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Oklahoma Native Plant Record
Volume 11

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Foreword

Looking back over the last 10 years of publishing the Oklahoma Native Plant Record gives us an honest sense of accomplishment. It has been an uphill struggle to establish our journal, but with the turning of the decade, the *Record* has also turned the corner. As of this year all volumes are available online through Oklahoma State University's Edmon Low Library as an e-journal publication. It can be accessed globally at **http://ojs.library.okstate.edu/osu/**.

This year the historic paper is one of the chapters of Linda Gatti Clark's 1997 Ph.D. dissertation for Oklahoma State University (OSU). We will have to wait for an update to this flora of Boehler Seeps from another source, but it should provide an important comparison of changes in species over time in this unique habitat.

Marian Smith is from Southern Illinois University and Paul McKenzie is Endangered Species Biologist and Coordinator for the US Fish and Wildlife Service. Their paper on hybridization of two local species of sedges is the first to be submitted entirely online, a good sign that we are finally getting established. Incorporating online submission and publishing seems to be one of the most effective ways to connect with out-of-state scientists. Yet, this article is also a link to the past, being inspired by Dr. Larry Magrath, late member of Oklahoma Native Plant Society.

Molly Parkhurst, Andrew Doust, Margarita Mauro-Herrera, Jeffrey Byrnes, and Janette Steets from OSU have introduced a brand new topic for the *Record*; a population genetics study of Scribner's panicum, one of our native grasses. This up-to-date molecular research paper is likely to be cited in larger journals and is yet another sign of our progress.

Jerad Linneman, one of Michael Palmer's former students, addressed some of the redcedar controversies in his M.S. thesis from OSU, but was hired by the U. S. government before he could publish it. Matthew Allen, also from OSU, was recruited to update and co-author it for our journal. We appreciate Michael Palmer's initiative and assistance in acquiring the manuscript. It is very timely, considering the redcedar controversies and their role in recent wildfires. This paper discusses the effects of removing redcedar from old field grasslands.

Richard Thomas's paper is also a "hot" topic. It is an interdisciplinary study based on climate change and biogeographic interaction. This article can be used by local botanists and teachers to relate environmental science and climate change to local consequences. It is a comparison of the composition of the Cross Timbers before Euro-American settlement.

Remember and tell everyone you know that the *Record* is now available online. If you want a printed copy of any of our future volumes, get your order in early. Only 50 copies will be printed each year.

Sheila Strawn
Managing Editor

SURVEY OF THE VASCULAR FLORA OF THE BOEHLER SEEPS AND SANDHILLS PRESERVE

**Submitted to the Department of Botany of Oklahoma State University
in partial fulfillment of the requirements for the Degree of Doctor of Philosophy
July 1997**

Linda Gatti Clark
E-mail: gatti.clark@gmail.com

Located in Atoka County of south-central Oklahoma, The Nature Conservancy's Boehler Seeps and Sandhills Preserve comprises sandhills, acidic hillside seeps, marshes, intermittent and permanent streams, and shallow lakes. The sandhills are the site of the highest quality, old-growth vegetation of the Western Gulf Coastal Plains (S. Orzell, pers. comm. to Ian Butler). The flora is a unique assemblage of plants that is present nowhere else in the state and considered globally rare. Approximately 400 species are believed to be present (Jones 1993). More than 20 rare species have been reported to occur in the area, including some that are globally rare (Oklahoma Natural Heritage Inventory 1997). *Eriocaulon kornickianum*, for example, is designated G2 and S1. Other rare species in the preserve include *Penstemon murrayanus* (G4, S1S3), *Polygonella americana* (G5, S1S2), and *Paronychia drummondii* (G4G5, S1S2).

Prior to this study, our knowledge of the vascular plant species in the preserve was incomplete. Although several partial lists of its flora had been compiled, a systematic survey of the area to inventory all of the plants had not been conducted. Such information is essential for understanding the ecology of the site and making decisions about its management. This study was undertaken to provide this information. Specific objectives were to: (1) compile a list of the terrestrial and aquatic vascular plant species present and (2) prepare a set of herbarium specimens to document the preserve's flora. This note summarizes my findings and provides a reference to the information compiled in Gatti Clark (1997).

BOEHLER SEEPS AND SANDHILLS PRESERVE

The preserve is a 235 ha site located in southern Atoka County, Oklahoma, approximately 11 miles north of Boswell (S25 & 26, T4S, R13W; Boswell NW Quad). It comprises two tracts bisected by a paved country road and is located in the watersheds of Muddy Boggy and Clear Boggy Creeks. Situated in the Dissected Coastal Plain Geomorphic Province and Western Coastal Plain Land Resource Area (Johnson et al. 1979, USDA Natural Resources Conservation Service 1992), its underlying strata are Cretaceous in age. Also underlying the preserve is the Antlers Sandstone Aquifer that is composed primarily of non-marine sand and clay, and marine limestone and clay up to 915 m thick and is saturated with water that has a moderate to high mineral content (Johnson et al. 1979). The water table is generally within 1-1.3 m of the surface, with seeps occurring where it reaches the surface (Jones 1993, pers. comm.). Soil series of the site are the Bernow-Romia complex, 8-12% slopes; Boggy fine sandy loam; and Larue loamy fine sand, 0-8% slopes (Shingleton and Watterson 1979). All are susceptible to erosion by both water and wind. Precipitation in the area of the preserve

Clark, L. G.
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occurs primarily in the spring and summer, and averages 119 cm per year (Ruffner 1980). The average growing season is 255 days; mean maximum annual temperature is 24.5° C and mean minimum is 11° C; the average number of days below 0° C is 52 (Ruffner 1980).

Vegetation of the area is Oak-Hickory Forest (Duck and Fletcher 1943) with several communities present. *Quercus stellata*, *Carya texana*, and *Sideroxylon lanuginosum* spp. *Lanuginosum* (=Bumelia lanuginose) dominate and form an almost continuous canopy in the drier areas. Typically a thick leaf layer is present on the ground, and understory vegetation is sparse. *Juniperus virginiana* and *Pinus echinata*, while not dominant, can be found scattered throughout the preserve. Common woody understory species are *Nyssa sylvatica*, *Vaccinium arboreum*, *Berchemia scandens*, and *Vitis rotundifolia*. Herbaceous understory taxa include *Galium arkansanum*, *G. obtusum*, *Tephrosia virginia*, *Carex* spp., *Cyperus* spp., and *Juncus* spp. Scattered throughout the preserve and most conspicuous are glades dominated by *Aristida desmantha* and *Selaginella rupestris*. Other glades are present and are dominated by various grasses, such as *Panicum* spp., mosses, and forbs, such as *Gaillardia aestivalis* and *Hieracium longipilum*. At the glade edges, trees other than the forest dominants are encountered, in particular *Quercus incana*. Its saplings are occasionally found in the centers of the glades.

Hassel and Boehler Lakes are small, shallow bodies of water maintained by beaver dams. Both have dense stands of emergent and floating-leaved species at their edges and open water in their centers. Dominant taxa include *Typha angustifolia*, *Nuphar lutea*, and *Nymphaea odorata*. Often quite abundant, free-floating species are *Azolla caroliniana* and *Utricularia biflora*. Two types of seeps are present in the preserve. One has water percolating slowly to the surface and accumulating in one area because of the topography. The ground surface has a spongy feel because of the thick carpet of vegetation, primarily mosses; *Sphagnum lescurii* and *Polytrichum commune* in particular dominate. Occupying natural drainage ways, the second type is characterized by water flowing away from the seepage point. Ferns, sedges, and rushes typically are in abundance along these watercourses. Between the lakes and the seeps are marshes dominated by *Osmunda regalis*, *O. cinnamonea*, *Cephalanthus occidentalis*, *Scirpus* spp., *Rhynchospora* spp., and *Cyperus* spp. Associated with Boehler Lake are rather deep drainages that resemble sloughs. They have less vegetation and are often banked by large trees such as *Quercus falcata*, *Q. nigra*, and *Q. phellos*.

METHOD OF SURVEY

A systematic collection of the terrestrial and aquatic vascular plants occurring in the preserve was conducted during the 1994 and 1995 growing seasons. The area was divided into three survey units using roads and fences as boundaries. Each unit was traversed on foot several times during the growing season. Plants were collected in both the flowering and fruiting stages, and prepared using standard herbarium techniques (Radford et al. 1974). One set of 440 voucher herbarium specimens (Appendix H) was prepared and deposited in the Oklahoma State University Herbarium (OKLA). Specimens previously collected by Conservancy personnel were identified and included in the inventory (Gatti Clark 1997, Appendices I and J). Identification was accomplished using the resources of the herbarium. Nomenclature used was based primarily on that of Waterfall (1969), Correll and Johnston (1979), and Gray's Manual of Botany (Fernald 1950). Common names were taken from Correll and Johnston (1979) and Taylor and Taylor (1994).

FLORA OF THE PRESERVE

Three hundred forty-five species in 225 genera and 84 families were encountered in this survey or by previous workers (Gatti Clark 1997, Appendices H, I, and J). Three families, Asteraceae (56 taxa), Poaceae (41 taxa), and Cyperaceae (35 taxa), composed 38% of the preserve's vascular flora. Other large families were the Fabaceae (21 taxa), Apiaceae (11 taxa), Lamiaceae (10 taxa), and Scrophulariaceae (10 taxa). The largest genera present were *Carex*, represented by 17 species, and *Panicum*, represented by 12 species.

Species designated by the U.S. Fish and Wildlife Service (1996) as endangered, threatened, or candidate (formally category 1) were not encountered. Species ranked by the ONHI (1997) as S1 or S2 and present in the preserve included the previously mentioned *Eriocaulon kornickianum* (G2, S1), *Penstemon murrayanus* (G4, S1S3), *Polygonella americana* (G5, S1S2), and *Paronychia drummondii* (G4G5, S1S2). Other rare species are listed in the table.

Although demonstrably secure globally and ranked G4 or G5 by ONHI, several species of interest were found in the preserve. The insectivorous *Drosera brevifolia* and the mycotrophic/parasitic *Monotropa hypopithys* were encountered. *Lycopodiella appressa* (=Lycopodium appressum) is reported for the site but was not seen in this study or in collections of The Nature Conservancy personnel (L. K. Magrath, pers. comm.).

With 22 rare taxa reported for the site, monitoring of the Bluejack Oak sandhills and seep communities should continue. The communities and its assemblage of plants at Boehler Seeps and Sandhills Preserve are rare within the state and deserve continued study.

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Table Taxa of Boehler Seeps and Sandhills Preserve that are ranked as rare by the Oklahoma Natural Heritage Inventory (ONHI)

		ONHI Rankings*	
Scientific Name	Common Name	Global	State
Agalinis tenuifolia (Vahl.) Raf.	slender leaved agalinis	G5	S2S3
Aristolochia reticulata Jacq.	netleaved snakeroot	G4	S2
Azolla caroliniana Willd.	mosquito fern	G5	S2
Brasenia schreberi J. F. Gmel.	water-shield	G5	S1
Carex hyalina Boott	whitesheath sedge	G5	S1
Carex swanii (Fernald) Mack.	swan sedge	G5	S1
Carya myristiciformis (Michx. f.) Nutt.	nutmeg hickory	G5	S2S3
Drosera brevifolia Pursh	sundew	G5	S2S3
Dulichium arundinaceum (L.) Britton	threeway sedge	G5	S1
*Eriocaulon kornickianum v*an Heurch and Müll.Arg.	small pipewort	G2	S1
Galium arkansanum A. Gray	Arkansas bedstraw	G5	S1S2
Houstonia micrantha (Shinners) Terrell (=Hedyotis australis W.H. Lewis & D.M. Moore)	bluet	G4G5	S1S2
Iris virginica L.	southern blue flag	G5	S2?
Monotropa hypopithys L.	pinesap	G5	S1
Paronychia drummondii Torr. & A. Gray	Drummond's nailwort	G4G5	S1S2
Penstemon murrayanus Hook.	cupleaf beardtongue	G4	S1S3
Platanthera flava (L.) Lindl.	pale green orchid	G4	S1
Polygonella americana (Fisch. & C.A. Mey.) Small	southern jointweed	G5	S1S2
Quercus incana Bartram	bluejack oak	G5	S1S2
Rhynchospora caduca Elliott	anglestem beakrush	G5	S1
Saccharum giganteum (Walter) Pers. (=Erianthus giganteus (Walter) P. Beauv.)	giant plumegrass	G5	S1S2
Sacciolepis striata (L.) Nash	American cupscale	G5	S2

*ONHI Global Rankings:

G2 - Imperiled globally because of its rarity (6 to 20 occurrences or few remaining individuals or acres) or because of other factors demonstrably making it vulnerable to extinction throughout its range.

G4 - Apparently secure globally, though it may be quite rare in parts of its range, especially at the periphery.

G5 - Demonstrably secure globally though it may be quite rare in parts of its range, especially at the periphery.

S1 - Critically imperiled in Oklahoma because of extreme rarity (5 or fewer occurrences or very few remaining individuals or acres) or because of some factor of its biology making it especially vulnerable to extinction.

S2 - Imperiled in Oklahoma because of extreme rarity (6 to 20 occurrences or few remaining individuals or acres) or because of other factors making it very vulnerable to extinction throughout its range.

S3 - Rare and local in Oklahoma (thought it may be abundant at some of its locations); in the range of 21-100 occurrences.

APPENDIX

Vascular Plant Collections from Boehler Seeps and Sandhills Preserve arranged by family. Collections of L. C. Gatti Clark and The Nature Conservancy personnel.

[**Ed. Notes:** All plants are collected by L. Gatti Clark, unless indicated by an asterisk * for the Nature Conservancy or a tilde ~ for plants collected by both. Nomenclature has been updated using the PLANTS Database (plants.usda.gov/plants).]

FERN ALLIES	
Selaginellaceae – Spikemoss Family	
Selaginella rupestris (L.) Spring	rock spikemoss
FERNS	
Azollaceae – Azolla Family	
Azolla caroliniana Willd.	mosquito fern
Dryopteridaceae – Wood Fern Family	
Onoclea sensibilis L.	sensitive fern
Woodsia obtusa (Spreng.) Torr.	blunt-lobed cliff fern
Ophioglossaceae – Adder's-Tongue Family	
Botrychium virginianum (L.) Sw.	rattlesnake fern
Osmundaceae – Royal Fern Family	
Osmunda cinnamomea L.	cinnamon fern
~ *Osmunda regalis* L. var. *spectabilis* (Willd.) A. Gray	royal fern
GYMNOSPERMS	
Cupressaceae – Cypress Family	
Juniperus virginiana L.	eastern redcedar
Pinaceae – Pine Family	
~ *Pinus echinata* Mill.	shortleaf pine
ANGIOSPERMS	
<u>Liliopsida – Monocots</u>	
Alismataceae – Water Plantain Family	
Alisma subcordatum Raf.	water plaintain
Echinodorus tenellus (Mart.ex Schult. f.) Buchenau	lanceleaf burweed
Sagittaria latifolia Willd.	wapato, duck potato
Commelinaceae – Spiderwort Family	
Commelina erecta L.	erect day flower
Tradescantia ohiensis Raf.	Ohio spiderwort

Cyperaceae – Sedge Family

~	*Carex bicknellii* Britton	Bicknell's sedge
	Carex blanda Dewey	loose flowered sedge
	Carex cherokeensis Schwein.	Cherokee sedge
*	*Carex complanata* Torr. & Hook.	sedge
	Carex crinita Lam.	fringed sedge
~	*Carex digitalis* Willd.	sedge
*	*Carex frankii* Kunth	Frank's sedge
	Carex granularis Muhl. ex Willd.	meadow sedge
	Carex gravida L.H. Bailey	heavy sedge
	Carex hyalina Boott	whitesheath sedge
	Carex lupulina Muhl. Ex Willd.	hop sedge
*	*Carex muehlenbergii* Schkuhr ex Willd.	Muhlenberg's sedge
	Carex normalis Mack.	sedge
	Carex retroflexa Muhl. ex Willd.	reflexed sedge
*	*Carex squarrosa* L.	sedge
	Carex swanii (Fernald) Mack.	swan sedge
	Carex vulpinoidea Michx.	fox sedge
~	*Cyperus echinatus* (L.) Alph. Wood (=C. ovularis (Michx.) Torr.)	globe flatsedge
	Cyperus retroflexus Buckley *(*=C. uniflorus Torr. & Hook., non Thunb.	one-flower flatsedge
*	*Cyperus strigosus* L.	false nutgrass
	Cyperus virens Michx.	green flatsedge
	Dulichium arundinaceum (L.) Britton	threeway sedge
	Eleocharis acicularis var. *acicularis* (L.) Roem. & Schult. (=E. acicularis (L.) Roem. & Schult. var. gracilescens*)*	needle spikesedge
~	*Eleocharis compressa* Sull.	flatstem spikesedge
	Eleocharis engelmannii Steud.	Engleman's spikesedge
~	*Eleocharis lanceolata* Fernald (=E. obtusa (Willd.) Schultes var. lanceolata (Fernald) Gilly	blunt spikesedge
	Eleocharis parvula (Roem. & Schult.) Link ex Bluff, Nees. & Schauer (=E. parvula (Roem. & Schult.) Link var. anachaeta (Torr.) Svens.	dwarf spikesedge
	Eleocharis tenuis (Willd.) Schult. var. *verrucosa* (Svens.) Svens.	slender spikesedge
~	*Isolepis carinata* Hook. & Arn. ex Torr. (=Scirpus koilolepis (Steud.) Gleason	bulrush
*	*Lipocarpha aristulata* (Coville) G. Tucker (=Hemicarpha aristulata (Coville) Smyth	hemicarpa
	Rhynchospora caduca Elliott	anglestem beakrush
~	*Rhynchospora capitellata* (Michx.) Vahl	false bogrush
	Rhynchospora glomerata (L.) Vahl	clustered beakrush
	Scleria ciliata Michx.	fringed nutrush
	Scleria triglomerata Michx.	whip nutrush

	Eriocaulaceae – Pipewort Family	
~	*Eriocaulon kornickianum* van Heurch & Müll. Arg.	small pipewort
	Iridaceae – Iris Family	
	Iris virginica L.	southern blue flag
	Sisyrinchium angustifolium Mill.	blue-eyed grass
	Juncaceae – Rush Family	
	Juncus acuminatus Michx.	jointed rush
~	*Juncus coriaceus* Mack.	leathery rush
	Juncus effusus L.	bog rush
~	*Juncus marginatus* Rostk.	grassleaf rush
~	*Juncus scirpoides* Lam.	needlepod rush
	Juncus tenuis Willd.	tender rush
	Luzula bulbosa (Alph. Wood) Smyth & Smyth	bulb woodrush
	Lemnaceae – Duckweed Family	
	Spirodela polyrrhiza (L.) Schleid.	duck meat
	Liliaceae – Lily Family	
~	*Allium canadense* L.	wild onion
~	*Hypoxis hirsuta* (L.) Coville	yellow stargrass
	Orchidaceae – Orchid Family	
*	*Platanthera flava* (L.) Lindl.	pale green orchid
	Poaceae – Grass Family	
	Agrostis perennans (Walter) Tuck.	autumn bentgrass
*	*Andropogon gerardii* Vitman	big bluestem
	Andropogon ternarius Michx.	splitbeard bluestem
	Aira elegans Willd. ex Kunth	annual silver hairgrass
	Aristida desmantha Trin. & Rupr.	curly threeawn
	Bouteloua hirsuta Lag.	hairy grama
	Bromus arvensis L. (=B. japonicus Thunb.)	Japanese brome
	Bromus catharticus Vahl	rescue grass
*	*Bromus hordeaceus* L.	soft chess
~	*Cenchrus spinifex* Cav. (=C. incertus M. A. Curtis)	sandbur
~	*Chasmanthium latifolium* (Michx.) Yates	inland seaoats
~	*Chasmanthium sessiliflorum* (Poir.) Yates (=C. laxum (L.) Yates spp. sessiliflorum (Poir.) L. Clark)	spike-inland seaoats
	Danthonia spicata (L.) P. Beauv. ex Roem. & Schult.	poverty oatgrass
~	*Dichanthelium acuminatum* (Sw.) Gould & C.A. Clark var. *fasciculatum* (Torr.) Freckmann (=Panicum lanuginosum Eliott, non Bosc ex Spreng.)	wooly panicum
	Dichanthelium boscii (Poir.) Gould & C.A. Clark (=Panicum boscii Poir.)	Bosc panicum

Dichanthelium depauperatum (Muhl.) Gould (=Panicum depauperatum Muhl.)	slimleaf panicum
Dichanthelium dichotomum (L.) Gould var. *dichotomum* (=Panicum dichotomum L.)	forked panicum
Dichanthelium linearifolium (Scribn. ex Nash) Gould (=Panicum linearifolium Scribn.)	slimleaf panicum
~ *Dichanthelium oligosanthes* (Schult.) Gould var. *oligosanthes* (=Panicum oligosanthes Schult.)	small panicgrass
Dichanthelium ravenelli (Scribn. & Merr.) Gould (=Panicum ravenelii Scribn. & Merr.)	panicum
Dichanthelium sphaerocarpon (Elliott) Gould var. *sphaerocarpon* (=Panicum sphaerocarpon Elliott)	leafy panicum
~ *Elymus virginicus* L.	Virginia wildrye
* *Eragrostis capillaris* (L.) Nees	lacegrass
* *Eragrostis hirsuta* (Michx.) Nees	bigtop lovegrass
Eragrostis secundiflora J. Presl	red lovegrass
Eragrostis spectabilis (Pursh) Steud.	purple lovegrass
Gymnopogon ambiguus (Michx.) Britton, Sterns & Poggenb.	broadleaf skeletongrass
Leersia oryzoides (L.) Sw.	Swartz cutgrass
~ *Panicum anceps* Michx.	beaked panicum
Panicum dichotomiflorum Michx.	fall panicum
* *Paspalum laeve* Michx.	field paspalum
~ *Paspalum setaceum* Michx.	thin paspalum
* *Saccharum giganteum* (Walter) Pers. (=Erianthus giganteus (Walter) P. Beauv.)	giant plumegrass
Sacciolepis striata (L.) Nash	American cupscale
Setaria parviflora (Poir.) Kerguélen (=S. geniculata (Willd.) P. Beauv., nom. illeg.)	knotroot bristlegrass
~ *Sorghum halepense* (L.) Pers.	Johnsongrass
Sphenopholis obtusata (Michx.) Scribn.	prairie wedgescale
~ *Steinchisma hians* (Elliott) Nash (=Panicum hians Elliott)	gaping panicum
~ *Tridens flavus* (L.) Hitchc.	purpletop
Vulpia octoflora (Walter) Rydb.	sixweeks fescue
Zizaniopsis miliacea (Michx.) Döll. & Asch.	southern wildrice

