in schools where a high percentage of teachers completed CEMS studies. Almost all schools that met participation goals also impacted student achievement at the school level. The work in both the CPMPSA and the USP has proven that school leadership and a critical mass of teacher participants are important.

The Exemplary Schools that experienced both teacher commitment and student achievement were the sites where school leadership was significantly involved. Examples are Pinewood, Liberty, Lothrop, Minnie Lusa, and Central Park. In each of these schools the principals were engaged in and communicated with the teachers about the professional development work. As a result, the principals understood the work that the teachers were doing.

Though not as intricately involved in the professional development experience, principals at King Science Center and Nathan Hale collaborated to determine the staff needs and met with them to establish the positive resolve required to take action. This type of leadership is significant because it provides support for teachers that include resources and time. Principals took the time to think about ways of assisting the teachers in their work.

However, leadership can impact school change positively or negatively; positive support and participation by school leadership are essential for school change that maintains involvement of all teachers and increases achievement. However, participation demands by leadership without support...
systems lead only to resistance. Several Developing Schools began with teacher commitment but lost teachers over time, and thus never met participation requirements, as a result of this type of leadership.

Research related to pathway options suggests that no one pathway represented the ideal. Rather, different pathways worked best for different individual teachers. While there were some teachers who decided to leave the program, their reasons were rarely associated with the pathway they chose. Pathway options took into consideration the teacher's personal and professional circumstances and learning goals, thus provided effective professional development experiences for participants. Prior experiences did not allow teachers to make such choices. Teachers were told what they needed to do and they complied. Learning path flexibility was an effective way to implement the current teaching/learning model.

Professional development effectiveness alone will change only the teacher. While individual pathway choices met needs of individual teachers, pathways demonstrated varying retention rates. Efficiency requires engaging enough teachers in a school to make an impact. Support from the principal and collaboration among teaching peers are critical for teachers who want to implement best practices successfully. This study supports the idea that individual teachers participating in professional development and returning to their schools and expecting to produce an impact does not occur to the same degree as when critical masses of teachers are involved.

This research demonstrates that both professional development program effectiveness and efficiency can be addressed simultaneously. Path choice allows effective teacher learning, while involvement and support by leadership allows participation by many teachers, regardless of pathway. To balance effectiveness and efficiency requires options for professional learning from which teachers can choose, as well as school-wide support and focus over a long term on the impact of teacher learning on student understanding.

Based on these findings, recommendations for school systems considering use of an effective professional development model include:

1. Teacher beliefs must be examined in order to impact student learning.
2. Critical reflection on the impact of teaching practice on individual students is central to changing teacher beliefs.
3. Content and pedagogical content knowledge are essential to improved practice but must be addressed in concert with reflective practice in order to impact teacher and school change.
4. Choice is necessary for effectiveness of and significant participation in an intensive and ongoing professional development program.
5. A critical mass of teachers must be involved in order to improve achievement consistently at the school level.
6. Positive support and participation by school leadership are essential for school change that impacts achievement.

**LITERATURE CITED**


PREPARATION OF MANUSCRIPTS FOR PUBLICATION IN THE TRANSACTIONS

Two printed copies of the manuscript, tables, and figures, in finished form, should be sent to the Editor with the understanding that the work is to be published exclusively in the Transactions, unless otherwise arranged in advance. These copies will be sent to reviewers. Corrections and suggestions will be returned to the author if necessary. The final version of the manuscript, tables, and figures should be sent to the Editor via e-mail attachments. Text and figure captions should be in Microsoft Word™ (.doc) or rich text (.rtf) format. Figure captions should be placed at the end of the main file and not on the figures. Please submit tables and figures as separate files, avoiding complex formatting; we work with tables as tabbed text and prefer to receive them in that form although we can accept Excel™ (.xls) files. Black and white line drawings and photographs should be clearly distinguished by their file names and should be in .tif or .jpg format. Do not place illustrations of any kind in the main (.doc or .rtf) file.

The manuscript should be double-spaced throughout, including the Literature Cited. Title, author, address with zip code, e-mail, and shortened running title should appear on a separate page. Measurements should be reported in metric units. Headings used within the main text should be consistent: centered and all caps for primary headings, left margin/bold print for secondary headings. Avoid hyphenation at the ends of lines and do not right-justify the manuscript. Review a recent issue of the journal for details.

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