Potemogetonaceae – Pondweed Family

Potamogeton pulcher Tuck.	spotted pondweed

Smilacaceae – Catbriar Family

Smilax bona-nox L.	greenbrier
Smilax rotundifolia L.	common greenbrier

Typhaceae – Cattail Family

Typha angustifolia L.	narrow-leaved cattail

Magnoliopsida - Dicots

Acanthaceae – Acanthus Family	
Ruellia humilis Nutt.	fringed leaf ruellia
Amaranthaceae – Amaranth Family	
Froelichia floridana (Nutt.) Moq.	snake cotton
Anacardiaceae – Sumac Family	
Rhus aromatica Aiton	lemon sumac
Rhus copallinum L. (=R. copallina L., orth. var.)	winged sumac
Toxicodendron radicans (L.) Kuntze	poison ivy
Apiaceae – Carrot Family	
* *Chaerophyllum tainturieri* Hook.	hairy fruit wild chervil
~ *Daucus pusillus* Michx.	southwestern carrot
Eryngium prostratum Nutt. ex DC.	creeping eryngo
* *Hydrocotyle verticillata* Thunb.	whorled pennywort
~ *Ptilimnium capillaceum* (Michx.) Raf.	threadleaf mockbishopweed
~ *Sanicula canadensis* L.	black snakeroot
Sanicula odorata (Raf.) K.M. Pryer & L.R. Phillippe (=S. gregaria E.P. Bicknell)	cluster snakeroot
Spermolepis divaricata (Walter) Raf. ex Ser.	forked scaleseed
Spermolepis echinata (Nutt. ex DC.) A. Heller	bristly scaleseed
Spermolepis inermis (Nutt. ex DC.) Mathias & Constance	spreading scaleseed
Torilis arvensis (Huds.) Link	hedge parsley
Apocynaceae – Dogbane Family	
Apocynum cannabinum L.	Indianhemp
Aquifoliaceae – Holly Family	
Ilex decidua Walter	deciduous holly
Aristolochiaceae – Birthwort Family	
~ *Aristolochia reticulata* Jacq.	netleaved snakeroot
Asclepiadaceae – Milkweed Family	
Asclepias tuberosa L.	butterfly milkweed
Asclepias verticillata L.	whorled milkweed
Asclepias viridis Walter	green milkweed
Matelea biflora (Raf.) Woodson	twoflower milkvine
Asteraceae – Sunflower Family	
* *Achillea millefolium* L.	yarrow
* *Ambrosia artemisiifolia* L.	common ragweed
~ *Ambrosia bidentata* Michx.	lanceleaf ragweed
* *Ambrosia trifida* L.	giant ragweed
~ *Antennaria parlinii* Fernald	plainleaf pussytoes

	Astranthium integrifolium (Michx.) Nutt.	western daisy
*	*Bidens aristosa* (Michx.) Britton	tickseed sunflower
	Centaurea americana Nutt.	American basket flower
*	*Chaetopappa asteroides* Nutt. ex DC.	least daisy
~	*Chrysopsis pilosa* Nutt.	softhair golden aster
*	*Cirsium altissimum* (L.) Hill	tall thistle
	Cirsium horridulum Michx.	bull thistle
*	*Conoclinium coelestinum* (L.) DC. (=Eupatorium coelestinum L.)	blue boneset
~	*Conyza canadensis* (L.) Cronquist	horseweed
~	*Coreopsis grandiflora* Hogg ex Sweet	bigflowered tickseed
~	*Croptilon divaricatum* (Nutt.) Raf. (=Haplopappus divaricatus (Nutt.) A. Gray)	scratch daisy
~	*Echinacea pallida* (Nutt.) Nutt.	pale coneflower
~	*Elephantopus carolinianus* Raeusch.	elephant’s foot
*	*Erechtites hieracifolia* (L.) Raf. ex DC.	fireweed
~	*Erigeron strigosus* Muhl. ex Willd.	daisy fleabane
*	*Eupatorium perfoliatum* L.	boneset
	Evax prolifera Nutt. ex DC.	rabbit’s tobacco
	Evax verna Raf. var. *verna* (=E. multicaulis DC.)	rabbit’s tobacco
	Gaillardia aestivalis (Walter) H. Rock	prairie gaillardia
~	*Gamochaeta purpurea* (L.) Cabrera (=Gnaphalium purpureum L.)	purple cudweed
*	*Helenium amarum* (Raf.) H. Rock	sneezeweed
*	*Helianthus angustifolius* L.	narrow-leaf sunflower
~	*Helianthus hirsutus* Raf.	hairy sunflower
	Heterotheca villosa (Pursh) Shinners var. *villosa* (=Chrysopsis villosa (Pursh.) Nutt. ex DC.)	roughhair golden aster
~	*Hieracium gronovii* L.	hawkweed
	Hieracium longipilum Torr.	longbeard hawkweed
	Hymenopappus scabiosaeus L’Her.	old plainsman
~	*Krigia cespitosa* (Raf.) K. L. Chambers	common dwarf dandelion
~	*Krigia dandelion* (L.) Nutt.	potato dandelion
	Krigia virginica (L.) Willd.	dwarf dandelion
	Lactuca canadensis L.	wild lettuce
*	*Lactuca sativa* L.	prickly lettuce
	Liatris aspera Michx.	tall gayfeather
*	*Liatris elegans* (Walter) Michx.	beautiful gayfeather
	Liatris squarrosa (L.) Michx.	gayfeather
*	*Mikania scandens* (L.) Willd.	climbing hempweed
	Packera obovata (Muhl. ex Willd.) W.A. Weber & A. Love (=Senecio obovatus Muhl. ex Willd. var. rotundus Britton)	roundleaf groundsel
*	*Pluchea camphorata* (L.) DC.	camphorweed
	Pseudognaphalium obtusifolium (L.) Hilliard & B.L. Burtt ssp. *obtusifolium* (=Gnaphalium obtusifolium L.)	sweet everlasting
~	*Pyrrhopappus carolinianus* (Walter) DC.	false dandelion
*	*Rudbeckia grandiflora* (D. Don) J.F. Gmel. ex DC.	Mexican hat
~	*Rudbeckia hirta* L.	blackeyed Susan

Solidago canadensis L.	common prairie goldenrod
Solidago missouriensis Nutt.	Missouri goldenrod
* *Solidago odora* Aiton	fragrant goldenrod
* *Solidago rugosa* Mill.	rough-leaved goldenrod
~ *Solidago ulmifolia* Muhl. ex Willd.	elmleaf goldenrod
* *Symphyotrichum patens* (Aiton) G.L. Nesom var. *patens*	late purple aster
(=Aster patens Aiton)	
* *Symphyotrichum subulatum* (Michx) G.L. Nesom	salt marsh aster
(=Aster subulatus Michx.)	
~ *Verbesina helianthoides* Michx.	yellow crownbeard
* *Vernonia baldwinii* Torr.	western ironweed
Balsaminaceae – Touch-Me-Not Family	
Impatiens capensis Meerb.	spotted touch-me-not
Berberidaceae – Barberry Family	
Podophyllum peltatum L.	May apple
Bignoniaceae – Trumpet Creeper Family	
Campsis radicans (L.) Seem. ex Bureau	trumpet creeper
Boraginaceae – Borage Family	
~ *Lithospermum caroliniense* (Walter ex J.F. Gmel.) MacMill.	plains pucoon
Myosotis verna Nutt.	early scorpiongrass
Brassicaceae – Mustard Family	
Cardamine pensylvanica Muhl. ex Willd.	bitter cress
~ *Lepidium virginicum* L.	poorman's peppergrass
Buddlejaceae – Butterfly-Bush Family	
Polypremum procumbens L.	juniperleaf
Cabombaceae – Water Shield Family	
Brasenia schreberi J. F. Gmel.	water shield
Callitrichaceae – Water-Starwort Family	
Callitriche heterophylla Pursh	water-starwort
Campanulaceae – Bellflower Family	
~ *Triodanis perfoliata* (L.) Nieuwl.	clasping Venus looking-glass
Caprifoliaceae – Honeysuckle Family	
Lonicera japonica Thunb.	Japanese honeysuckle
Symphoricarpos orbiculatus Moench	buckbrush
Viburnum rufidulum Raf.	rusty blackhaw

Caryophyllaceae – Pink Family	
Arenaria serpyllifolia L.	thyme-leaved sandwort
Paronychia drummondii Torr. & A. Gray	Drummond's nailwort
Stellaria media (L.) Vill.	chickweed
Ceratophyllaceae – Hornwort Family	
Ceratophyllum demersum L.	coontail
Cistaceae – Rockrose Family	
Lechea villosa Elliott	pinweed
Clusiaceae – Mangosteen Family	
~ *Hypericum drummondii* (Grev. & Hook.) Torr. & A. Gray	nits-and-lice
~ *Hypericum hypericoides* (L.) Crantz	St. Andrew's cross
~ *Hypericum prolificum* L. (=H. spathulatum (Spach.) Steud.	St. John's wort
Convolvulaceae – Morning Glory Family	
~ *Ipomoea pandurata* (L.) G. Mey.	wild potatovine
~ *Stylisma pickeringii* (Torr. ex M.A. Curtis) A. Gray	stylisma
Cornaceae – Dogwood Family	
Cornus florida L.	flowering dogwood
Nyssa sylvatica Marsh.	black gum
Droseraceae – Sundew Family	
~ *Drosera brevifolia* Pursh	sundew
Ericaceae – Heath Family	
~ *Vaccinium arboreum* Marsh.	farkleberry
Euphorbiaceae – Spurge Family	
Acalypha rhomboidea Raf.	rhombic copperleaf
Acalypha virginica L.	three seeded Mercury
Chamaesyce serpens (Kunth) Small (=Euphorbia serpens Kunth)	round-leaved spurge
Cnidoscolus texanus (Müll. Arg.) Small	Texas bullnettle
Croton capitatus Michx.	woolly croton
Croton glandulosus L.	sand croton
Croton willdenowii G.L. Webster (=Crotonopsis elliptica Willd.)	rush-foil
~ *Stillingia sylvatica* L.	queen's delight
Fabaceae – Pea Family	
Apios americana Medik.	ground nut
Astragalus distortus Torr. & A. Gray	bentpod milkvetch
* *Baptisia bracteata* Muhl. ex Elliott	plains wild indigo
Baptisia leucophaea Nutt. var. *leucophaea* (Nutt.) Kartesz & Gandhi (=B. leucophaea Nutt.)	white wild indigo
Cercis canadensis L.	redbud

Chamaecrista fasciculata (Michx.) Greene var. *fasciculata* (=Cassia fasciculata Michx.)	partridge pea
Chamaecrista nictitans (L.) Moench ssp. *nictitans* var. *nictitans* (=Cassia nictitans L.)	sensitive pea
Clitoria mariana L.	butterfly pea
Dalea phleoides (Torr. & A. Gray) Shinners var. *phleoides* (=Petalostemon phleoides Torr. & A. Gray)	longbract prairie clover
Desmodium paniculatum (L.) DC. var. *paniculatum*	tall tickclover
Desmodium sessilifolium (Torr.) Torr. & A. Gray	sessile-leaved tickclover
Desmodium viridiflorum (L.) DC.	velvetleaf tickclover
Galactia regularis (L.) Britton, Sterns & Poggenb.	downey milkpea
Gleditsia triacanthos L. (=Caesalpiniaceae Family)	honey locust
Lespedeza stuevei Nutt.	tall lespedeza
Mimosa nutallii (DC. ex Britton & Rose) B.L. Turner (=Schrankia nuttallii (DC. ex Britton & Rose) Standl.)	sensitive briar
Mimosa microphylla Dryand. (=Schrankia ucinata Willd.)	catclaw briar
~ *Orbexilum pendunculatum* (Mill.) Rydb. var. *psoralioides* (Walter) Isely (=Psoralea psoraloides (Walt.) Cory)	Sampson's snakeroot
* *Orbexilum simplex* (Nutt. ex Torr. & A. Gray) Rydb. (=Psoralea simplex (Nutt. ex Torr. & A. Gray) Rydb.)	singlestem scurf pea
Pediomelum digitatum (Nutt. ex Torr. & A. Gray) Isely (=Psoralea digitata Nutt. ex Torr. & A. Gray)	palm-leaved scurf pea
* *Pediomelum hypogaeum* (Nutt. ex Torr. & A. Gray) Rydb. var. *subulatu*m (Bush) J. Grimes (=Psoralea subulata Bush)	Sara scurf pea
Rhynchosia latifolia Nutt. ex Torr. & A. Gray	broadleaf snoutbean
Strophostyles helvola (L.) Elliott	wild bean
Stylosanthes biflora (L.) Britton, Sterns & Poggenb.	pencil-flower
~ *Tephrosia virginiana* (L.) Pers.	goat's rue
~ *Trifolium campestre* Schreb.	low hop clover
Vicia sativa L.	common vetch
Fagaceae – Beech Family	
Quercus falcata Michx.	southern red oak
Quercus falcata Michx (=Q. falcata Michx. var. triloba (Michx.) Nutt)	*s*outhern red oak
* *Quercus incana* Bartram	bluejack oak
~ *Quercus nigra* L.	water oak
* *Quercus phellos* L.	willow oak
Quercus stellata Wangenh.	post oak
Quercus velutina Lam.	black oak
Fumariaceae – Fumitory Family	
Corydalis micrantha (Engelm. ex A. Gray) A. Gray	slender fumewort
Geraniaceae – Geranium Family	
Geranium carolinianum L.	Carolina cranesbill

Hydrophyllaceae – Waterleaf Family	
* *Hydrolea ovata* Nutt. ex Choisy	hairy hydrolea
~ *Phacelia strictiflora* (Engelm. & A. Gray) A. Gray var. *robbinsii* Constance	prairie blue curls
Juglandaceae – Walnut Family	
Carya myristiciformis (Michx. f.) Nutt.	nutmeg hickory
Carya texana Buckley	black hickory
Lamiaceae – Mint Family	
* *Lycopus virginicus* L.	Virginia bugleweed
~ *Monarda punctata* L.	horsemint
Monarda russeliana Nutt. ex Sims.	red spotted horsemint
~ *Prunella vulgaris* L.	heal-all
~ *Pycnanthemum albescens* Torr. & A. Gray	whiteleaf mountainmint
* *Pycnanthemum tenuifolium* Schrad.	narrowleaf mountainmint
~ *Salvia lyrata* L.	lyreleaf age
Scutellaria elliptica Muhl. ex Spreng.	hairy skullcap
* *Scutellaria laterifolia* L.	sideflowering skullcap
Scutellaria parvula Michx. var. *missouriensis* (Torr.) Goodman & C.A. Lawson (=S. parvula Michx. var. leonardii (Epling) Fernald)	skullcap
Lauraceae – Laurel Family	
Sassafras albidum (Nutt.) Nees (=S. albidium (Nutt.) Nees var. molle (Raf.) Fernald	sassafras
Lentibulariaceae – Bladderwort Family	
Utricularia gibba L. (=U. biflora Lam.)	twoflower bladderwort
Lythraceae – Loosestrife Family	
Rotala ramosior (L.) Koehne	toothcup
Melastomaceae – Melastome Family	
Rhexia mariana L.	meadow beauty
Menyanthaceae – Buckbean Famiy	
Nymphoides peltata (S.G. Gmel.) Kuntze	yellow floating heart
Monotropaceae – Indian Pipe Family	
~ *Monotropa hypopithys* L.	pinesap
Nymphaeaceae – Water Lily Family	
Nuphar lutea (L.) Sm.	yellow pond lily
Nymphaea odorata Aiton	American water lily

	Onagraceae – Evening Primrose Family	
	Ludwigia alternifolia L.	bushy seedbox
	Oenothera laciniata Hill	cutleaf evening primrose
	Oxalidaceae – Wood Sorrel Family	
	Oxalis stricta L.	yellow wood sorrel
	Oxalis violaceae L.	violet wood sorrel
	Plantaginaceae – Plantain Family	
	Plantago lanceolata L.	buckhorn plantain
	Plantago patagonica Jacq.	wooly plantain
	Plantago virginica L.	paleseed plantain
	Plantago wrightiana Decne.	Wright's plantain
	Polemoniaceae – Phlox Family	
	Phlox glaberrima L.	smooth phlox
	Phlox pilosa L.	prairie phlox
	Polygalaceae – Milkwort Family	
*	*Polygala sanguinea* L.	blood polygala
	Polygonaceae – Buckwheat Family	
~	*Eriogonum longifolium* Nutt.	longleaf eriogonum
*	*Eriogonum multiflorum* Benth.	heartsepal wild buckwheat
~	*Polygonella americana* (Fisch. & C.A. Mey.) Small	southern jointweed
~	*Polygonum hydropiperoides* Michx.	mild water pepper
	Polygonum persicaria L.	lady's thumb
*	*Polygonum sagittatum* L.	arrowvine
~	*Rumex hastatulus* Baldw.	heartwing sorrel
	Primulaceae – Primrose Family	
~	*Hottonia inflata* Elliott	American featherfoil
*	*Lysimachia lanceolata* Walter	lanceleaf loosestrife
	Ranunculaceae – Buttercup Family	
	Delphinium carolinianum Walter	prairie larkspur
	Ranunculus laxicaulis (Torr. & A. Gray) Darby	spearwort
	Rhamnaceae – Buckthorn Family	
	Berchemia scandens (Hill.) K. Koch	rattan vine
	Ceanothus americanus L.	New Jersey tea
	Frangula caroliniana (Walter) A. Gray (=Rhamnus caroliniana Walter)	buckthorn
	Rosaceae – Rose Family	
	Crataegus spathulata Michx.	littlehip hawthorn
	Potentilla simplex Michx.	old-field cinquefoil

Prunus serotina Ehrh.	black cherry
Rubus occidentalis L.	blackberry
Rubus ostryifolius Rydb.	highbush blackberry
Rubiaceae – Madder Family	
Cephalanthus occidentalis L.	buttonbush
Diodia teres Walter	rough buttonweed
~ *Galium arkansanum* A. Gray	Arkansas bedstraw
Galium circaezans Michx.	woods bedstraw
~ *Galium obtusum* Bigelow	bluntleaf bedstraw
Galium pilosum Aiton	hairy bedstraw
Houstonia micrantha (Shinners) Terrell (=Hedyotis australis W.H. Lewis & D.M. Moore)	bluet
Sapotaceae – Sapodilla Family	
Sideroxylon lanuginosum Michx. ssp. *lanuginosum* (=Bumelia lanuginosa (Michx.) Pers.)	chittamwood
Scrophulariaceae – Figwort family	
* *Agalinis tenuifolia* (Vahl.) Raf.	slenderleaf agalinus
* *Castilleja coccinea* (L.) Spreng.	Indian paintbrush
Castilleja indivisa Engelm.	Indian paintbrush
Collinsia violacea Nutt.	violet collinsia
Gratiola virginiana L.	Virginia hedgehyssop
Nuttallanthus canadensis (L.) D.A. Sutton (=Linaria canadensis (L.) Chaz.)	blue toadflax
Lindernia dubia (L.) Pennell	yellowseed false pimpernell
Pedicularis canadensis L. ssp. *canadensis* (=P. canadensis L. var. dobbsii Fernald)	common lousewort
* *Penstemon laxiflorus* Pennell	loose flower penstemon
Penstemon murrayanus Hook.	cupleaf penstemon
Solanaceae – Potato Family	
Physalis heterophylla Nees.	clammy ground cherry
Solanum carolinense L.	Carolina horsenettle
Ulmaceae – Elm Family	
Celtis tenuifolia Nutt.	dwarf hackberry
Urticaceae – Nettle Family	
~ *Boehmeria cylindrica* (L.) Sw.	false nettle
Valerianaceae – Valerian Family	
~ *Valerianella radiata* (L.) Dufr.	common beaked cornsalad
Verbenaceae – Verbena Family	
Callicarpa americana L.	American beautyberry

Phryma leptostachya L.	lopseed
* *Verbena simplex* Lehm.	narrow-leaved verbena
Violaceae – Violet Family	
Viola villosa Walter	wooly violet
Vitaceae – Grape Family	
Ampelopsis arborea (L.) Koehne	peppervine
Parthenocissus quinquefolia (L.) Planch.	Virginia creeper
Vitis aestivalis Michx.	pigeon grape
Vitis rotundifolia Michx.	muscadine

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SCHOENOPLECTUS HALLII, *S. SAXIMONTANUS,* AND THE PUTATIVE *S. HALLII* × *S. SAXIMONTANUS* HYBRID: OBSERVATIONS FROM THE WICHITA MOUNTAINS WILDLIFE REFUGE AND THE FORT SILL MILITARY RESERVATION 2002 – 2010

Marian Smith
Southern Illinois State University
Edwardsville, IL 62025
msmith@siue.edu

Paul M. McKenzie
U.S. Fish and Wildlife Service
101 Park DeVille Drive, Suite A
Columbia, MO 65203

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ABSTRACT

Schoenoplectus hallii, *S. saximontanus*, and the putative *S. hallii* × *S. saximontanus* hybrid are obligate wetland sedges that occur in the sparsely vegetated margins of ponds, ditches or swales with fluctuating water levels. The species are amphicarpic and have easily identified differences between spikelet and basal achenes. We surveyed selected sites at the refuge in 2001, 2002, and 2007 – 2010, surveyed 4 sites on the Fort Sill Military Reservation in 2009 and 2010, and collected voucher specimens from all populations. Scanning Electron Microsope (SEM) photographs of spikelet and basal achenes indicate distinct morphological differences between species and the presence of "winged" ridges on *S. saximontanus*. Field observations indicated that populations at all sites vary in size and species distribution annually, and that both parental species appeared to be declining in number. We concluded that in populations where *S. hallii* and *S. saximontanus* co-occur, hybridization may be a threat to one or both parental species. The distribution of achenes by waterfowl and ungulates indicates that management to prevent establishment of mixed populations, and therefore hybridization, is not practical. We recommend that *S. hallii* be evaluated for federal listing under the Endangered Species Act, a range-wide assessment be completed for *S. saximontanus,* and that all sites with mixed populations should be examined for the presence of hybrids.

INTRODUCTION

Schoenoplectus hallii (A. Gray) S .G. Sm. and *S. saximontanus* (Fernald) Raynal are sedge species that were once thought to be separated geographically, with *S. hallii* present in the Midwest and eastern U. S. and *S. saximontanus* largely confined to the West (Gleason and Cronquist 1991, Beatty et al. 2004). *Schoenoplectus hallii* has a global ranking of G2 (imperiled). It is listed as "critically imperiled" in eight of the 12 states in which it occurs (NatureServe 2010) and as "imperiled" or "vulnerable" in three other states. Herbarium records indicate that it had been reported from Georgia and Massachusetts prior to 1981 (McKenzie et al. 2007), but those populations are thought to have been extirpated (NatureServe 2010, McKenzie et al. 2007). *Schoenoplectus saximontanus* has a global ranking of G5 (secure) (NatureServe 2010), but it is listed as "critically imperiled" in British Columbia as well as in seven of the 12 states where it occurs. It has been reported from two states in Mexico (Flora of North America 2002). Throughout its range, *S. saximontanus* is considered to be an uncommon species

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whose distribution is scattered (Flora of North America 2002).

Schoenoplectus hallii and *S. saximontanus* are obligate wetland species that have similar habitat requirements: most often sandy, rocky, or gravelly soil, occasionally clay, around the margins of ponds, ditches and swales with fluctuating water levels, and a scarcity of other plants as competitors (Flora of North America 2002, McKenzie et al. 2007). They most commonly complete their life cycle as annuals, but short-lived perennials have been reported from Texas (O'Kennon and McLemore 2004). Both species have 2-3 small basal leaves and tufted stems ~4-40 cm long with small, inconspicuous rhizomes. The species are amphicarpic (having two distinct types of achenes), with numerous inflorescences on aerial stems containing perfect flowers and occasional, pistillate flowers enclosed in a leaf sheath at the plant base. It is difficult to distinguish between the species from vegetative characteristics alone. Achenes of *S. hallii* are 2-sided, and flowers have 2-lobed styles; whereas, achenes of *S. saximontanus* are distinctly 3-sided, and flowers have 3-lobed styles (Flora of North America 2002). Achenes of both species have transverse ridging, and Magrath (2002) reported that the ridges on *S. saximontanus* were "winged;" whereas, those on *S. hallii* were smooth. This character had not been reported prior to his 2002 publication.

Both species have been reported from five states (KS, MO, NE, OK, and TX) (O'Kennon and McLemore 2004, McKenzie et al. 2007, NatureServe 2010); however, only Oklahoma (Magrath 2002), Kansas (C. Freeman, pers. comm. 2006), and Texas (Bob O'Kennon, pers. comm. 2007) have sites with mixed populations (Magrath 2002, Smith et al. 2004). Although *S. saximontanus* occurs in eight counties in OK, it only co-occurs with *S. hallii* in Comanche County (Oklahoma Vascular Plant Database 2006). In 2000, 134 sites at the Wichita Mountains Wildlife Refuge (WMWR) in Comanche County were surveyed for *S. hallii* and *S. saximontanus* by Dr. Larry Magrath and personnel from the refuge (Magrath 2002). In August 2001, M. Smith and P. Mettler-Cherry re-examined the population sites surveyed by Magrath in 2000, and in subsequent years, 2002 and 2007 – 2010, the authors conducted surveys of selected sites at the refuge and Fort Sill Military Reservation (FSMR).

During the 2001 survey, M. Smith noted what appeared to be plants containing achenes that were intermediate between the two species, i.e., some appeared to be 2-sided like those of *S. hallii*, except the usually flat or convex side contained a conspicuous bulge, and the achenes often had the "winged" appearance reported by Magrath (2002). Some plants had both 2- and 3-sided achenes, some with, and some without "winged ridges." Other individuals produced only a few viable-looking achenes, with the majority of inflorescences bearing a preponderance of aborted achenes. Smith interpreted these anomalies as suggestive of hybridization between *S. hallii* and *S. saximontanus*.

The objectives of this report are to discuss the results of a seed bank study for three sites conducted in 2001; to provide photographic documentation of the winged-ridge appearance of *S. saximontanus* achenes reported by Magrath (2002); to summarize field observations made during visits to WMWR in 2002 and 2007 – 2010 and FSMR in 2009 and 2010; and to discuss the presence of putative hybrids of *S. hallii* and *S. saximontanus* and potential conservation concerns associated with hybridization among rare species.

Botanical nomenclature listed in this report follows Yatskievych and Turner (1990) except for *Marsilea vestita* which follows Diggs et al. (1999), *Eleocharis coloradoensis* which follows Smith (Flora of North America 2002), and *Eleocharis ovata* which follows Yatskievych (1999).

CHARACTERISTICS OF SPIKELET AND BASAL ACHENES

In July 2001, spikelet and basal achenes were collected from individuals of *S. hallii* and *S. saximontanus* for Scanning Electron Microscopy (SEM) examination of achene surfaces and cross-sectional shape. Seeds were mounted onto aluminum stubs using double-stick transfer tabs (Electron Microscopy Sciences) and examined with a Hitachi S2460N variable pressure SEM at 30 kV and 20 Pa pressure. Images were digitally recorded using a Noran Voyager III interface. For achene cross-sectional views, plastic blocks containing embedded specimens were sectioned until a transverse median section was obtained.

Both species exhibit transverse ridges (Figure 1 a – h) as described in Flora of North America (Flora of North America 2002) and Flora of the Great Plains (Great Plains Flora Association 1986), except that the distinct difference between ridge morphology in *S. hallii* compared to *S. saximontanus* (see Figure 1 a – h) is not discussed in either account. In Flora of the Great Plains (1986), the achenes of both species were described simply as having "transverse ridges," and no description of the amphicarpic (basal) achenes was provided. In Flora of North America (2002), spikelet achenes of both species were described as having "mostly sharp ridges." The basal achenes of *S. hallii* were described as "rugose with rounded edges," and this is confirmed by the SEMs in this article, but basal achenes of *S. saximontanus* were characterized in Flora of North America (2002) as "with obscure to evident horizontal ridges." The SEMs portrayed in Figure 1 (a – h) illustrate a distinctive species-difference in ridge shape on spikelet achenes and depict the basal achenes in *S. saximontanus* as having distinct, sharp ridges (see Figure 1 f, h). Ridges on spikelet achenes in *S. saximontanus*, compared to *S. hallii*, are sharper and more elaborate in design, resulting in the "winged" appearance described by Magrath (2002). Ridges on basal achenes are subtle and incomplete in *S. hallii* (see Figure 1 e, g), but prominent, more complete, and "winged" in *S. saximontanus* (see Figure 1 f, h).

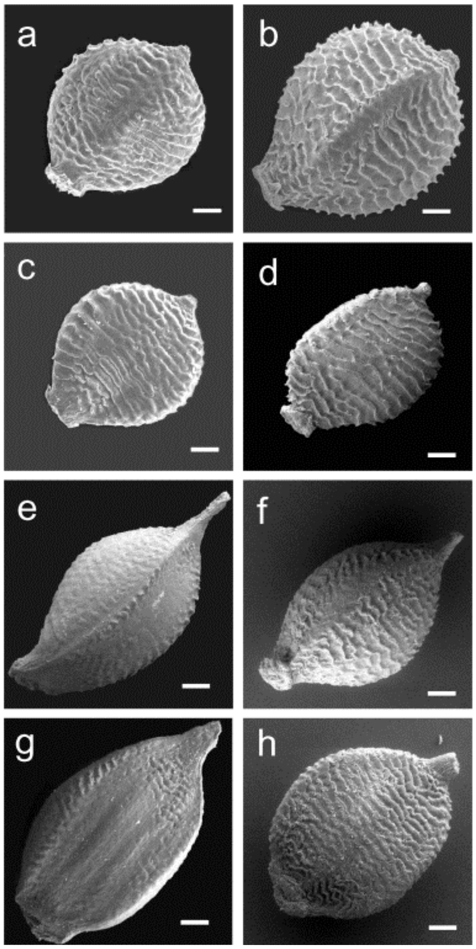

Figure 1 Surface views of front (a) and opposite (c) sides of spikelet achene of *S. hallii* and front (b) and opposite (d) sides of spikelet achene of *S. saximontanus*. Front (e) and opposite (g) sides of basal achene of *S. hallii* and front (f) and opposite (h) sides of basal achene of *S. saximontanus*. Bars = 130 μm

Figure 2 (a – b) illustrates the often described cross-sectional shape of spikelet achenes: "plano-convex" (Flora of North America 2002) for *S. hallii* (see Figure 2 a) and "equilaterally, sharply trigonous," (Flora of North America 2002) for *S. saximontanus* (see Figure 2 b). Magnified views of surface features (Figure 2 e – h) in both types of achenes reinforce the differences in surface ridges between the two species shown in Figure 1. Ridges in *S. hallii* spikelet achenes (see Figure 2 e) are not sharp compared to the elaborate, sharp-tipped wings of *S. saximontanus* (see Figure 2 f). Surfaces of the basal achene of *S. hallii* (see Figure 2 g) are mostly absent of ridges, but those of *S. saximontanus* (see Figure 2 h) are prominent and elaborate, although not quite as sharp as in the spikelet achene.

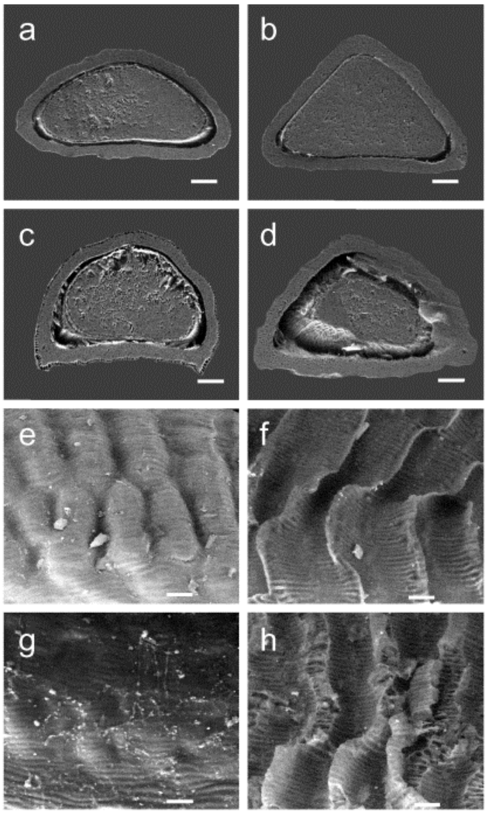

Figure 2 Cross-sectional views of spikelet (a) and basal (c) achenes of *Schoenoplectus hallii* and spikelet (b) and basal achenes (d) of *S. saximontanus*. Bars = 100 μm. Surface views of ridges of spikelet (e) and basal (g) achenes of *S. hallii*. Surface views of ridges of spikelet (f) and basal (h) achenes of *S. saximontanus*. Bars = 20 μm

SOIL SEED BANK STUDY OF 2001

In 2001, 15 plants were selected at each of three sites that had been included in Magrath's 2002 report (Boggy Flat, Quanah Parker Lake, and Hollis Lake at WMWR), and soil cores (1.75 cm × 8 cm) were collected and separated into 2 cm sections. Achenes were recovered, counted, and separated by species and soil depth. Achenes were tested for viability as in Malone (1967); all achenes were viable. Eighty-six percent of the achenes were contained within the first 2 cm of the soil. All three sites had achenes of both species present in the soil; however, at the time of the site visit, extant populations at Boggy Flats appeared to have only *S. saximontanus* and Hollis Lake had only *S. hallii*. Both species were present in the extant population at Quanah Parker. The presence of viable achenes of *S. hallii* and *S. saximontanus* in the soil at all three sites indicates either the undetected presence of both species during the site visit or the existence of both species at each site in previous years. As achenes of these species may remain dormant and viable for extended periods (McClain et al. 1997), their presence in the above-ground population might have occurred many years in the past and the current extant population may reflect an increase in one species and a decline or elimination of the other.

FIELD OBSERVATIONS
2002, 2007 – 2010

In 2002, the authors visited selected sites at WMWR (Table) and specimens of *Schoenoplectus* were collected from five sites where *S. hallii* or *S. saximontanus* had been previously collected or reported (Magrath 2002). Field and laboratory observations indicated that the achenes of most spikelets of *S. hallii* and *S. saximontanus* were mature and exhibited characteristics typical for the species as described in the introduction;

however, some achenes of the presumed *S. hallii* and *S. saximontanus* hybrids appeared to be abortive or malformed, while other putative hybrids produced both fully developed 2- and 3-sided achenes. Individuals of the putative hybrids were noticeably taller with longer inflorescences than either parent, and the spikelet scales were conspicuously brownish-orange (Smith et al. 2004). Specimens were sent to Dr. Alfred Schuyler, Dr. S. Galen Smith, and Dr. Anton Rezniceik for verification. The presence of a putative hybrid (McKenzie #2028) was independently confirmed by each scientist based on morphological characters (Smith et al. 2004). Subsequent visits to WMWR and FSMR were made to collect material for a future genetic analysis.

The only site to be visited every year from 2007 – 2010 was Medicine Tank at WMWR; therefore, we will discuss some apparent trends in population size and species distribution at that site. In 2002, *S. hallii* was abundant and concentrated on the west shore of the pond while *S. saximontanus* was abundant on the south and east shore (see Table). The putative hybrid was scattered but present in various locations. In contrast, populations of all three species were abundant and widely distributed along the shore in 2007. In 2008, populations of *S. hallii* and *S. saximontanus*, although present at the site (see Table), appeared to be smaller and more restricted than in 2002 and 2007. As in 2007, *S. hallii* and *S. saximontanus* were scattered along the entire pond margin without any noticeable concentration at different shore edges; however, the putative *S. hallii* × *S. saximontanus* hybrids were more abundant and concentrated along the northwest shore (see Table).

In 2009, the water level at Medicine Tank was lower than had been observed on previous visits, and there was a noticeable reduction in population size of *S. hallii* and *S. saximontanus*, especially the latter which was scattered and extremely rare. The putative hybrid was common and the population had expanded beyond the northwest shore (see Table). *Schoenoplectus hallii* was rare at Medicine Tank in 2010, and *S. saximontanus*, which had been present in previous years, was notably absent. Conversely, the putative hybrid was abundant (see Table) and had apparently overtaken habitat around the pond that had been previously occupied by *S. hallii* or *S. saximontanus.*

In addition to Medicine Tank, we visited three other sites in 2009 at WMWR, and water levels were lower at all of them than in previous years. Ponds that were composed mostly of hardened clay were lacking, or had very few, *Schoenoplectus* individuals (Ingram Pond and Rock Dam), but ponds that had rocks, cobble, and/or sand had healthy flowering and fruiting plants (Medicine Tank, Quanah Parker Lake), although in reduced numbers compared to 2007 and 2008 (see Table). No bulrushes were observed at two sites where *S. saximontanus* was found in 2007 (Boggy Flat and unnamed pond ~1.5 mi east, see Table). In 2010, we collected *S. saximontanus* from Grama Lake, which was the only time we documented any bulrush at this site during our visits between 2001 and 2010. Other sites were visited and vouchers were collected at WMWR from 2007 – 2010 as noted in the table.

We visited four sites at FSMR in 2009 and two sites in 2010 and documented the presence of *S. hallii, S. saximontanus,* and putative *S. hallii* × *S. saximontanus* hybrids at the reservation in both years. In 2009, *S. hallii* was found at all four sites, and *S. saximontanus* and the putative hybrid were present at two (see Table). In 2010 *S. hallii* and *S. saximontanus* had disappeared from Pottawatomie Pond and the putative hybrid had increased in number (see Table). *Schoenoplectus* spp. observed at FSMR were all at ponds that had a sandy or gravelly shoreline**.** Our collections constitute the first documented records of *S. hallii, S.*

saximontanus, and the putative hybrids from FSMR and confirm the predictions of Magrath (2002) that the two parent species would likely be discovered at Fort Sill.

HABITAT AND PLANT ASSOCIATES

Schoenoplectus hallii, S. saximontanus, and putative *S. hallii* × *S. saximontanus* hybrids occurred along the edges of ponds and lakes at WMWR and at FSMR that had receding shorelines. Very little vegetation competed with the *Schoenoplectus* spp. in the narrow marginal areas along the water's edge. Although the majority of populations of *Schoenoplectus* occurred in sandy or gravelly/rocky soil, a few were found on clay substrates. Many sites were heavily grazed by elk, bison, or longhorn cattle, and the soil was significantly trampled by ungulates or disturbed by foraging feral hogs.

Plant associates varied widely from site to site and included the following species: *Ammannia coccinea* Rottb., *Bacopa rotundifolia* (Michx.) Wettst., *Bergia texana* (Hook.) Seub. ex Walp., *Cyperus acuminatus* Torr. & Hook. ex Torr., *C. difformis* L., *C. setigerus* Torr. & Hook., *C. squarrosus* L., *Eclipta prostrata* (L.) L., *Eleocharis acicularis* (L.) Roem. & Schult., *E. atropurpurea* (Retz.) J. Presl. & C. Presl., *E. coloradoensis* (Britt.) Gilly, *E. ovata* (Roth) Roem. & Schult., *E. parvula* (Roem. & Schult.) Link ex Bluff, Nees & Schauer, *Juncus* spp., *Justicia americana* (L.) Vahl, *Lindernia dubia* (L.) Pennell, *Marsilea vestita* Hook. & Grev., *Panicum scoparium* Lam., *Paspalidium geminatum* (Forssk.) Stapf., var. *geminatum, Phyla nodiflora* (L.) Greene, *Pilularia americana* A. Braun, *Tribulus terrestris* L., and *Xanthium strumarium* L.

DISCUSSION

We observed culms of *S. saximontanus*, *S. hallii*, and the putative hybrid flowering and producing viable fruit from July through mid-October, indicating that they are able to do so anytime during the growing season when conditions for germination and growth are favorable (Baskin et al. 2003). At all four sites where *S. hallii* and *S. saximontanus* occur in mixed populations, the putative hybrid was present (Medicine Tank, Quanah Parker Lake, Zania Pond, and Pottawatomie Pond) (see Table), suggesting that hybridization is a definite possibility in any mixed population. Soil cores collected in 2001 from Boggy Flat and Hollis Lake appeared to contain achenes of both *S. hallii* and *S. saximontanus*, but as hybrids had not been verified at the time the cores were processed, it is possible that hybrid seed might have been present. In any case, it is likely that in some years individuals of both species (and possibly those of the putative hybrid) may emerge at those sites in the future.

Schoenoplectus hallii and *S. saximontanus* co-occur at Rhodes Lake, TX where they are on opposite ends of the reservoir (Robert O'Kennon, pers. comm. Oct. 2007); however, the ease with which waterfowl may transport achenes for long distances (deVlaming and Proctor 1968; Powers et al. 1978) suggests that the species may form a mixed population in the near future. Historically, *S. hallii* and *S. saximontanus* were apparently allopatric and likely came in contact with one another via the muddy feet of migrating waterfowl, as suggested by McClain et al. (1997) and Beatty et al. (2004). It was postulated by Magrath (2002) that large herbivores such as bison and other animals were dispersal agents for achenes of *S. hallii* and *S. saximontanus* at WMWR. Our observations support the possibility of elk and bison as dispersal agents, as hoofprints of both were evident at every site. As neither elk nor bison are common at FSMR, we propose that achenes of the two species at the reservation are more likely to have been transported among ponds via waterfowl, white-tail deer, and feral hogs. Toni Hodgkins, naturalist at FSMR, reported that feral hogs equipped with radio transmitters were documented moving to and from the reservation and noted that 1200 pigs had been captured in less than a year (Toni Hodgkins, pers. comm. 2010).

There is an historical site in Kansas where *S. hallii* and *S. saximontanus* were known to be sympatric in 1997, but Craig Freeman at the University of Kansas examined the voucher specimens from the site in 2006 and did not note any evidence of hybridization (Craig Freeman, pers. comm. 2006). Nevertheless, it would be advisable to continue to monitor these areas in KS and TX to further assess the incidence of hybridization in mixed populations**.**

We suggest that when viewing live material in the field, or when examining dried voucher specimens, a thorough evaluation of multiple spikelets from different plants is necessary for reliable identification of plants collected from populations where *S. hallii* and *S. saximontanus* co-occur. Spikelets should be carefully examined for the presence of mixed style numbers, abortive achenes, or abnormally shaped, 2- or 3-sided achenes. Some spikelets that have achenes characteristic of one species may have an achene that would be better identified as the other species. Thus, the failure to examine multiple spikelets from different plants may result in a premature determination of specimens collected from mixed populations.

The presence of *S. hallii* × *S. saximontanus* hybrids at WMWR and FSMR may threaten the long term persistence of *S. hallii* and *S. saximontanus* in OK and constitute a threat to the conservation of the species in North America. According to conservation geneticists, the possible dangers of hybridization are numerous and pose a serious threat to the survival of rare species that hybridize with a closely related congener (Levin et al. 1996). Although the extinction of rare species typically is attributed to environmental change that renders the habitat unsuitable (Harrison 1991; National Research Council 1995), hybridization may have a profound effect on the persistence of a species (Rieseberg 1991; Ellstrand 1992; Rieseberg and Linder 1999). Hybrids compete for space and resources with parental species and reduce the potential for plants to replace themselves, thereby inhibiting the growth of their populations – the lower the rate of population growth, the greater the potential for extinction in a variable environment (Menges 1992). The numerical disadvantage of a rare species is compounded by the proliferation of fertile hybrids (Rhymer and Symberloff 1996). If one of the species is rarer than the other, the addition of hybrids to a population containing congeners decreases the proportional representation of the less abundant parent. In time, backcrossing can result in the assimilation of the rare species whose genetic identity will become extinct, and, over evolutionary time, the DNA of the former rare species may be lost from the gene pool altogether (Rieseberg et al. 1996). In the case of *S. hallii* and *S. saximontanus* in OK, both of which appear to be rare, it is possible that although much of the DNA of both species may survive, the two species may be subsumed into a new species with a new genetic identity.

FUTURE ACTIONS

Because of the impossibility of controlling achene dispersal-agents at WMWR and FSMR, it is unlikely that management to prevent hybridization is possible. We recommend, however, that monitoring of the populations of *Schoenoplectus* at WMWR and FSMR be continued to confirm or dismiss the importance of hybridization as a threat in the area.

Given the documented hybridization between *S. hallii* and *S. saximontanus* in

Oklahoma and the identification of new threats to *S. hallii* in Illinois (McKenzie et al. 2010), the species should be re-evaluated as a possible candidate for federal listing under the Endangered Species Act. No range-wide status assessment exists for *S. saximontanus*, and as noted in the introduction, the species is critically imperiled in seven of the 12 states where it has been documented. We recommend that a thorough analysis of the distribution and size of populations of *S. saximontanus* be made, and that potential threats to the species be assessed. Further studies may provide evidence that this species may also warrant protection under the Endangered Species Act.

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Table *Schoenoplectus hallii* (Sh), *S. saximontanus* (Ss), and putative hybrid (Hy) at Wichita Mountain Wildlife Refuge (WMWR) and Fort Sill Military Reservation (FSMR) at selected sites: 2002, 2007-2010; Boggy Flat (BF), Elmer Thomas (ET), Engineer Pond (EP), Grama Lake (GL), Hollis Pond (HL), Ingram Pond (IP), Medicine Tank (MT), Pottawatomie Pond (PP), Quanah Parker Lake (QPL), Rock Dam (RD), Zania Pond (ZP)

Date	Area	Site	Species collected	*Collection #	Abundance
July 2002	WMWR	HP	Sh	2023	~100 flowering and fruiting culms
		MT	Sh	2029	Abundant on W shore
			Ss	2027	Abundant on S & E shore
			Hy	2028	Scattered
		IP	Sh	2031	~ 200 plants scattered
		ET	Sh	2035	~ 200 plants scattered
		BF	Ss	2026	Abundant- 100,000s of plants
Oct 2007	WMWR	MT	Sh	2315	Common, widely distributed
			Ss	2316	Common, widely distributed
			Hy	2317	Common, scattered
		BF	Ss	2313	~ 100 plants scattered
		RD	Ss	2318	~ 10,000s plants
		Pond E of RD	Ss	2314	~ 100 plants scattered
Sep 008	WMWR	MT	Sh	2349	Thinly scattered
			Ss	2350	Thinly scattered
			Hy	2351	Concentrated along NW corner of pond
Aug 2009	WMWR	MT	Sh	2391	Uncommon, scattered
			Ss	2392	Rare
			Hy	2393	Common
		IP	Sh	2395	Uncommon, scattered
		QPL	Sh	2406	Rare
			Ss	2407	Rare, scattered
			Hy	2408	Uncommon, scattered
		RD	Ss	2390	Rare

Table continued

Date	Area	Site	Species collected	*Collection #	Abundance
Aug 2009	FSMR	ET	Sh	2397	30 plants, scattered
		EP	Sh	2399	50 plants, scattered
		ZP	Sh	2400	Rare
			Ss	2401	Rare
			Hy	2402	Common
		PP	Sh	2403	Abundant
			Ss	2404	Uncommon, scattered
			Hy	2405	Abundant
Sep 2010	WMWR	MT	Sh	2459	Rare
			Hy	2406	Common
		RD	Ss	2457	Uncommon, scattered; heavily grazed
		GL	Ss	2464	Uncommon, scattered
Sep 2010	FSMR	ET	Sh	2462	Uncommon, scattered
		PP	Hy	2461	~10,000s plants

*Collections were sent to one or more of the following herbaria: BRIT, MICH, MO, OKL, WISC, UMO

SPATIAL GENETIC STRUCTURE OF THE TALLGRASS PRAIRIE GRASS *DICHANTHELIUM OLIGOSANTHES* (SCRIBNER'S PANICUM)

Molly J. Parkhurst[1]
Andrew Doust[1]
Margarita Mauro-Herrera[1]
Jeffrey M. Byrnes[2]
Janette A. Steets[1]
janette.steets@okstate.edu

[1]Oklahoma State University
Department of Botany
301 Physical Sciences
Stillwater, OK 74078

[2]Oklahoma State University
Boone Pickens School of Geology
105 Noble Research Center
Stillwater, OK 74078

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ABSTRACT

The spatial genetic structure within plant populations and genetic differentiation among populations can vary in strength due to the forces of natural selection, gene flow and genetic drift. In this study, we investigate the level of genetic structure and differentiation present in Oklahoma populations of *Dichanthelium oligosanthes* (Schult.) Gould (Scribner's panicum), a C_3 grass native to the United States and a frequent member of the tallgrass prairie. To examine fine-scale spatial genetic structure of *D. oligosanthes*, we collected leaves from 48 spatially separated plants in a population in Stillwater, OK. To examine genetic differentiation among adjacent populations, we sampled leaf tissue from eight individuals at each of three populations in Stillwater, OK. DNA was extracted from these samples and Inter-Simple Sequence Repeats (ISSR) markers were amplified. Within a single population of *D. oligosanthes*, we found a weak and non-significant negative relationship between genetic similarity and geographical distance. In contrast, we found evidence for moderate and significant genetic differentiation among populations.

INTRODUCTION

Genetic variation is the sum total of all genetically based variation within and among species and represents an important component of biodiversity. Maintaining genetic variation within and among native plant populations is a central goal of conservation biology, as genetic variation provides the raw material for plants to evolve in response to environmental change and contributes to population fitness (Leimu et al. 2006, Reed and Frankham 2003, Wagner et al. 2011). Given the importance of genetic variation for the maintenance and evolution of plant populations, it is critical to understand the levels of genetic diversity within species and determine how this variation is organized spatially, both within and between populations.

The way in which genetic variation is organized within plant populations (spatial genetic structure) is affected by many factors, including selection pressures within a population, mating system (relative production of selfed to outcrossed individuals), and whether gene flow is restricted (Loiselle et al. 1995, Loveless and Hamrick 1984, Miyazaki and Isagi 2000, Perry and Knowles 1991). Plants are sessile organisms and gene flow can only occur through pollen and seed movement. Restricted dispersal of seed or pollen can

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occur due to the dispersal mechanism utilized by the plant, the presence of physical barriers, and when rates of inbreeding are high. Under these conditions, population genetic structure is predicted to develop, with a clustering of genetically related individuals among plants within a population and a high level of genetic differentiation among geographically separated populations (Epperson and Li 1997, Hamrick and Nason 1996).

Dichanthelium oligosanthes is a short, C_3 perennial grass native to the United States that is commonly found in open prairies, meadows, and disturbed areas (Kansas State University Libraries 2011). Although it is not a dominant species of the tallgrass prairie, it is a highly consistent member of this community (Adams and Wallace 1985).

The mating system and ecology of *D. oligosanthes* are likely to affect population genetic structure. First, *D. oligosanthes* has a mixed mating system resulting from the production of two types of flowers within a single individual: closed, self-fertilizing cleistogamous flowers and open, potentially outcrossing chasmogamous flowers. The chasmogamous flowers form on a terminal panicle in May – June, are open-pollinated for a short time, then close and self-fertilize in the absence of pollination (Bell and Quinn 1985, Freckmann and Lelong 2003). The cleistogamous flowers extend from within the sheath and appear from June – November (Bell and Quinn 1985, Freckmann and Lelong 2003). Grasses in the genus *Dichanthelium* tend to reproduce proportionately more through cleistogamy than through chasmogamy (Bell and Quinn 1985, Bell and Quinn 1987). This high rate of self-fertilization should lead to significant spatial genetic structure within populations and genetic differentiation among populations. Second, as an element of the tallgrass prairies, *D. oligosanthes* has a relatively short stature of less than 45 cm. In tallgrass prairies, *D. oligosanthes* is imbedded within a matrix of the dominant grass species (*Andropogon gerardii*, *Panicum virgatum, Sorgastrum nutans,* and *Schizachyrium scoparium*). These dominant grasses can reach heights of up to 2 m (USDA, NRCS 2011) and thus may serve as a physical barrier to *D. oligosanthes* pollen and seed dispersal, further contributing to spatial genetic structure within populations. In contrast to the first two factors, which would tend to increase fine-scale spatial genetic structure within *D. oligosanthes* populations, one aspect of *D. oligosanthes* fruit dispersal could lead to reduced genetic structure. In particular, the fruits of *D. oligosanthes* can disperse great distances when the inflorescence breaks off of the plant, leading to a "tumbleweed" dispersal mechanism (Campbell et al. 1983).

We examined spatial genetic structure and population differentiation of *D. oligosanthes* in Stillwater, OK. Through our study we aimed to answer the following questions: (1) How is genetic diversity distributed spatially within a population of *D. oligosanthes*? (2) Are populations of *D. oligosanthes* genetically differentiated? To address these questions, we examined genetic diversity in Inter-Simple Sequence Repeats (ISSR)markers in three *D. oligosanthes* populations. Within a single population of *D. oligosanthes,* we expected genetically related individuals to be aggregated spatially, and thus we expected to find a negative correlation between genetic similarity and geographical distance. Among populations of *D. oligosanthes,* we expected to find a significant degree of genetic differentiation.

MATERIALS AND METHODS

How is genetic diversity distributed spatially within a population of *D. oligosanthes*?

We collected leaf samples from 48 representatives of *D. oligosanthes* from the southern portion of the Oklahoma State University (OSU) Cross Country Field South in Stillwater, OK (CCS population: 36°08'12.0"N, 97°04'36.6"W; Figure 1). Thirty-eight of these samples were located across three approximately parallel transects, each approximately 36 m in length and five to ten m apart. Material from an additional ten plants was collected at increasing distances from these transects. Locations of all plants were recorded using a Trimble 2008 GeoXH handheld GPS with an external Zephyr antenna and were differentially corrected relative to a stationary base station to increase the accuracy of the GPS data. The locations of each of the 48 plant samples were mapped on an aerial photograph of the site (see Figure 1).

We extracted DNA from each individual following the procedure of Junghans and Metzlaff (1990). For each sample, genomic DNA concentrations were quantified using NanoDrop spectrophotometry and 1% agarose gel electrophoresis. We tested 12 ISSR markers (Zietkiewicz et al. 1994) from the UBC primer set #9 (University of British Columbia Nucleic Acid-Protein Service Unit) and successfully amplified five of these via polymerase chain reaction (PCR) (Table 1). We ran 10 μL PCRs using 1 μL of diluted genomic DNA (from a 1:30 dilution corresponding to 10 to 20 ng of genomic DNA), dNTPs at 100 μM each, ISSR primer at 0.5 μM, 1X Green GoTaq® Flexi Buffer (Promega, Madison, WI), $MgCl_2$ at 1.5 mM, and 0.6 units of Promega Go *Taq* polymerase (Promega, Madison, WI). Amplifications were performed in an Eppendorf Mastercycler Pro thermal cycler using the following touchdown conditions: single initial denaturation step at 95° C for two minutes; followed by 32 cycles each with three steps: a denaturation step at 94° C for 40 seconds, followed by an annealing touchdown step (starting at 56° C or 58° C, depending on the primer, for two cycles; then 54° C or 56° C for two cycles to reach 52° C or 54° C for 28 cycles) for 40 seconds, and an extension step at 72° C for 50 seconds; and a final extension at 72° C for eight minutes. PCR products were resolved electrophoretically on 1% agarose gels run at 150 V in TBE buffer, visualized by staining with ethidium bromide, and photographed under UV illumination. Fragment sizes were estimated using Hyper Ladder II (Bioline, Tauton, MA). ISSR bands were scored as present or absent for each plant sample. Bands were scored and compared by two different people to reduce subjectivity in the scoring procedure. Twelve individuals showed poor amplification of some of the ISSR markers, resulting in missing data in the dataset. As the statistical analyses described below do not allow for missing data, we eliminated these individuals from further analysis. Thus, the analysis of genetic structure in the CCS population used a total of 36 individuals.

Geographical distances between plants were estimated using Euclidean distances. Genetic similarities between plants were estimated using a matrix of Dice genetic similarity coefficients created with the PAST program (Hammer et al. 2001). The Dice coefficient, which weighs positive matches between plant samples and ignores negative matches, was used because ISSRs are dominant markers, and therefore only the presence of a PCR product is meaningful. A Mantel test was performed to determine whether there was a relationship between geographical distance and genetic similarity with both the PAST program and the *zt* program (Bonnet and Van der Peer 2009), using 10,000 permutations of the data. Finally, to examine hierarchal clustering in the samples, we generated an Unweighted Pair Group Method with Arithmetic mean (UPGMA) tree of the genetic distance data using the PAST program (Hammer et al. 2001). A bootstrap analysis using 1000 replications was performed to determine the support for the hierarchical clustering.

Are populations of *D. oligosanthes* genetically differentiated?

To determine whether nearby populations of *D. oligosanthes* in Stillwater, OK are genetically differentiated from one another, we examined the diversity of six ISSR markers (see Table 1) in three populations (Figure 2): OSU Cross Country Field South (CCS;

36°08'12.0"N, 97°04'36.6"W), OSU Cross Country Field North (CCN; 36°08'20.8"N, 97°04'39.9"W), and Lakeview Road West (LW; 36°08'42.6"N, 97°05'38.9"W). Populations CCS and CCN were separated from one another by 0.3 km, CCN and LW by 1.6 km and CCS and LW by 1.8 km. Within each of the three populations, we collected leaf material from eight randomly chosen individuals. We extracted DNA, amplified ISSR markers via PCR, and visualized PCR products via gel electrophoresis as described above.

We used the program Hickory version 1.1 (Holsinger and Lewis 2003, Holsinger et al. 2002) to estimate genetic differentiation among populations of *D. oligosanthes*. Hickory allows for estimation of heterozygosity within populations and genetic differentiation among populations using dominant markers without assuming Hardy-Weinberg equilibrium (Holsinger and Lewis 2003, Holsinger et al. 2002). This program uses Bayesian methods to estimate the average heterozygosity within subpopulations (*hs*; an analog of the expected heterozygosity) and test for genetic differentiation among populations through the unbiased estimate θ^{I}, which is analogous to Weir and Cockerham's (1984) F_{ST} (Holsinger and Lewis 2003). θ^{I} measures the amount of genetic differentiation among contemporaneous populations (Holsinger and Lewis 2003); values close to 0 suggest little genetic differentiation between populations (i.e., complete panmixia), whereas values close to one suggest genetic isolation between populations.

The *D. oligosanthes* ISSR data were fitted to four models: (1) full (uses non-informative priors for f), (2) $f = 0$ (assumes no inbreeding; f is analogous to the inbreeding coefficient F_{IS}), (3) $\theta^{II} = 0$ (assumes no population differentiation), and (4) f-free (decouples the estimation of θ^{II} from the estimation of f). In each model run, the default parameters were used (burn-in = 5,000; number of samples = 25,000; thinning = 5). The models were compared to one another based on the deviance information criterion (DIC) of Spiegelhalter et al. (2002) implemented in Hickory. The full model best fit our dataset as it provided the lowest DIC value; thus, we present the results of the full model in the *Results* section.

RESULTS

How is genetic diversity distributed spatially within a population of *D. oligosanthes*?

The five ISSR primers produced a total of 21 loci that could be reliably scored in the CCS population, of which 13 were polymorphic (Table 2).

The Mantel test revealed a non-significant negative relationship between genetic similarity and geographic distances, with a negative correlation between geographical distance and similarity (r = -0.042, P = 0.755). The UPGMA analysis revealed weak hierarchical clustering among the plant samples, consistent with the results of the Mantel test (data not shown). Thus, we find no evidence for significant spatial genetic structure in the CCS population of *D. oligosanthes*.

Figure 1 Map of the Oklahoma State University Cross Country Field South (CCS) *Dichanthelium oligosanthes* population in Stillwater, OK. Yellow points indicate the location of *D. oligosanthes* plants sampled; base image is an aerial photograph acquired by the USDA Farm Service Agency.

Figure 2 Map of *Dichanthelium oligosanthes* populations in Stillwater, OK; base image from Google Earth. CCS = Oklahoma State University (OSU) Cross Country Field South, CCN = OSU Cross Country Field North, LW = Lakeview Road West.

Table 1 ISSR primers used for DNA amplification from UBC primer set #9 (University of British Columbia Nucleic Acid-Protein Service Unit). The right-most column indicates whether the given primer was used in the study of genetic diversity in the Oklahoma State University Cross Country Field South population of *D. oligosanthes* (A) and/or the study of genetic differentiation among three Stillwater, OK populations of *D. oligosanthes* (B).

Primer	Sequence (5' - 3')	Study using primer
UBC – 808	AGA GAG AGA GAG AGA GC	B
UBC – 809	AGA GAG AGA GAG AGA GG	A and B
UBC – 810	GAG AGA GAG AGA GAG AT	A and B
UBC – 816	CAC ACA CAC ACA CAC AT	A and B
UBC – 817	CAC ACA CAC ACA CAC AA	A and B
UBC – 818	CAC ACA CAC ACA CAC AG	A and B

Table 2 Numbers of loci reliably scored, numbers of polymorphic loci, and percentage of polymorphic loci for each of the five ISSR primers used in the study of genetic diversity in the Oklahoma State University Cross Country Field South (CCS) population of *D. oligosanthes*.

Primer	Number of loci reliably scored[1]	Number of reliably scored polymorphic loci	Percentage polymorphic loci[2]
UBC – 809	6	3	50.0
UBC – 810	4	2	50.0
UBC – 816	5	2	40.0
UBC – 817	3	3	100.0
UBC – 818	3	3	100.0
Total	21	13	61.9

[1] For all primers, additional bands were present but could not be reliably scored (i.e., band was weak or too close to adjacent band). The number of loci reliably scored does not include these additional unscored bands.

[2] Given that bands that could not be reliably scored were excluded from this calculation, this is an approximate percentage of polymorphic loci.

Table 3 Number of loci reliably scored, number of polymorphic loci, and percentage of polymorphic loci for each of the six ISSR primers used in the study of genetic differentiation among three *D. oligosanthes* populations in Stillwater, OK.

Primer	Number of loci reliably scored[1]	Number of reliably scored polymorphic loci	Percentage polymorphic loci[2]
UBC - 808	13	4	30.8
UBC - 809	6	3	50.0
UBC - 810	7	5	71.4
UBC - 816	8	5	62.5
UBC - 817	4	4	100.0
UBC - 818	3	3	100.0
Total	41	24	58.5

Are populations of *D. oligosanthes* genetically differentiated?

The six ISSR primers produced a total of 41 loci that could be reliably scored, of which 24 were polymorphic across the three populations (Table 3). In the CCS and LW populations 51.2% of the 41 ISSR loci were polymorphic and in the CCN population 53.7% were polymorphic. The average heterozygosities (*hs*) within each of the three populations were similar (mean ± s.d.; CCS: 0.36 ± 0.022, CCN: 0.35 ± 0.023, LW: 0.37 ± 0.020), indicating that genetic diversity does not differ drastically among the populations. On average, *hs* was 0.36 ± 0.016 across the three populations.

In the Bayesian analysis of population genetic differentiation using the full model, θ^{II} (analogous to Weir and Cockerham's (1984) F_{ST}) was estimated to be 0.134 (s.d. = 0.0428), indicating a moderate proportion of differentiation among populations.

DISCUSSION

Given the central role of genetic diversity in the evolutionary process, it is critical to understand how genetic diversity is distributed within and among populations. In this study, we found no evidence for fine-scale spatial genetic structure within a single population of *D. oligosanthes*. However, we found significant levels of genetic differentiation among three *D. oligosanthes* populations. Below we expand on these findings and discuss potential factors contributing to the patterns of genetic structure and differentiation observed in *D. oligosanthes*.

In the CCS population of *D. oligosanthes*, we found a negative but non-significant relationship between genetic similarity and geographic separation of plants. The lack of significance is contrary to our expectations, although the trend fits our hypothesis that plants in close spatial proximity to one another were more genetically similar than plants that were more spatially separated. Such findings can be contrasted with those of other plant species, such as the self-compatible annual herb *Polygonum thunbergii*. In this species, Konuma and Terauchi (2001) found a significant negative correlation between genetic similarity and geographic distance (*r* = -0.64). The difference in fine-scale spatial genetic structure of these plant species may be due to differences in seed dispersal. Grasses in the genus *Dichanthelium* may disperse fruits over greater distances as the inflorescence breaks off of the plant, leading to a "tumbleweed" dispersal of the fruits (Campbell et al. 1983). In contrast, *P. thunbergii* shows restricted seed dispersal, with seeds being dispersed in close proximity to the maternal plant (Konuma and Terauchi 2001). An additional factor that may contribute to the non-significant relationship found between genetic similarity and geographic distance in the CCS population of *D. oligosanthes* is low germination and recruitment of selfed (i.e., cleistogamous) individuals. However, in a related *Dichanthelium* species, *D. clandestinum*, Bell and Quinn (1985) found that cleistogamous seeds germinated and emerged, both in the greenhouse and in the field, at a higher rate than chasmogamous seeds. Future work is needed in *D. oligosanthes* to determine whether differences in cleistogamous and chasmogamous germination and recruitment may contribute to the observed patterns in spatial genetic structure.

We found significant levels of genetic differentiation among three *D. oligosanthes* populations. This pattern of genetic differentiation could be due to the cleistogamous mating system of *D. oligosanthes*. Grasses in the genus *Dichanthelium* tend to reproduce proportionately more through cleistogamy than through chasmogamy (Bell and Quinn 1985, Bell and Quinn 1987). With elevated levels of inbreeding, genetic differentiation between populations is expected. The differentiation we observed amongst three neighboring populations of *D. oligosanthes* indicates that it is necessary to conserve multiple populations of this species to maintain genetic diversity.

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THE EFFECTS OF REMOVAL OF *JUNIPERUS VIRGINIANA* L. TREES AND LITTER FROM A CENTRAL OKLAHOMA GRASSLAND

Jerad S. Linneman[1]
Matthew S. Allen[2]
Michael W. Palmer[2]
mike.palmer@okstate.edu

[1]USDA
Animal & Plant Health Inspection Service
4700 River Rd., Unit 153, 5D-06G
Riverdale, MD 20737-1228

[2]Oklahoma State University
Department of Botany
301 Physical Sciences
Stillwater, OK 74078-3013

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ABSTRACT

We studied species composition after *Juniperus virginiana* tree and litter removal in a central Oklahoma grassland. Tree removal had the most significant effect on stems per quadrat and vegetation cover. Litter removal effects were not as strong. However, stems per quadrat and vegetation cover in litter removal treatments were higher than in litter intact treatments. Species richness increased for all treatments in the first year post-treatment, after which species richness declined at every sampling period and in every treatment for the duration of the study. Absolute cover of typical prairie species increased in the cut with no litter treatment whereas cover of woody forest species increased in the no cut with no litter treatment. We suggest that even without prescribed fire, redcedar tree removal may result in a return of prairie vegetation. However, additional efforts besides tree removal may be required to restore some invaded grasslands.

INTRODUCTION

For the last several decades, there has been a growing interest in management techniques required to maintain and/or restore vegetation. The two most common problems faced in grassland restoration are habitat destruction and the loss of native species diversity due to the encroachment of woody species. Concerns about decreased diversity and the invasion of exotic woody species have spurred extensive study throughout the world including Argentina (Ghersa et al. 2002), Australia (Costello et al. 2000, Whiteman and Brown 1998), Canada (Peltzer and Köchy 2001), French Prealps (Barbaro et al. 2001), South Africa (Holmes et al. 2000, Holmes and Marais 2000) and the United States (Petranka and McPherson 1979, Callaway and Aschehoug 2000, Fitch et al. 2001, Briggs et al. 2002b, van Els et al. 2010).

In the United States, two examples of fire adapted vegetation types that have received much attention regarding restoration are the longleaf pine sandhill vegetation of northwestern Florida (Kush et al. 1999, Provencher et al. 2000, Provencher et al. 2001) and the tallgrass prairie of the eastern Great Plains (Axmann and Knapp 1993, Briggs et al. 2002a, Briggs et al. 2002b). In both instances the elimination of fire has caused a decrease in species richness and facilitated their conversion into forests. Tallgrass prairie researchers have suggested that reductions in abundance and altered community composition are related to a

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multitude of environmental factors associated with woody invasion. Examples of such altered environmental factors include soil moisture (Engle et al. 1987, Facelli and Pickett 1991b), solar radiation (Smith and Stubbendieck 1990, Facelli and Pickett 1991a & b) and soil temperature (Weaver and Rowland 1952, Hulbert 1969). In addition, leaf litter from woody species may alter grassland litter dynamics (Facelli and Pickett 1991b).

Within the tallgrass prairie region, eastern redcedar (*Juniperus virginiana* L.) has increased dramatically, converting millions of hectares of grassland to woodland or closed canopy forest (Schmidt and Leatherberry 1995, Briggs et al. 2002a). Redcedar invasion is not restricted to impacted or degraded sites and exhibits high survivorship in diverse native grasslands (Ganguli et al. 2008). Typical control methods include mechanical felling via chainsaws, large cutting machinery, or cabling and prescribed fire. Although felling and prescribed fire are effective in reducing redcedar abundance in prairies, the continuous application of this management technique has left a significant gap in our understanding about the role redcedar litter plays in tallgrass prairie restoration. In particular, we do not understand the role of the overstory tree versus the leaf litter in determining species composition.

We conducted this study to disentangle the effects of redcedar overstory canopy and accumulated litter on prairie species richness and composition. Elucidating these effects will allow for a more informed approach to redcedar removal and prairie restorations.

METHODS

Study Site

We conducted this experiment at the James K. McPherson Botanical Preserve located 16 km west of Stillwater, Oklahoma (36°06'00"N, 97°12'30"W). After a brief period of row crop agriculture, the site was converted into pastureland and grazed until the 1960's. Oklahoma State University (OSU) purchased the land and managerial control was turned over to the Department of Botany. In 1995, the Department of Botany introduced a burning regime, consisting of a three to five year return interval, to the northwestern half of the preserve with the goal of stimulating the return of a native tallgrass prairie community.

Tree Selection and Classification

We selected 47 potential study trees based on several criteria including tree isolation, minimization of surrounding tree effects, the existence of an intact litter layer underneath the tree, and tree size. We recorded canopy diameter in the north-south and east-west direction, height, stem diameter at both 10 cm and diameter-at-breast-height (DBH), and gender. For those trees with multiple stems, we recorded separate diameter measurements for each primary stem, which we later converted into basal area (BA) at 10 cm and DBH, respectively. We randomly assigned all trees into two groups (cut and no cut); ten study trees were then randomly selected from each group.

Sampling Design

*S*ampling design was based on a two by two factorial design of tree removal and litter removal. Underneath each study tree, we positioned two 50 cm × 50 cm quadrats so that each quadrat was completely under the canopy of the overstory redcedar. In addition, we positioned the two quadrats in such a way to maintain homogenous litter cover between quadrats and to minimize inter-quadrat variation in vegetation. After permanently marking each quadrat, we randomly assigned a litter removal treatment to one of the two quadrats under each tree. We conducted an initial vegetation sampling in May 2001, prior to treatment application.

All subsequent sampling occurred biennially in May and September of 2002 – 2003.

Sampling of species composition consisted of identifying each plant species rooted inside the quadrat and estimating its percent cover to the nearest percent for any cover less than 5% and to the nearest 5% for any cover over 5%. We marked unknown species for later identification. Species nomenclature and code symbols follow that of the USDA PLANTS database (USDA 2004). In addition, at several locations within this paper we refer to the response of *J. virginiana* redcedar seedlings and not the study tree or any of its structures.

Experimental Treatments

The tree removal treatment was applied using a chainsaw and pruning shears between 17 and 19 May, 2001. We removed crowns and branches from the top down, with the aid of rigging equipment, to minimize the amount of disturbance to the litter layer and vegetation in the quadrats. We removed litter from litter removal quadrats by hand, taking care to minimize disturbance to vegetation. However, plants that had germinated in the litter layer and had not reached the soil surface were removed along with the litter during the initial treatment. The litter removal treatment was applied between 21 and 24 May, 2001. Treatment acronyms for tree and litter removal are: cut with no litter (CN), cut with litter (CL), no cut with no litter (NN), and no cut with litter (NL); i.e. the control.

At each post-treatment sampling, we removed newly accumulated litter from the litter removal quadrats after observing vegetation. On a few occasions we removed branches from surrounding trees that started to grow over the tree removal quadrats.

Statistical Analyses

Statistical analysis included the use of both ANOVA and ordination techniques. We performed repeated measures ANOVA using PROC MIXED for each environmental variable recorded using SAS (Version 8). For each environmental variable, initial (pre-treatment) observations were used as a baseline for all subsequent samplings (post-treatment). Preliminary analyses included tree gender as an explanatory variable. However, because gender showed no significant main or interaction effects, we removed gender and re-ran all ANOVAs.

We analyzed compositional data using direct gradient analysis. Direct gradient analysis uses species data and directly relates it to measured environmental variables, in this case dummy variables representing the treatments. We selected partial Redundancy Analysis (pRDA) because it is generally considered more appropriate in short-term experimental studies where species responses are believed to be linear and over relatively short gradients. All ordinations were conducted using CANOCO FOR WINDOWS 4.5 (ter Braak and Šmilauer 2002) on absolute cover of each species within a sample.

We developed *a priori* hypotheses about the potential affect of treatment application on species cover. We hypothesized that tree removal and litter removal would have a positive effect on stems per quadrat, vegetation cover and species richness. In addition, the combination of tree removal with litter removal, conditions most similar to open prairie (CN), would have the largest effect; whereas, the combination of no tree removal and no litter removal, the control condition (NL), would have no effect or the least positive effect on species. We have not included any correction factors for statistical problems associated with multiple comparisons (Legendre and Legendre 1998, Hallgren et al. 1999).

RESULTS

Density and Richness

There were significant differences in stem density (p<0.001) between all quadrats prior to treatment application. However, the difference between the means of the densest and sparsest treatments was only 2.5 stems per quadrat. Both the cut with litter (CL) and cut with no litter (CN) treatments had the lowest stems per quadrat prior to treatment application. Stem density increased for all treatments except no cut with litter (NL) treatment by the second sampling. This increase was roughly 2-2.5 fold thus resulting in an increase of 10-13 stems per treatment (Figure 1). Significant differences (p=0.0052) in density between NL & NN (no cut-no litter) only occurred in May 2002. On the other hand, there were significant differences in stems density between litter treatments within the cut treatment, CL and CN, in September 2002 (p=0.0366) and 2003 (p=0.0483). The cut treatment had a much more pronounced effect on density regardless of litter treatment. In September and May 2002 - 2003, there were significant differences between both CN and NN (p=0.006, 0.004, 0.001 respectively) and CL and NL (p=0.0052, 0.003, 0.0159 respectively).

As with density, there were significant differences in initial species richness (p<0.001) between all quadrats prior to treatment application. Again, the magnitude of the mean difference was quite small, fewer than 1.0 species per treatment. Additionally, the CL and CN treatments again had the lowest richness. The increase in species richness by the second sampling was not as dramatic as that observed in stems per quadrat by the same sampling. Generally increases in mean species richness were in the order of 0.4-1.25 species per quadrat (Figure 2). Significant differences in species richness between NL and NN only occurred in September 2002 (p=0.0244); however May 2002 was marginally insignificant (p=0.0533). Conversely, significant differences in species richness between CL and CN occurred in both May 2002 (p=0.0381) and September 2002 (p=0.0026). The cut treatment had a slightly weaker influence on species richness as compared to stems per quadrat. Significant differences in species richness were observed between CN and NN in September 2002 (p=0.0055) and 2004 (p=0.0007). Significant differences in species richness were also observed between CL and NL in September 2002 (p=0.0457) and September 2003 (p=0.0358).

Vegetation Cover

There was no significant difference in total vegetation cover prior to treatment application. There was a substantial increase in total cover through samplings two and three in both the CL and CN treatments (Figure 3). This increase in total cover was in the order of 8.75-11.25%. On the other hand, total cover in both the NN and NL treatments only increased by ~2%. No significant differences in total cover were observed between the NL and NN treatments at any sampling. On the other hand, there was a significant difference between the CL and CN treatments in September 2003 (p=0.0024). Although litter removal did not have a major effect on total cover, tree removal did. Significant differences between CN and NN were observed in September and May 2002-2003 (p=0.001, 0.0023, <0.001 respectively). In addition, significant differences between CL and NL were also observed in September and May 2002-2003 (p=0.0071, 0.0075, 0.0318 respectively).

Unlike total vegetation cover, there were significant differences (p<0.001) in initial mean forb cover between treatments; however these differences were only 0.125%. Forb cover in both of the cut treatments, CL and CN, increased over the duration of the study although both no cut treatments, NL and NN, were relatively static throughout the study (Figure 4). There were no significant differences in forb cover for NL or NN treatments at any time, whereas a significance difference between CL and CN only occurred in September 2002 (*p*=0.0056). The tree removal treatment yielded a significant difference between CN and NN in May 2002 (*p*<0.0001) and September 2002 (*p*=0.0486), whereas a significant difference between CL and NL occurred only in May 2003 (*p*=0.0131).

Graminoid cover responded similarly to forb cover with significant differences in initial mean graminoid cover between treatments (*p*=0.0164). Once again, the differences between treatments were small (0.15%). Graminoid cover increased over the first post-treatment sampling for all treatments (Figure 5). Graminoid cover was not significantly affected by litter in NL or NN treatments. However, litter had a significant effect in September 2003 (*p*=0.0012) in the CL and CN treatment. The tree removal treatment had a stronger affect with significant differences in graminoid cover between CN and NN in September and May 2002-2003 (*p*=0.0253, 0.0092, <0.0001 respectively) and between CL and NL in September 2002 (*p*=0.0133). Marginal insignificance was also observed between CL and NL in May, 2003 (*p*=0.052).

Significant differences in woody cover (*p*=0.0197) were also present at the onset of this study. However, differences in mean woody cover between treatments were once again small (0.15%). Woody cover increased in all treatments over the duration of this study although these increases were only in the 0.5-2.0% range (Figure 6). In fact, no significant differences were found between any combination of litter removal and/or tree removal treatments at any sampling.

Direct Gradient Analysis

Partial Redundancy Analysis (pRDA) was conducted to test *a priori* hypotheses regarding the effects of tree removal, litter removal and their interaction at each sampling. Results of pRDA only showed significant differences in absolute species cover between litter removal treatments in May, 2002 and September, 2002 (*p*<0.001). Conversely, pRDA showed significant differences (*p*<0.001) in absolute species cover between tree removal treatments at every post-treatment sampling period. The litter removal with tree removal interaction effect was only significant in September 2002 (*p*=0.029). Therefore, it appears that tree removal does have a stronger effect on species composition over time than litter removal. When treatment centroids by sampling period are plotted in ordination space three items become apparent: First, tree removal results in an increased magnitude of movement of treatment centroids over time (Figure 7 a, b). Second, litter removal also results in an increased magnitude of movement of treatment centroids over time (see Figure 7 a, b). Finally, the overall amount of compositional change of cut treatments was greater than litter removal treatments.

A pRDA scatter plot of absolute species cover, treatment centroids and passive environmental variables based on all post-treatment samplings is displayed in Figure 8. The four dummy treatment variables accounted for 5.4% of the total explained species variance. Although woody cover was not significantly affected by tree removal or litter removal treatments at any sampling, woody forest species such as *Cercis canadensis, Celtis occidentalis, Parthenocissus quinquefolia, Quercus stellata, Juniperus virginiana* seedlings, and *Ulmus rubra* all dominated the no cut treatments with a slightly higher cover in the litter treatment (NL). Alternatively, grasses typical of the open prairie such as *Tridens flavus, Eragrostis* *spectabilis, Dicanthelium oligosanthes, Sorghastrum nutans, Bothriochloa saccharoides,* and *Sporobolus compositus* dominated the tree removal treatments. In addition, each one of these graminoids (with the exception of *T. flavus*) also had higher absolute cover in the litter removal treatment (CL). Sedges such as *Carex festucacea* and *C. bushii* both dominated the NN treatment. On the other hand, forb species typically associated with pastures such as *Ambrosia* sp., *A. psilostachya, Amphiachyris dracunculoides, Acalypha gracilens,* and *Croton monanthogynus* dominated the CN treatment.

DISCUSSION

Increases in stem density and species richness were expected as a result of litter removal and tree removal treatments. Our results are similar to those of Monk and Gabrielson (1985) who observed a stronger influence of overstory cover compared to litter cover on old field vegetation. For all manipulated quadrats (CL, CN, and NN) increased stems per quadrat is more likely to be due to increased perennial graminoid stems than woody or forb stems. Reductions in stems per quadrat in NL and NN treatments after September 2002 are likely the result of continued overstory tree presence and its associated reductions in solar radiation. Studies by Monk and Gabrielson (1985), Yager and Smeins (1999), and Joy and Young (2002) have all suggested that reductions in light similar to those observed in this study resulted in significant decreases in plant density and cover. On the other hand, we believe that reductions in stems per quadrat in September 2003 for CL and only the slight increase for CN were caused by relatively little precipitation received in 2002 – 2003. Total precipitation recorded at the Marena Mesonet Station, located approximately 4 km from the study site, was 63.0 cm from October 2002 to September 2003. This precipitation total is only 64-69% of annual precipitation for the site of 91.4-99.1 cm (Oklahoma Mesonet, Oklahoma Climatological Survey).

By comparison, the decreases in species richness over the course of this study suggest relatively little recruitment of new species occurred regardless of treatment. Provencher et al. (2000) found that species richness also decreased after the application of felling and slash burning in Florida's sandhill vegetation. However, Provencher et al. (2000) observed an increase in species richness two years after treatment application. Results from pRDA (see Figure 8) suggest a transition from pre-treatment species composition dominated by mesic or forest species to post-treatment tallgrass prairie species. It is possible that during this transition, forest species were lost faster than prairie species were added; therefore, we observe a decrease in species richness. However, the majority of species present in each treatment's cumulative species pool were, on average, not present in each quadrat. Generally only 10-20% of each treatment's cumulative species pool was observed in each quadrat (see Figure 2). It should be noted that species richness may be strongly linked to density (i.e. rarefaction effect) and thus the richness-per-quadrat should not be interpreted independently of stem counts (Palmer et al. 2000). This suggests that given more time species richness may increase as these rare species become more universally distributed into cut quadrats.

Linneman and Palmer (2006) suggested that species composition underneath redcedar trees may be a random subset of the species from the surrounding matrix. The results from this study suggest that this subset of species is nonrandom and comprised of two main types. The first group appears to be remnant prairie grasses, and the second is disturbance-tolerant forbs. The absolute cover of almost all graminoid species increased as a result of tree removal. Of particular interest is that the most abundant graminoid species were native tallgrass prairie species such as *Sorghastrum nutans* and *Sporobolus compositus*. Conversely, the positive response of disturbance favoring forb species like *Amphiachyris dracunculoides, Ambrosia psilostachya and Croton monanthogynus* may lead to further reductions in species richness if they become dominant. Several researchers, including Clary (1971), Clary and Jameson (1981), Brockway et al. (1998), and Provencher (2000), have all observed increases in graminoid and forb cover following overstory tree removal. In this study, annual species increased in cut treatments; however, few annuals dominated cover in any treatment. Although the increase of disturbance-tolerant forbs may be inhibitive in the short term, the observed increases in absolute cover of native tallgrass prairie species suggest that even without subsequent prescribed fire treatments, community composition may return to its pre-invasion condition with time.

The long-term effects of eastern redcedar in grasslands are unclear. The results from this study suggest the continued presence of eastern redcedar in grasslands may (1) facilitate the forestation of grasslands or at least (2) continue to reduce the tallgrass prairie species pool in invaded grasslands. Briggs et al. (2002a) determined that species present in the prairie were not consistently different from those found in a closed canopy redcedar forest. However, both this study and Linneman and Palmer (2006) show an apparent shift in community composition away from tallgrass prairie species toward forest tree species such as *Cercis canadensis, Celtis occidentalis, Juniperus virginiana, Quercus stellata* and *Ulmus rubra*. These same tree species frequently occur under redcedar canopies in nearby Cross Timbers forest environments as well (van Els et al. 2010) and, it should be noted, the cedars studied here were in relatively close proximity to Cross Timbers stands. Additionally, it is possible that the dynamics of cedar invasion may differ in old fields (studied here) from those in previously undisturbed prairie.

Although complete extirpation of native tallgrass prairie species is not likely in the short term, areas with extensive invasion and subsequent tree removal may require seeding of prairie species to encourage the return of characteristic prairie vegetation. This will inevitably increase the cost of restoration beyond the already high cost of tree removal (Bidwell et al. 2002). Areas with less than 75% cover of redcedar, however, have greater potential for recovery, as most tallgrass prairie species persist in inter-tree spaces until this point (Limb et al. 2010).

Continued invasion by eastern redcedar in the Great Plains has serious implications not only for the existence of native grasslands but also for biodiversity and potential future restorations. As shown here, removal of redcedar, even in the absence of subsequent prescribed fire, has the potential to increase the number of stems per quadrat and increase species richness for several years post-treatment. Litter removal, either by mechanical means or prescribed fire, should further benefit and accelerate the return of tallgrass prairie vegetation. Without tree removal, these grasslands will continue to lose native prairie species in favor of mesic and/or forest species. In the absence of broad-scale control efforts, redcedar will continue to fragment and replace native grasslands, perhaps to the extent that future prairie restoration efforts may require seed inputs beyond what is available from surrounding sources via natural dispersal.

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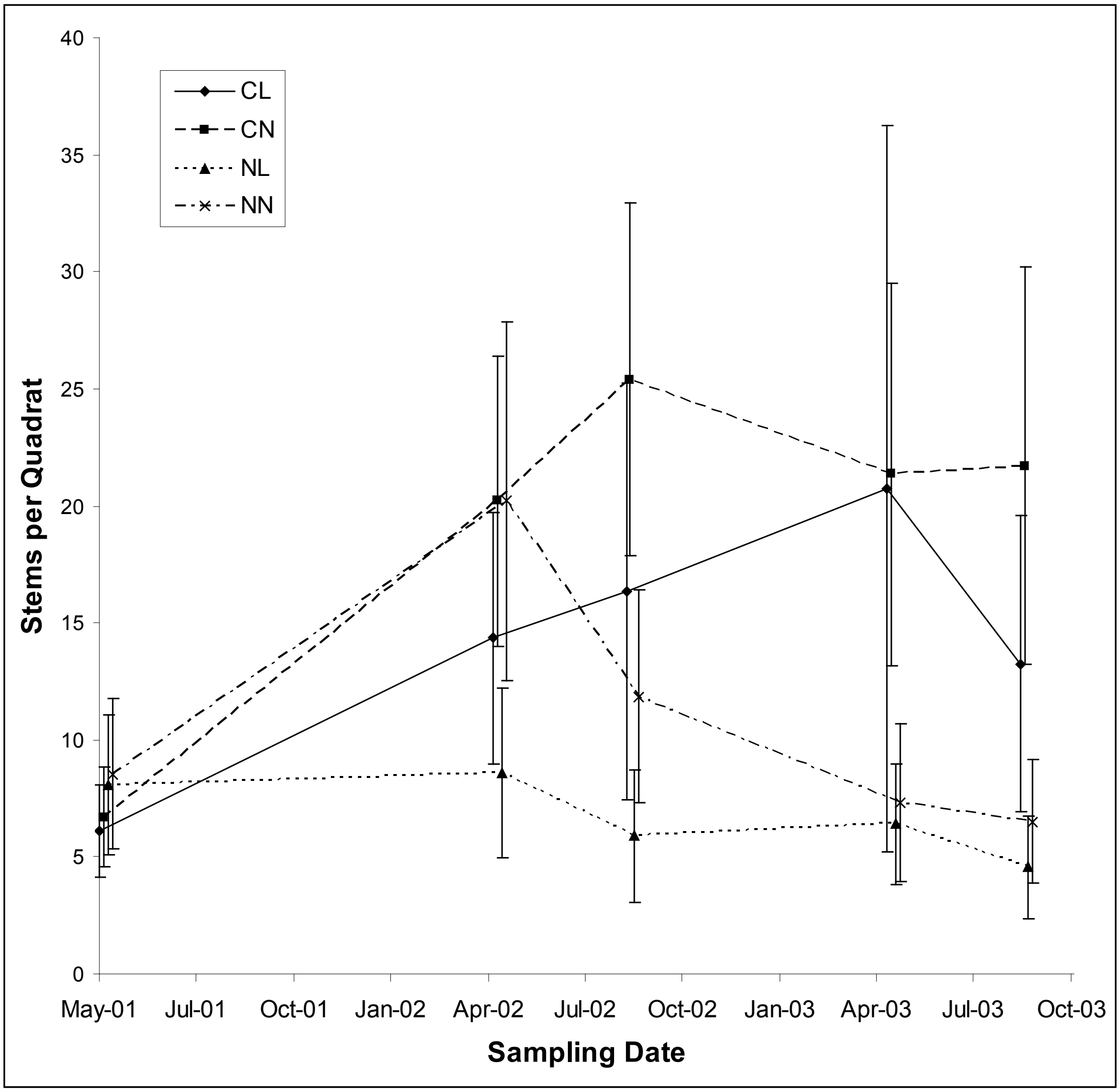

Figure 1 Mean stems per 0.25 m^2quadrat in tree removal and litter removal treatments for 2.5 years. The data points have been staggered to increase visibility of 95% confidence intervals (determined for each treatment at each sampling). CL=cut with-litter, CN=cut with no litter, NL=no cut with litter, NN=no cut with no litter.

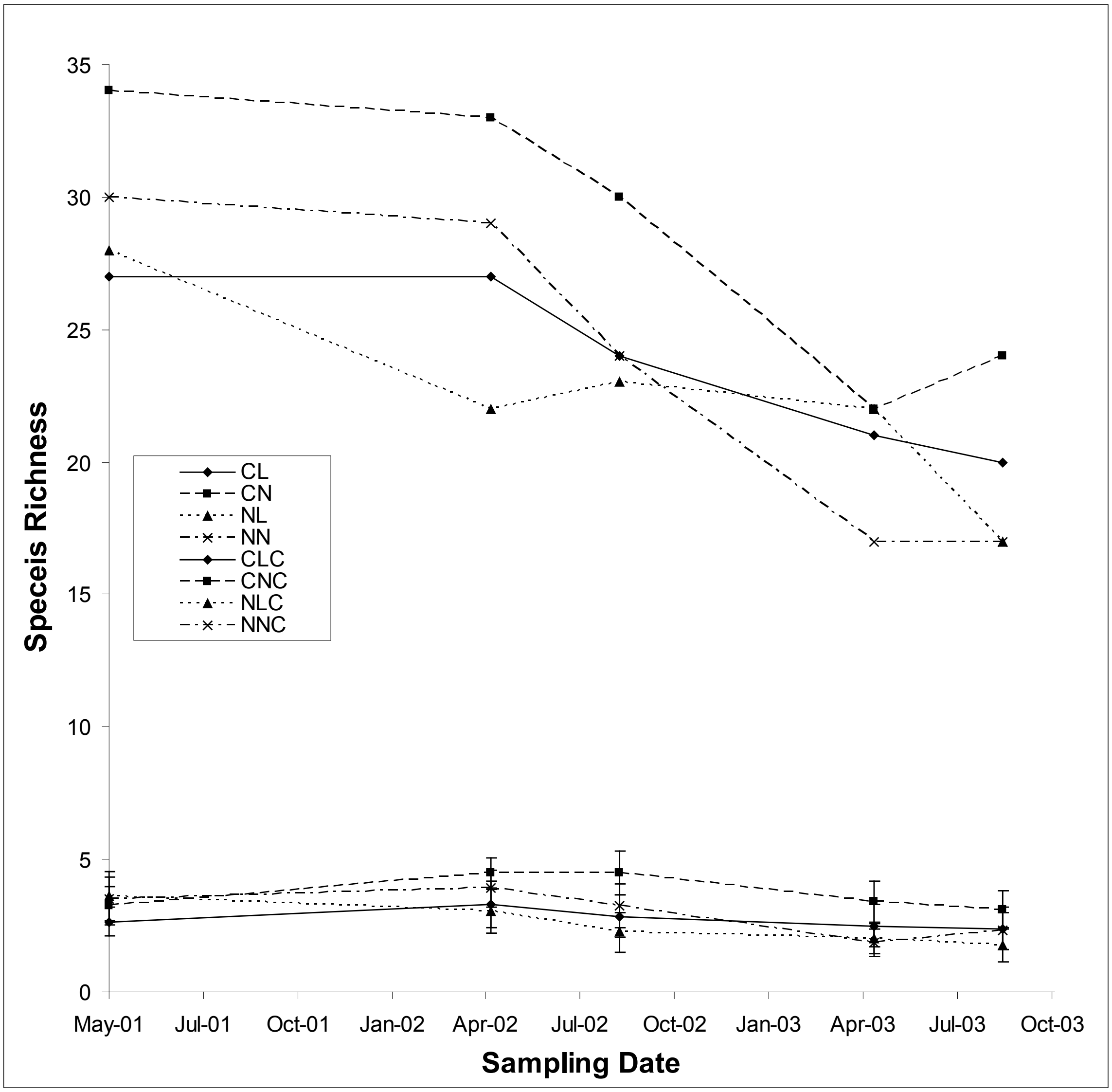

Figure 2 Mean species richness per 0.25 m^2 and cumulative species richness of tree removal and litter removal treatments for 2.5 years. The data points have been staggered to increase visibility of 95% confidence intervals (determined for each treatment at each sampling). CL=cut with litter, CLC=cumulative cut with litter, CN=cut with no litter, CNC=cumulative cut with no litter, NL=no cut with litter, CNL=cumulative no cut with litter, NN=no cut with no litter, CNN=cumulative no cut with no litter of tree removal and litter removal treatments for 2.5 years.

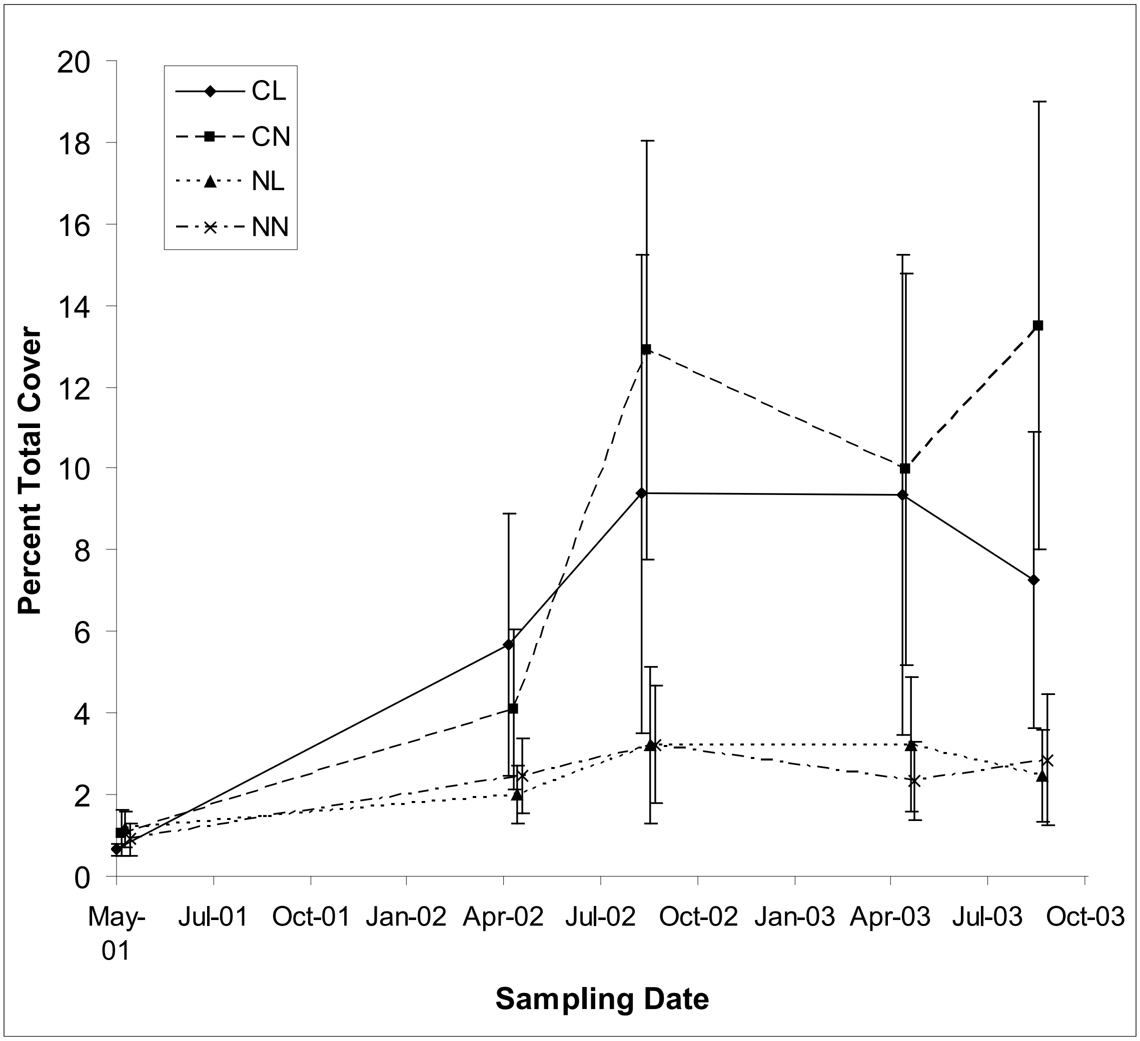

Figure 3 Mean percent total cover of tree removal and litter removal treatments for 2.5 years. The data points have been staggered to increase visibility of 95% confidence intervals (determined for each treatment at each sampling). CL=cut with litter, CN=cut with no litter, NL=no cut with litter, NN=no cut with no litter.

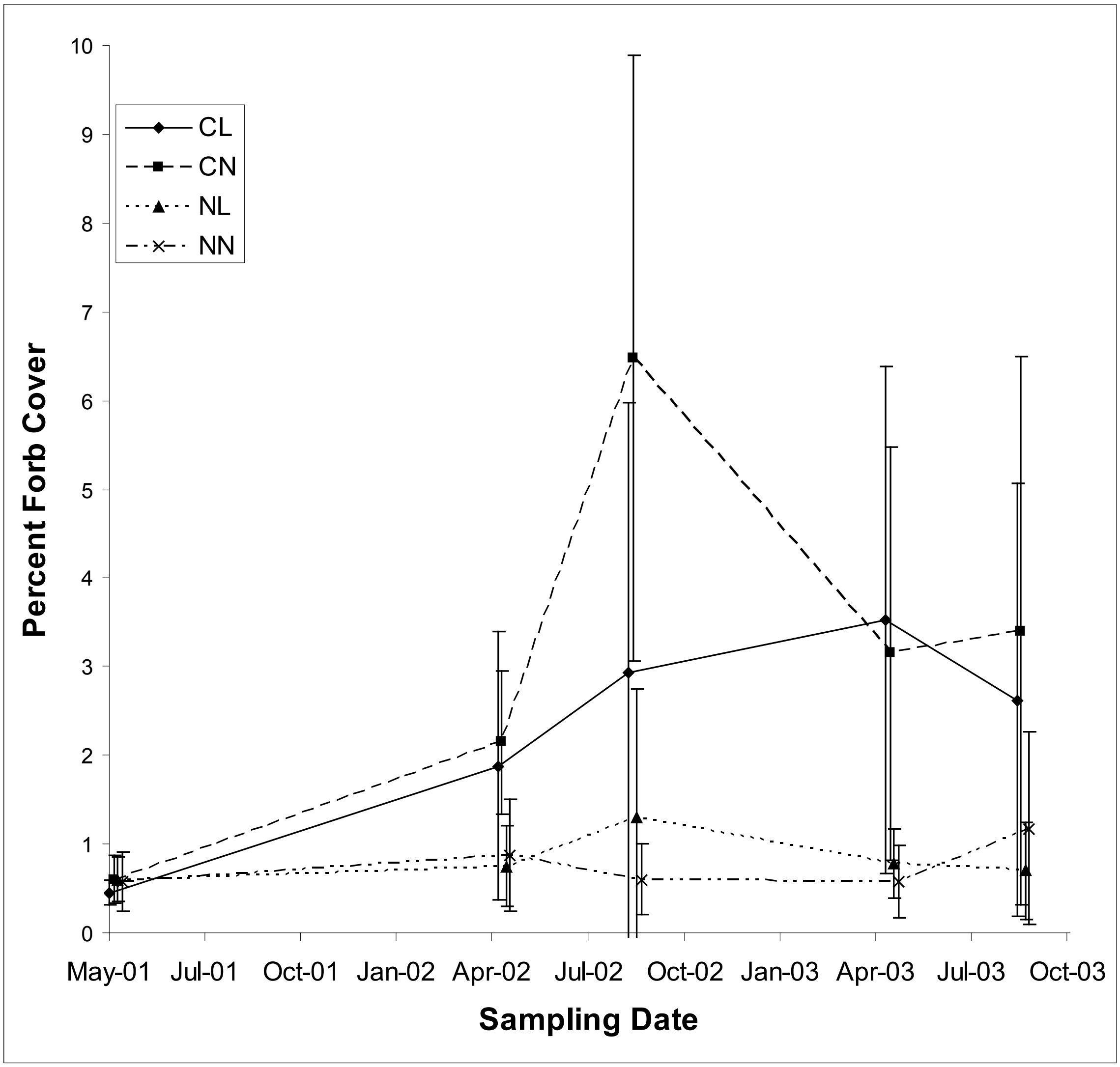

Figure 4 Mean percent forb cover of tree removal and litter removal treatments for 2.5 years. The data points have been staggered to increase visibility of 95% confidence intervals (determined for each treatment at each sampling). CL=cut with litter, CN=cut with no litter, NL=no cut with litter, NN=no cut with no litter.

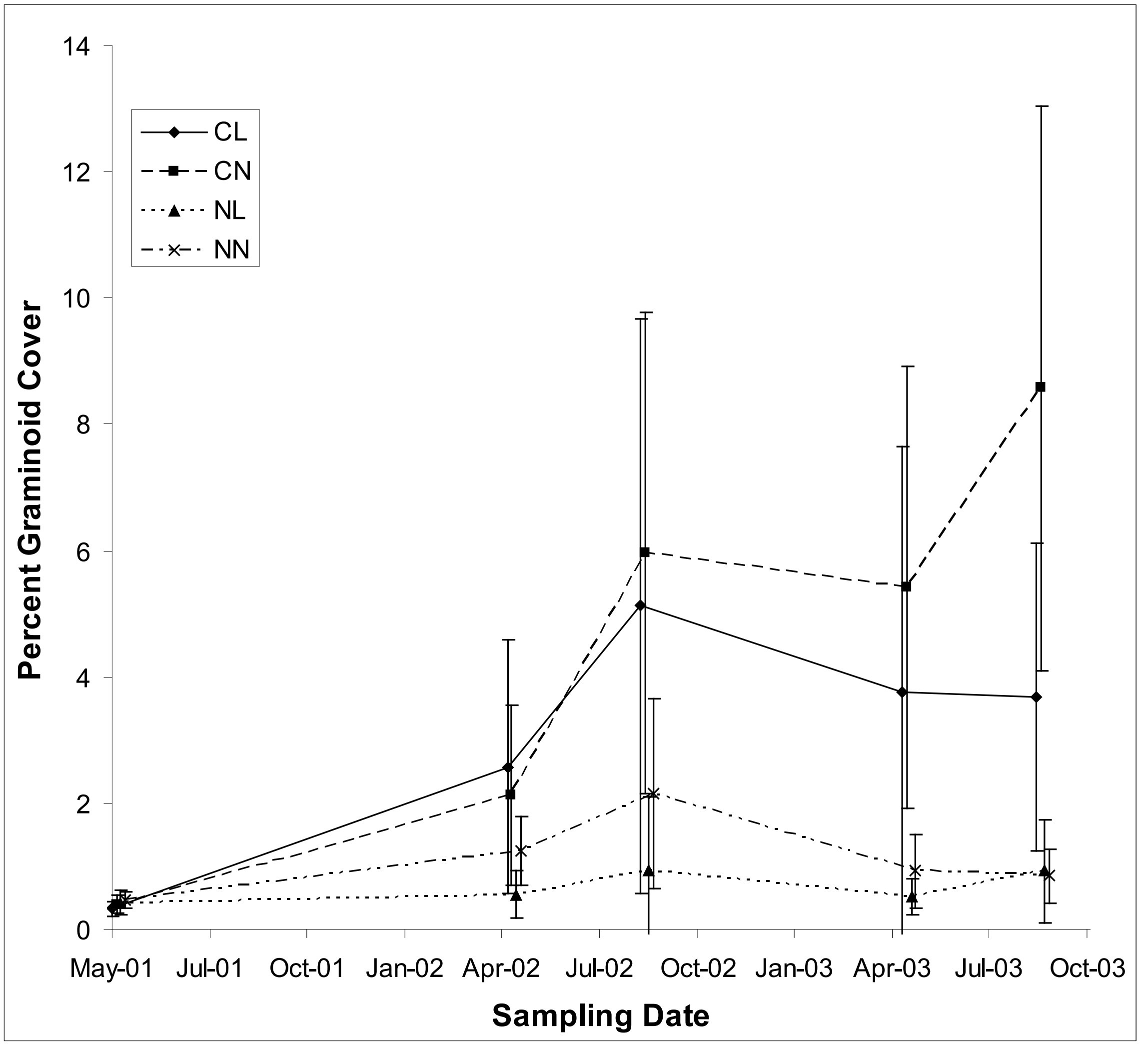

Figure 5 Mean percent graminoid cover of tree removal and litter removal treatments for 2.5 years. The data points have been staggered to increase visibility of 95% confidence intervals (determined for each treatment at each sampling). CL=cut with litter, CN=cut with no litter, NL=no cut with litter, NN=no cut with no litter.

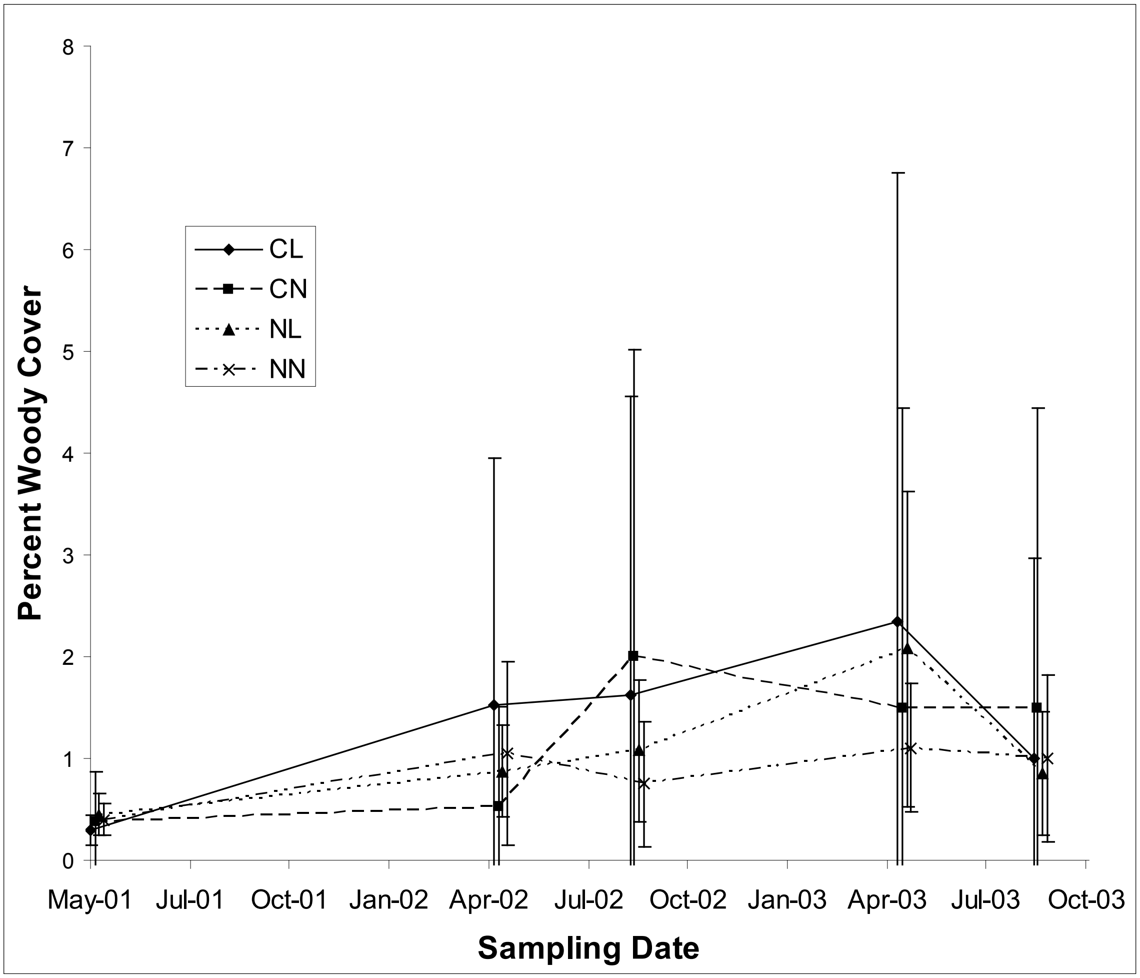

Figure 6 Mean percent woody cover of tree removal and litter removal treatments for 2.5 years. The data points have been staggered to increase visibility of 95% confidence intervals (determined for each treatment at each sampling). CL=cut with litter, CN=cut with no litter, NL=no cut with litter, NN=no cut with no litter.

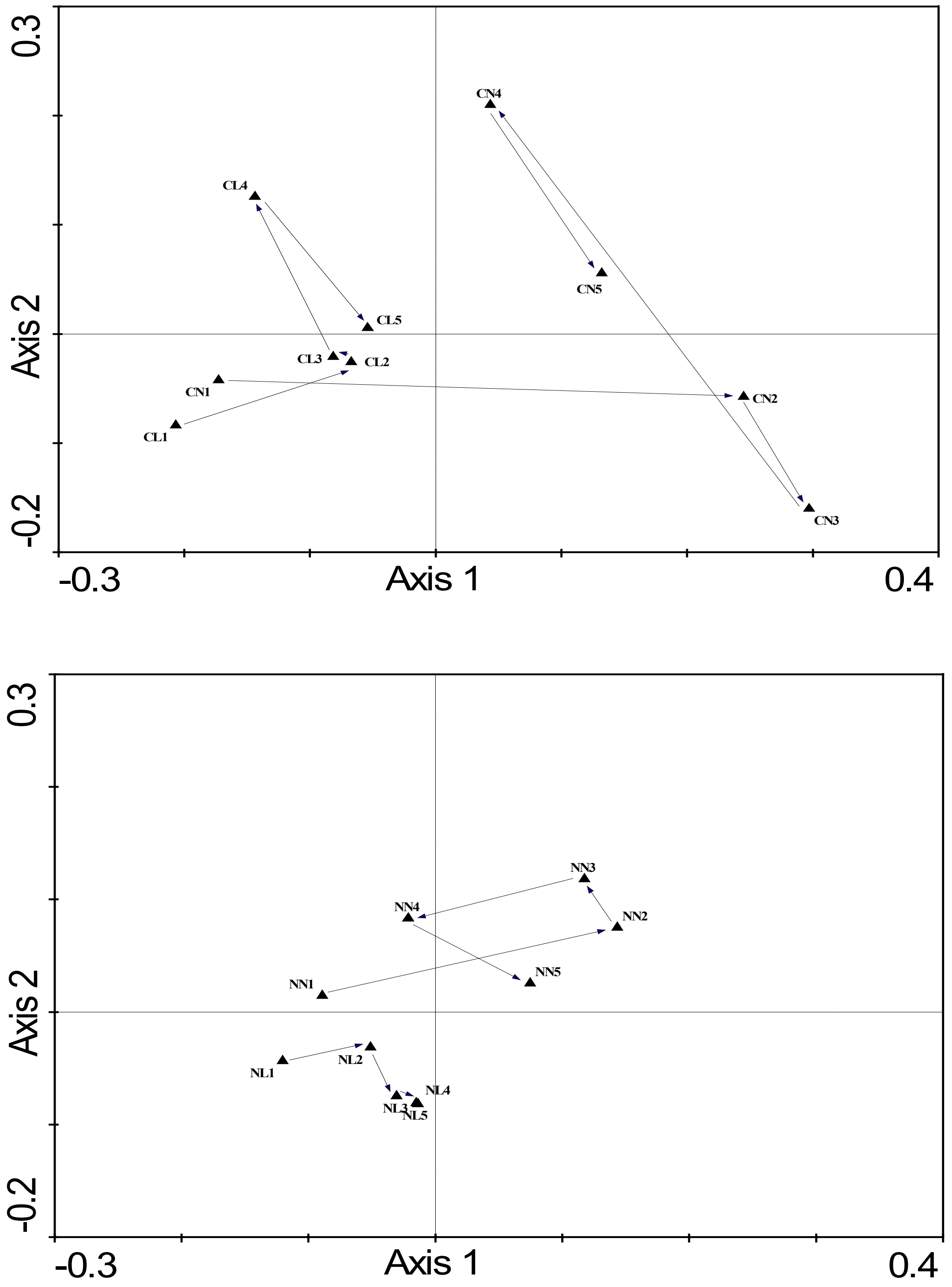

Figure 7 pRDA trajectory of tree and litter removal treatment centroids for each sampling period. The two figures are from the same analysis but were separated to increase legibility. CL=cut with litter, CN=cut with no litter, NL=no cut with litter, NN=no cut with no litter. Axes 1 and 2 are displayed in both figures.

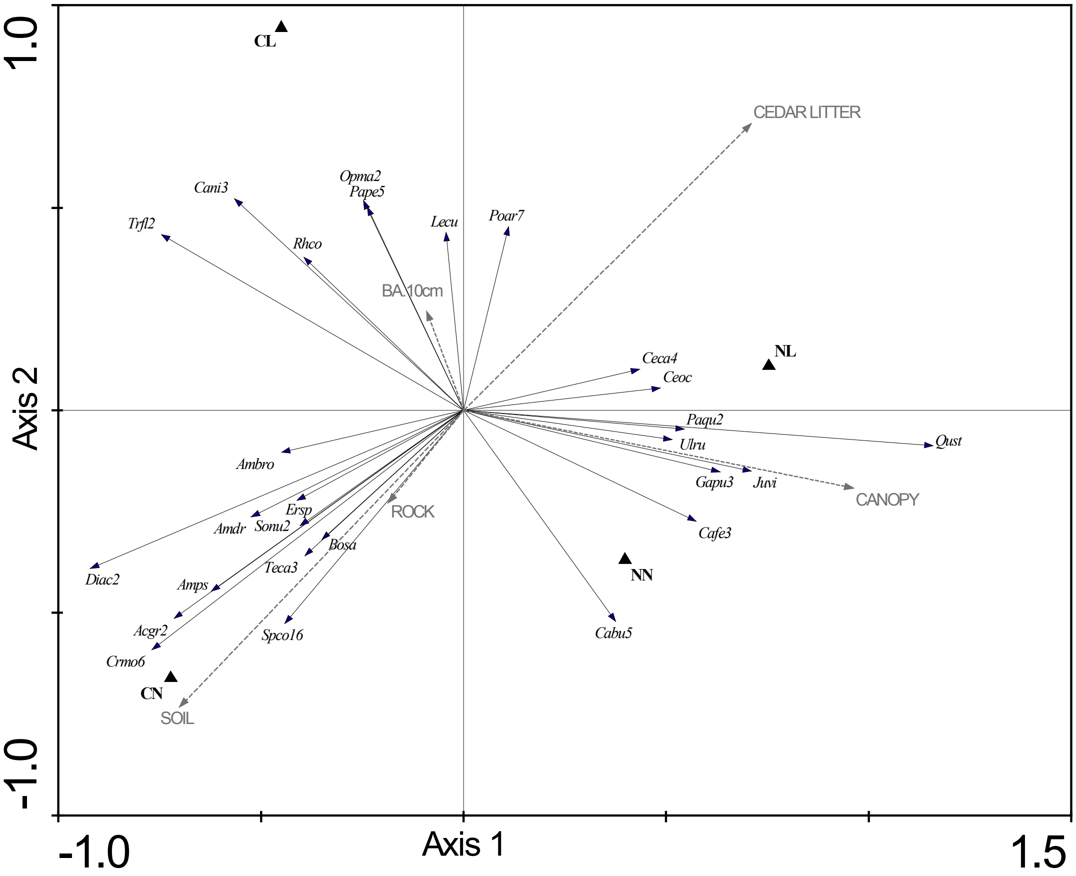

Figure 8 pRDA triplot of species codes, treatment centroids and supplemental environmental variables. All post-treatment samplings are included and axes 1 and 2 are displayed. Species codes represent the relative multi-dimensional position of each species in ordination space based on absolute cover of each species. Species codes are indexed in Appendix 1. Arrow length indicates the relative strength of supplemental variables. CL=cut with litter, CN=cut with no litter, NL=no cut with litter, NN=no cut with no litter.

APPENDIX

Species names and USDA PLANT codes

Species	**USDA Code**
Acalypha gracilens	Acgr2
Ambrosia psilostachya	Amps
Ambrosia sp.	Ambro
Amphiachyris dracunculoides	Amdr
Bothriochloa saccharoides	Bosa
Carex bushii	Cabu5
Carex festucacea	Cafe3
Carex nigromarginata	Cani3
Celtis occidentalis	Ceoc
Cercis canadensis	Ceca4
Croton monanthogynus	Crmo6
Dichanthelium acuminatum	Diac2
Eragrostis spectabilis	Ersp
Gamochaeta purpurea	Gapu3
Juniperus virginiana	Juvi
Lespedeza cuneata	Lecu
Opuntia macrorhiza	Opma2
Oxalis stricta	Oxst
Parietaria pensylvanica	Pase5
Parthenocissus quinquefolia	Paqu2
Quercus stellata	Qust
Rhus copallinum	Rhco
Sorghastrum nutans	Sonu2
Sporobolus compositus	Spco16
Teucrium canadense	Teca3
Tridens flavus	Trfl2
Ulmus rubra	Ulru

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THE CHANGING FORESTS OF CENTRAL OKLAHOMA: A LOOK AT THE COMPOSITION OF THE CROSS TIMBERS PRIOR TO EURO-AMERICAN SETTLEMENT, IN THE 1950S, AND TODAY

Richard E. Thomas
Department of Geography
and Environmental Sustainability
University of Oklahoma
Norman, OK 73019

Bruce W. Hoagland
Department of Geography
and Environmental Sustainability,
Oklahoma Natural Heritage Inventory
University of Oklahoma
Norman, OK 73019

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ABSTRACT

Prior to Euro-American settlement, the Cross Timbers of the Southern Plains marked the edge of "civilization," beyond which lay a prairie ecosystem ruled primarily by Plains Indian tribes. War, trade, and pasture for cattle brought an increased Euro-American presence by the middle of the 19th century. In the early 1870s a large portion of what was to become the state of Oklahoma was surveyed by the General Land Office (GLO). Although these surveys were not conducted for ecological purposes, they have provided information on pre-settlement vegetation that has been invaluable for researchers seeking to reconstruct the historical landscape. Perhaps the most beneficial information for historical ecologists and biogeographers comes from data on bearing trees recorded by GLO surveyors, which have given present-day researchers a good idea of the species composition of Cross Timbers forests during this time. When compared to modern studies of the Cross Timbers, it documents a change in species composition over time, believed to be the result of fire suppression and perhaps the beginning of a wetter climate cycle. In central Oklahoma, this has meant a shift from forests dominated by *Quercus marilandica* and *Quercus stellata* (with the former being more abundant) to forests containing an equal abundance of these two species, and an increase in *Carya texana*, *Juniperus virginiana*, and other mesophytic and invasive woody species.

INTRODUCTION

Cross Timbers Overview

The Cross Timbers are a mosaic of riparian forest, woodland, and grassland that extends from southeastern Kansas, through Oklahoma, and into north-central Texas (Dyksterhuis 1948 and 1957, Rice and Penfound 1959, Omernik 1987, Hoagland et al. 1999, Francaviglia 2000; Figure 1). The Cross Timbers encompass an estimated 4.8 million ha in this region (Kuchler 1964). Slightly more than half of the total area (2.5 million ha) is located in Oklahoma, where it comprises a larger area than all other forest types in Oklahoma combined (Duck and Fletcher 1945; Rice and Penfound 1959; Dwyer and Santelman 1964). As a result, the Cross Timbers are the most studied forest type in Oklahoma.

These studies note the importance of *Quercus stellata* (post oak) and *Q. marilandica* (blackjack oak) in Cross Timbers stands. Combined, these two species constitute over 90% of the canopy cover and 50% of the basal area (Rice and Penfound 1959, Kennedy 1973). *Q. marilandica* is the more xeric and fire-tolerant of the two species (Brown and Davis 1973; Givnish 1981; Dooley 1983; Dooley and Collins 1984). Stem density (number of

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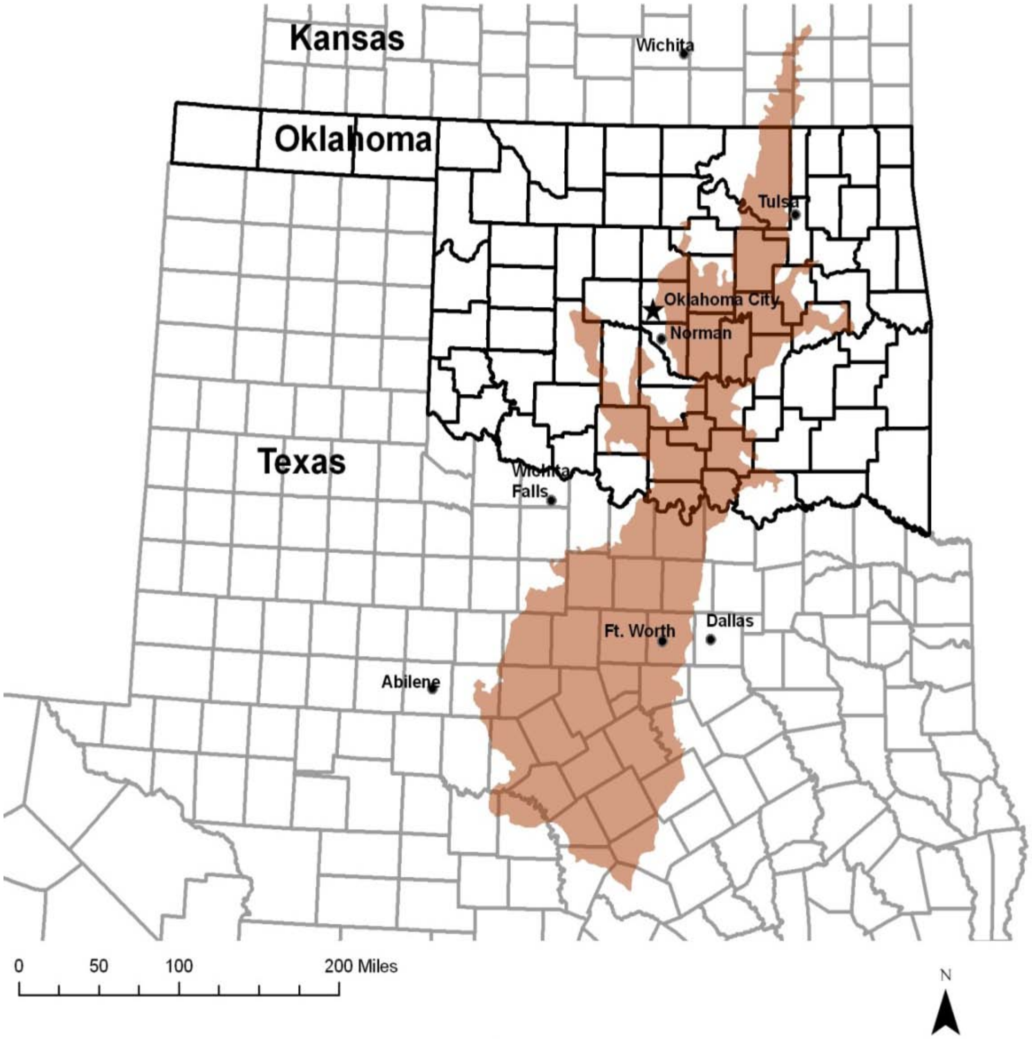

Figure 1 The present-day Cross Timbers (from Omernik, 1987).

stems per unit area) is correlated with slope, aspect, and/or geographic location, but the ratio of *Q. stellata* to *Q. marilandica* has generally ranged from 2:1 to 3:1, (Luckhardt and Barclay 1938, Kennedy 1973). Although stem density of *Q. marilandica* may surpass *Q. stellata* on south-facing slopes, *Q. marilandica* rarely exceeds 30 cm in diameter and, therefore, basal area values of the two species are roughly equivalent in these instances (Luckhardt and Barclay 1938, Rice and Penfound 1955, 1959).

Woody species of secondary importance include *Carya texana* (black hickory), *Quercus velutina* (black oak), and *Juniperus virginiana* (eastern redcedar) (Coppock et al. 1955, Hale 1955, Rice and Penfound 1955 and 1959, Penfound 1963, Johnson and Risser 1972, Hoagland et al. 1999). The herbaceous understory of the Cross Timbers, which becomes more prevalent in the woodland aspect, is similar to the surrounding prairie (Dyksterhuis, Kuchler 1964 and 1974). *Schizachyrium scoparium* (little bluestem) dominates most Cross Timbers stands, but *Andropogon gerardii* (big bluestem) and *Sorghastrum nutans* (Indiangrass) may be co-dominant (Kuchler 1964).

The Changing Cross Timbers

Three major factors influencing the Cross Timbers region today are urban fringe development, woody plant encroachment, and the "mesophication" of *Quercus*-dominated portions of the Cross Timbers (Coppedge 2001a; Dillard et al. 2006, DeSantis et al. 2010). Urban fringe development (UFD) is currently more geographically ubiquitous in the mainland United States than any other human activity that negatively impacts ecosystems (Czech et al 2000). UFD produces some of the highest local extinction rates and often eliminates most of the native species (Vale and Vale 1976, Luniak 1994, Kowarik 1995, Marzluff 2001, McKinney 2002). Biological communities around these areas are increasingly homogenized (McKinney 2004), producing a "distinct and rapid trajectory of vegetation change towards historically unprecedented and simplified conditions" in some regions (Schulte et al. 2007).

In their study of landscape structure and change within a forest-prairie ecotone, Boren et al. (1997) indicated that increased human activity in densely populated rural areas surrounding urban centers in northern Oklahoma lowered biodiversity, increased homogeneity, and resulted in greater patch fragmentation than a rural landscape with a low-density population. Fragmentation was higher in forested areas than in grasslands in each year of their twenty-four year study, in both low- and high-density areas.

In Oklahoma, the main culprit in woody plant expansion is *Juniperus virginiana* (eastern redcedar), a native species that has advanced beyond its pre-settlement range and density in the Great Plains and portions of the Cross Timbers (Engle et al. 1997, Coppedge et al. 2001b, Briggs et al. 2002, Horncastle et al. 2005). Encroachment at a rate of 300,000 acres per year in Oklahoma (Drake and Todd 2001) by *J. virginiana* has many negative consequences, including displacement of native plant species (Engle et al. 1997, Cooper 1998, Coppedge et al. 2002), wildlife species (Engle et al. 1997, Smith 2001, Guthery 2001, Coppedge et al. 2002), a decrease in livestock forage production (Stritzke and Bidwell 1989, Engle and Stritzke 1992, Engle et al. 1997), and a deterioration of water quality (Thurow and Carlson 1994, Cooper 1998).

In a recent study, DeSantis et al. (2010) make the contention that drought and fire suppression are changing the woody species composition of relatively undisturbed portions of the Cross Timbers in Oklahoma. They indicate that woodland portions of the Cross Timbers "appear to be in transition to closed-canopy mesophytic forest stands with less *Quercus* and more shade-tolerant tree species." In their study, they draw heavily on the work of Nowacki and Abrams (2008), who coined the term "mesophication," which they define as a process "whereby microenvironmental conditions (cool, damp, and shaded conditions; less flammable fuel beds) continually improve for shade-tolerant mesophytic species and deteriorate for shade-intolerant, fire-adapted species." According to the authors, this process is widespread in the forests of North America as a result of fire suppression.

This study sought to characterize Cross Timbers forest and woodland in an urban area in central Oklahoma, focusing specifically on Cross Timbers vegetation that had undergone little visible disturbance (i.e. few invasive species present, trees of varying ages). The area chosen for this was the southeast sector of Oklahoma City, the least developed portion of the city. As a baseline for comparison, General Land Office (GLO) Public Land Survey (PLS) bearing tree data from the 1870 to 1873 survey were analyzed. This analysis relied on results produced in Thomas (2010), which contradict previous analyses of the Cross Timbers in Oklahoma (Shutler and Hoagland 2004, Fagin 2009), but are in line with primary historical sources along with past and present research on the woody plant composition of the Oklahoma Cross Timbers.

STUDY AREA

The southeast sector of Oklahoma City is almost equally divided between Oklahoma and Cleveland counties in central Oklahoma, with a portion falling in Pottawatomie County (Figure 2). Average temperature is around 15° C, ranging from an average January low of -3° C to an average July high of 34° C. Average annual precipitation ranges between 91 and 99 cm, and winds from the south and southeast predominate (OCS 2009).

Cross Timbers forest and woodland in the study area is found on the Darnell-Stephenville soil series, which is made up of moderately deep, well-drained, moderately permeable upland soils with slight to moderate slopes (Fisher and Chelf 1969).

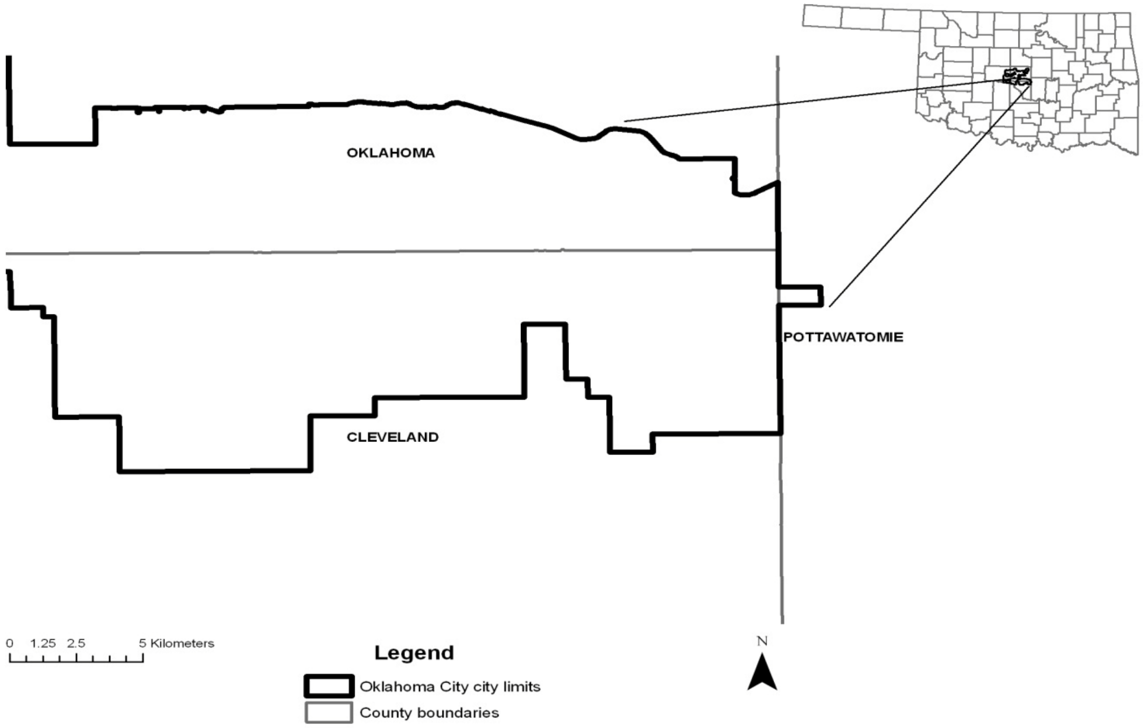

Figure 2 Study area – southeastern Oklahoma City.

METHODS

The Public Land Surveys

The PLS, conducted in the United States beginning with the Land Ordinance of 1785, subdivided land into square townships six miles on a side, which were further subdivided into thirty-six sections of one square mile (Stewart 1935). Surveyors would travel along the section lines, erecting monuments at the intersections of section lines and making notes about the landscape, soil, and vegetation in order to draw an accurate plat of the township following the survey (Bourdo 1956). Surveyors were also instructed to list tree species encountered in order of predominance at the end of each section line, known as "ranked timber observations" (Bourdo 1956, Grimm 1981).

In order to facilitate the relocation of a section corner, at the intersection of section lines the surveyors would record the distance, direction, species, and diameter of four near and "durable" trees. One tree was recorded in each quadrant formed by the intersection of the section lines (Grimm 1981). These were known as bearing trees and were inscribed by the surveyors. Two trees were also marked as bearing trees at the half-mile interval between the intersections of section lines (Bourdo 1956, Fagin and Hoagland 2002, Figure 3).

Since the 1873 bearing tree data was not taken in individual plots, relative frequency (RF) was not calculated, and relative basal area (RBA) and relative density (RD) were combined to provide an importance value (IV).

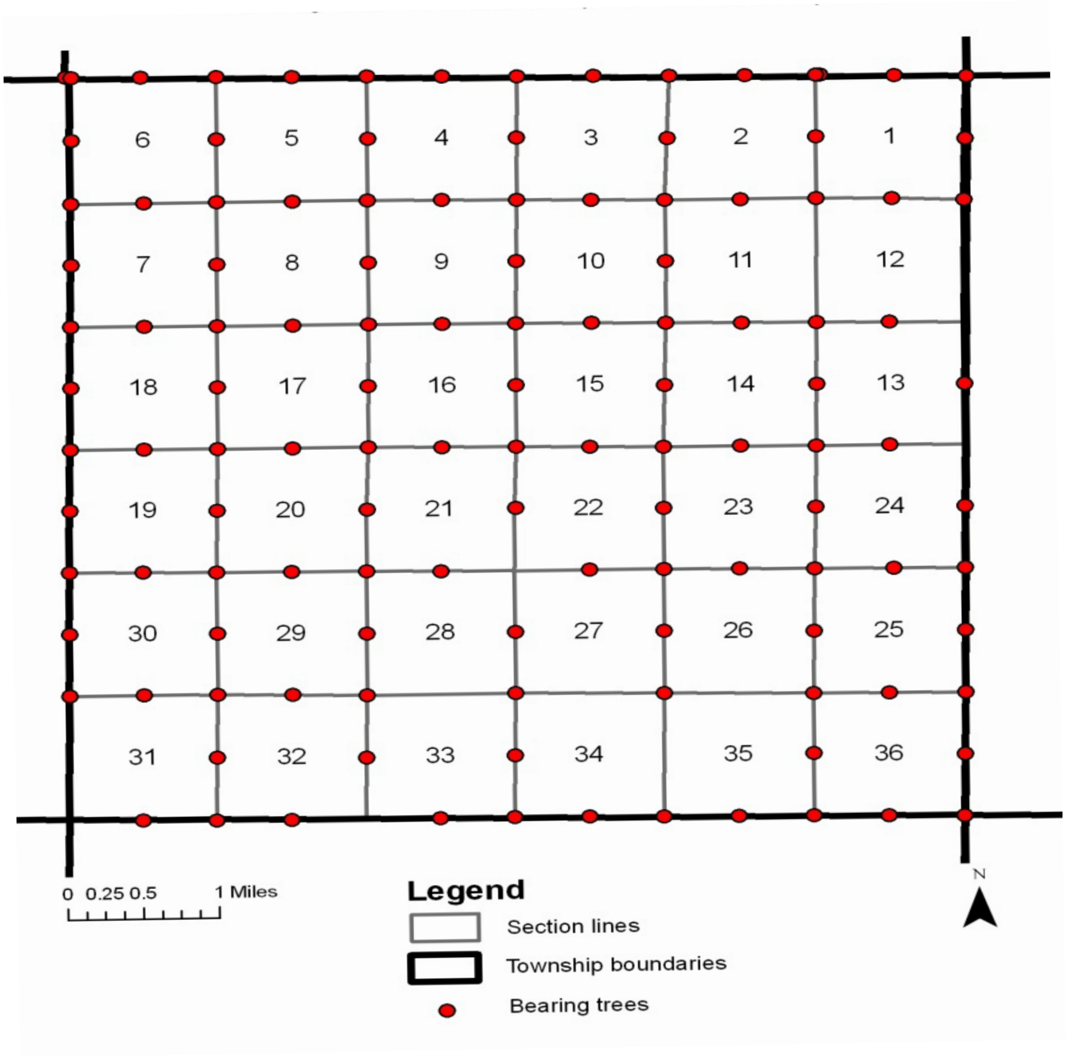

Figure 3 Bearing trees noted at the intersection of section lines and at halfway points along the section lines.

Contemporary vegetation

The first stage of analysis was the interpretation and delineation of forest vegetation in the study area using four Digital Orthoquarter Quads (DOQQs) from June 2006. Each DOQQ was imported into Arcmap GIS and joined into a complete coverage. The resulting layer was reviewed and forest vegetation delineated, resulting in a map of either "potential" or "probable" undisturbed Cross Timbers.

Ground-verification of the preliminary map began in the winter of 2007 and consisted of two phases. First, sites were visited to determine the accuracy of the initial disturbance designations of potential or probable. Sites that were verified as or upgraded to probable were then considered for the collection of quantitative vegetation data pending contact with and approval of the landowner. Following the verification of the accuracy of these designations, field studies commenced in order to characterize the structure and species composition of forest/woodland vegetation at these sites, using twenty-by-twenty meter plots. Where possible, multiple plots were established at a site. However, collection of quantitative data even at "probable" sites was somewhat limited by low quality of vegetation and access restrictions. Each tree and shrub was identified to species (nomenclature follows the US Department of Agriculture-Natural Resources Conservation Service [USDA-NRCS 2006]) and stems exceeding 7.5 cm diameter-at-breast-height (DBH) were measured within plots, so that this data could be compared to the PLS bearing tree data, as few trees below this size were marked by GLO surveyors. Basal area (BA) was calculated for each species in each plot using the formula Area=Πr^2. Relative Basal Area (RBA) was calculated as:

$$(\sum BA_{\text{species I}} / \sum BA_{\text{all species}}) \text{ X } 100 = RBA$$

Density (D) was defined as the number of stems for each species occurring in a plot. Relative density (RD) was calculated as:

$$(\sum D_{\text{species I}} / \sum D_{\text{all species}}) \text{ X } 100 = RD$$

Frequency was defined as the number plots in which a species occurred. Relative Frequency (RF) as calculated as:

$$(\sum FREQ_{\text{species I}} / \sum FREQ_{\text{all species}}) \text{ X } 100 = RF$$

An importance value (IV) was calculated for each species in order to determine which trees were stand dominants:

$$IV = RBA + RD + RF$$

RESULTS

Public Land Survey

A total of 608 trees were recorded by PLS surveyors within the study area. Ten different species were recorded. Of these, 397 individuals were *Q. marilandica* and 182 were *Q. stellata*. Fourteen stems of *Ulmus sp.* were recorded, but no other species was recorded more than three times. *Q. marilandica* had a total basal area of 9.76 m², *Q. stellata* 16.37 m². No other species had a total basal area over 1 m². The highest importance values for 1873 bearing tree data were scored by *Q. marilandica* at 100.89 and *Q. stellata* at 89.65 (Table 1). The importance values of other species marked as bearing trees were very low. *Ulmus* sp. had an importance value of 3.29, *Carya texana* 2.87 and *Populus deltoides* 1.20. Public land surveyors also reported finding *Fraxinus nigra* (black ash), a species native to northeastern North America and not found in Oklahoma. It is likely that different common names applied to species at the time resulted in this anomaly.

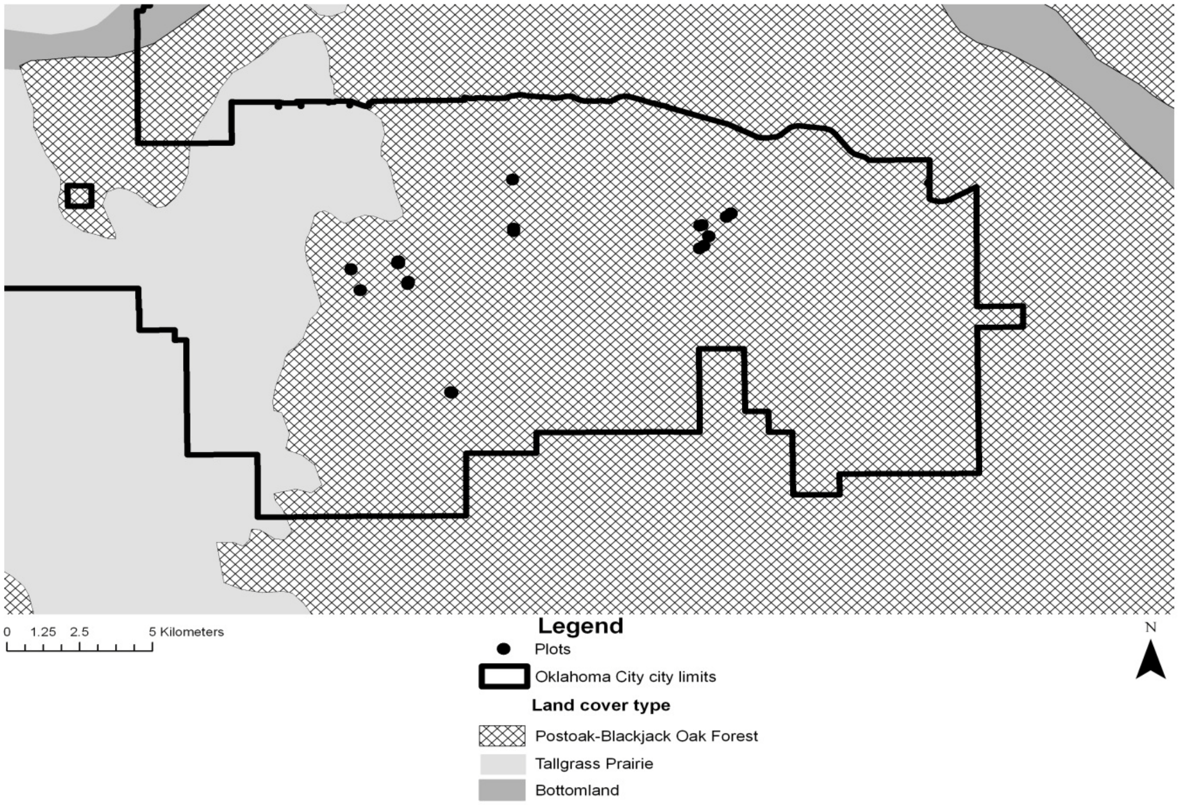

Figure 4 Locations of vegetation plots on sites within the study area.

Contemporary Vegetation

Vegetation was quantified using a total of twenty-two plots (some in close proximity) on about ten sites (Figure 4). A total of 944 stems with a diameter of at least 7.5 cm were sampled. Stem diameters ranged from the minimum of 7.5 cm to 55.5 cm, with a mean diameter of 15.21 cm and a median diameter of 13 cm. Eighteen woody plant species were encountered (Table 2). The most common were *Quercus marilandica* (blackjack oak), *Quercus stellata* (post oak), *Carya texana* (black hickory), and *Juniperus virginiana* (eastern redcedar), respectively. Four hundred and two stems of *Q. marilandica* were recorded, ranging in diameter from 7.5 cm to 42 cm, with a mean diameter of 14.3 cm and a median diameter of 13 cm. Three hundred ninety-four stems of *Q. stellata* were recorded, ranging in diameter from 7.5 cm to 55.5 cm, with a mean diameter of 16.49 cm and a median diameter of 14.5 cm. Forty-two stems of *C. texana* were recorded, ranging in diameter from 7.5 cm to 44 cm, with a mean diameter of 17.55 cm and a median diameter of 16.25 cm. Twenty-four stems of *J. virginiana* were recorded, ranging in diameter from 7.5 cm to 22 cm, with a mean diameter of 12.46 cm and a median diameter of 12 cm.

The highest importance values were scored by *Q. stellata* at 115.26 and *Q. marilandica* at 96.33 (see Table 2). *C. texana* at 20.12 and *J. virginiana* at 14.49 fell far below these two dominant oaks. Other notable species include *Ulmus rubra* (Slippery elm) at 9.45 and *Celtis occidentalis* (common hackberry) at 6.31.

Plot total basal area values ranged from 0.66 m^2 to 1.88 m^2 (mean 0.95 m^2, median 0.88 m^2, standard deviation 0.28 m^2). The highest basal area values were reported for trees dominant in the Cross Timbers in the following order: *Q. stellata* > *Q. marilandica* >

C. texana. *Q. stellata* had the highest frequency (22), followed by *Q. marilandica* (19), *J. virginiana* (10), and *C. texana* (9) (see Table 2). Mean basal area for *Q. stellata* was 0.506 m²/plot, median basal area 0.38 m²/plot (range = 0.057 m² to 1.876 m², standard deviation 0.474 m²), mean basal area for *Q. marilandica* was 0.343 m²/plot, median basal area 0.305 m²/plot (range 0.0 m² to 0.765 m², standard deviation 0.252 m²), mean basal area for *C. texana* was 0.064 m²/plot, median basal area 0.0 m²/plot (range 0.0 m² to 0.506 m², standard deviation 0.168 m²), and median basal area for *J. virginiana* was 0.017m²/plot, median basal area 0.004 m²/plot (range 0.0 m² to 0.133 m², standard deviation 0.038 m²).

Plot density values ranged from 20 to 65 (mean = 42.91, median = 43, standard deviation = 15.16). The highest density values were for *Q. marilandica* with 21.16 stems/plot (range 0 to 56, median 25, standard deviation 16.3), *Q. stellata* with 17.91 stems/plot (range 1 to 56, median 17.5, standard deviation 17.16), *C. texana* with 4.67 stems/plot (range 0 to 13, median 0, standard deviation 3.84), and *J. virginiana* with 2.4 stems/plot (range 0 to 11, median 1, standard deviation 3.10).

Table 1 Species scores for bearing trees that fell within the boundaries of the study area from the 1873 PLS data. DEN = total number of stems, BA = total basal area in study area (m^2), RD = relative density, RBA = relative basal area, and IV = importance value.

1873 Bearing trees	DEN	BA (m²)	RD	RBA	IV
Quercus marilandica	397	9.76171	65.29605	35.59868	100.8947
Quercus stellata	182	16.3742	29.93421	59.71289	89.6471
Ulmus sp.	14	0.270201	2.302632	0.98536	3.287992
Carya texana	2	0.697738	0.328947	2.544488	2.873435
Populous deltoides	3	0.194575	0.493421	0.70957	1.202991
Salix sp.	3	0.04915	0.493421	0.179239	0.67266
Juglans nigra	3	0.020775	0.493421	0.075762	0.569183
Fraxinus nigra	2	0.016214	0.328947	0.059129	0.388076
Celtis occidentalis	1	0.032429	0.164474	0.118261	0.282735
Cercis canadensis	1	0.00456	0.164474	0.016629	0.181103

Table 2 Species scores for woody plants in the twenty-two plots sampled. FRQ = frequency, RF = relative frequency, BA = total basal area in study area (m^2), MPLT = median basal area/plot (m^2), RBA = relative basal area, DEN = total number of stems, MSTM = average density/plot, RD = relative density, and IV = importance value.

Species	**FRQ**	**RF**	**BA**	**MPLT**	**RBA**	**DEN**	**MSTM**	**RD**	**IV**
Quercus stellata	22	22.92	10.6	0.481	50.61	394	17.91	41.74	115.26
Quercus marilandica	19	19.8	7.112	0.374	33.95	402	21.16	42.58	96.33
Carya texana	9	9.38	1.319	0.147	6.3	42	4.67	4.45	20.12
Juniperus virginiana	10	10.42	0.321	0.032	1.53	24	2.4	2.54	14.49
Ulmus rubra	5	5.21	0.445	0.089	2.12	20	4	2.12	9.45
Celtis occidentalis	4	4.17	0.183	0.046	0.87	12	3	1.27	6.31
Quercus muhlenbergii	3	3.13	0.202	0.067	0.96	14	4.67	1.48	5.57
Morus alba	4	4.17	0.173	0.043	0.83	4	1	0.42	5.42
Carya illinoinensis	3	3.13	0.196	0.065	0.94	4	1.33	0.42	4.48
Prunus mexicana	3	3.13	0.101	0.034	0.48	4	1.33	0.42	4.03
Cercis canadensis	3	3.13	0.033	0.011	0.16	5	1.67	0.53	3.81
Viburnum rufidulum	3	3.13	0.051	0.017	0.24	3	1	0.32	3.69
Morus rubra	2	2.08	0.102	0.051	0.49	7	3.5	0.74	3.31
Prunus angustifolia	2	2.08	0.052	0.026	0.25	5	2.5	0.53	2.86
Celtis laevigata	1	1.04	0.028	0.028	0.13	1	1	0.11	1.28
Sideroxylon lanuginosum	1	1.04	0.013	0.013	0.06	1	1	0.11	1.21
Quercus macrocarpa	1	1.04	0.01	0.01	0.05	1	1	0.11	1.19
Diospyros virginiana	1	1.04	0.005	0.005	0.02	1	1	0.11	1.17

DISCUSSION

Two previous studies that have utilized PLS bearing tree data from the Cross Timbers of central Oklahoma provide apt comparison here. Shutler and Hoagland (2004) reported that PLS surveyors sampled 6886 stems in Carter County in the early 1870s, with *Quercus stellata* (2,648 stems) and *Quercus velutina* (1,740 stems) being the two most abundant species by far, and only 18 stems of *Quercus marilandica* recorded. Fagin (2009) reported that PLS surveyors sampled 2,578 trees in the Arbuckle Mountains of south-central Oklahoma in the early 1870s, recording 1,234 stems of *Q. stellata* and 529 stems of *Q. velutina*. These reports would indicate that the composition of Cross Timbers forests in central Oklahoma were drastically different than they are today. However, Thomas (2010) demonstrated that the stems labeled as "black oak" by the PLS surveyors and assumed to be *Q. velutina* in these studies were almost certainly *Q. marilandica*. "Black oak" was another common name for blackjack oak, and references to *Q. velutina* are almost completely absent from any historical accounts of the Cross Timbers. "Blackjack oak" (*Q. marilandica)*, on the other hand, is almost universally present in these accounts.

Even so, it still appears that in south-central Oklahoma *Q. stellata* was twice as abundant as *Q. marilandica* during the first PLS in Oklahoma in the early 1870s. The 2:1 ratio of *Q. stellata* to *Q. marilandica* at the time seems to demonstrate that the Cross Timbers of south-central Oklahoma contained more mesophytic vegetation than the Cross Timbers found in Oklahoma and Cleveland counties in central Oklahoma, where a ~ 1:2.2 ratio of *Q. stellata* to *Q. marilandica* was reported by the PLS surveyors in the early 1870s. *Carya texana* was also much more abundant in south-central Oklahoma as well, with 118 stems reported by Fagin (2009), but only two recorded by PLS surveyors in Oklahoma and Cleveland counties. This further lends credence to the idea that the Cross Timbers in Carter County and the Arbuckle mountains contained more mesophytic vegetation than those in Cleveland and Oklahoma counties, perhaps as a result of protection from prairie fires, as prairie fires select for fire-tolerant species in environments that would ordinarily trend toward a more mesophytic species composition (Thomas 2010).

In their study of the upland forests of Oklahoma, Rice and Penfound (1959) sampled three sites in Oklahoma County and three sites in Cleveland County (for their sampling methods see Hoagland and Hough 2008). In Oklahoma County they recorded 39 stems of *Q. stellata* and 137 stems of *Q. marilandica*. In Cleveland County they recorded 66 stems of *Q. stellata*, 129 stems of *Q. marilandica*, 10 stems of *C. texana,* and 7 stems of *Q. velutina* (Hoagland and Hough 2008). This ~1:2.5 ratio of *Q. stellata* to *Q. marilandica* is much more in line with the ~1:2.2 ratio recorded by PLS surveyors in the early 1870s than with the ~1:1 ratio recorded in the current study.

However, with the reports of *C. texana* and *Q. velutina* by Rice and Penfound (1955, 1959), we begin to see the results of the "mesophication" of the Cross Timbers noted by this study and by DeSantis et al. (2010). As mentioned in the introduction, this mesophication process is believed to occur as a result of fire exclusion, which "can alter stand structure and create microclimatic conditions that are more beneficial to mesophytic woody species" (DeSantis et al. 2010). In his study, DeSantis (2010) re-sampled 30 forest stands originally sampled by Rice and Penfound (1959) and noted substantial increases in the abundance of *C. texana*, *Juniperus virginiana*, and *Q. stellata*, while *Q. marilandica* declined in abundance. These results are consistent with this study, as we recorded a large increase in *C. texana* and the fire-intolerant *J. virginiana* since the 1870s PLS, and the replacement of

Q. marilandica by the less fire-tolerant *Q. stellata* as the most important species in the Cross Timbers of central Oklahoma.

CONCLUSION

It is apparent from this study and other studies conducted in the Cross Timbers and in *Quercus* forests worldwide that the dominance of *Quercus*, especially those species at the xeric end of the spectrum, is in decline. Fire exclusion seems to be a plausible mechanism, and with the pace of urban, suburban, and ex-urban development the urgency and necessity of fire exclusion will only continue to expand in coverage. Thus, there will likely be nothing to check the mesophication trend in *Quercus*-forests, save greatly altered land management practices. Noting these trends, future studies might attempt to document what changes in woody species composition mean for other flora and fauna found in *Quercus*-dominated forests. Documenting changes such as these might increase the urgency for conservation and preservation practices in the Cross Timbers ecoregion.

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SOME THOUGHTS ON OKLAHOMA PLANTS AND SUMMER 2011'S EXCEPTIONAL DROUGHT

Leslie E. Cole, D.V.M.

Oklahoma has just had a summer of incredible heat and exceptional drought (D4), the worst such designation possible from the National Drought Monitor and marked by a menacing dark red on the drought maps they make. The impacts of this tough climate event can be seen everywhere one looks from the dormant or dead Blackjacks and Eastern Redcedars to the thin young crows, and felt in the economy and our communities.

We can set the stage for these musings by quoting Mr. Gary McManus, Associate State Climatologist, Oklahoma Climatological Survey.

> Oklahoma is "… just coming off one of our driest you-name-the-period on record. The current drought originated in September 2010 with the arrival of La Nina in the equatorial pacific waters. This water year, which ended September 2011, finished as the second driest on record for Oklahoma with a statewide average precipitation total of 20.26 inches, 16.43 inches below normal. The driest such period on record was 18.69 inches from the 1955-1956 water year. For the Panhandle, west central, central and southwestern parts of the state, it was easily the driest water year on record. Southwest Oklahoma's water year average of 12.68 inches was more than 18 inches below normal and nearly 5 inches drier than the previous record low total of 17.45 inches, again from the 1955-56 water year."

And to gain perspective on the record heat of summer 2011, also from Mr. McManus…

> "According to data from the Oklahoma Mesonet, the state's climatological summer, June 1 through August 31, ended with a statewide average of 86.8 degrees, obliterating the previous state record of 85.2 degrees from the summer of 1934."

Oklahoma has won the prize for hottest summer for any state since records began.

Oklahoma agriculture has experienced nearly $2 billion dollars in losses due to the current drought, according to estimates by Oklahoma State University's Division of Agricultural Sciences and Natural Resources. The Oklahoma Department of Agriculture, Food, and Forestry estimates crop losses of more than $953 million and cattle losses of about $1 billion. Much of Oklahoma is still prairie grassland and well suited to produce protein from grazing herbivores like cattle. Oklahoma is home to the second largest beef cattle herd in the United States and the drought, with its withered grasses and forage and dried ponds, has hit the state's beef producers hard, particularly those west of Interstate 35 and in southwest Oklahoma, according to the Oklahoma Cattlemen's Association. These agricultural losses will be the highest ever recorded in a single year for our state.

As a veterinarian, I suspect that a lot of less than ideal hay will be fed and less than ideal areas will be grazed in Oklahoma this fall and winter. We could see increased oral injury in livestock due to the presence of higher numbers of mature grass seed heads in graze and late cut hay (like *Setaria* or foxtail grass) with stiff barbed bristles that easily penetrate flesh and are kept there by the barbs. Relatively small amounts of these types of

Cole, L.E.
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bristled seed heads in hay can produce these lesions (1.8% for *Setaria*).

A significant volume of hay is being shipped into Oklahoma from out of state. There could be toxic plants and seeds associated with this out of state hay that we don't normally see in Oklahoma. Those concerned about livestock health and Oklahoma native plants should be on the lookout for these aliens.

Drought stressed plants can accumulate or produce toxins not usually present under more "normal" conditions. Cyanogenetic glycosides that yield hydrocyanic acid (HCN-cyanide) upon hydrolysis are a concern in stressed *Sorghum* spp. (sudan grass, Johnsongrass, etc.), *Prunus* spp. and others. Nitrate levels in stocks, other forage or some hay are a concern as well.

Plants that accumulate or produce toxins are usually avoided by browsers and grazers; however, when said browsers and grazers are faced with eating dirt or that less than palatable toxic plant, the toxic plant gets eaten. Oklahoma has many toxic plants that can cause problems if ingested by livestock; for example, the loco weeds (*Astragalus* spp. and *Oxytropis* spp.), selenium accumulators (*Astragalus* spp. again and *Stanleya* spp.), oxylate accumulators (*Rumex* spp. and *Chenopodium* spp.) and saponin producers (*Phytolacca* and *Sesbania* spp.).

Even some of Oklahoma's smallest plants have been important in this past summer's heat and drought. "Blooms" or explosive reproduction of bluegreen algae in warm state waters this summer have made the headlines. Individual cells of these organisms are microscopic but they are collected into colonies, filaments or masses of filaments. Cattle, sheep, horses, swine, dogs, cats, fowl, geese, wild and domestic ducks, game and song birds, fish, rodents, and small game have been killed by ingesting these smallest of plants.

Lack of water can eventually lead to catastrophic biological failures and death in plants. One can think about the wilting of leaves and decreased turgor pressure, hydraulic failure with stomata closure and reduced photosynthesis and the myriads of other adaptations, mechanisms and strategies that plants employ to survive the stresses of Oklahoma's wild climate and unique ecology. What I remember most about this year's drought was the amazing green-up of the grasses and the abundant fall flowers that followed the relatively meager fall rains. The native plants of Oklahoma are scientifically fascinating, true survivors, and incredibly beautiful.

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Dr. Sheila A. Strawn, Managing Editor, Oklahoma Native Plant Record
Oklahoma Native Plant Society c/o Tulsa Garden Center
2435 South Peoria, Tulsa, Oklahoma 74114
Email: sastrawn@hotmail.com

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