

# *Oklahoma*

## *Native Plant Record*



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**Volume 18, December 2018**

# *Oklahoma Native Plant Record*

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# *Oklahoma Native Plant Record*

## *Volume 18*

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† Indicates an author who is deceased

Cover photo: *Plectrocephalus americanus* (Nutt.) D. Don (American basketflower) by Lynn Michael  
for the 2017 ONPS Photo Contest

## Foreword

This issue of the *Oklahoma Native Plant Record* includes articles that deal with some threats to our native plant communities from both native and non-native species. It also contains an article about a "hidden gem" population of a native plant and another about a relative newcomer to our state.

Chad King and graduate student Joseph Buck, at the University of Central Oklahoma, used dendrochronological techniques to quantify the population structure and growth of *Fraxinus pennsylvanica* (green ash) in a bottomland hardwood forest at Arcadia Lake in Oklahoma County. Populations of green ash in the state are being threatened by the non-native *Agilus planipennis* (emerald ash borer). This baseline study, conducted prior to the range expansion of emerald ash borer to this area, might help identify traits of ash trees that survive infestation by this borer.

Issac Walker of Holland Hall High School and Paulina Harron, an Oklahoma State University graduate student, report a large and apparently long-established but previously undocumented population of *Pueraria montana* (kudzu vine) in Tulsa County. Their article reiterates that, although kudzu has so far had a relatively minor impact on Oklahoma's native communities, we need to be vigilant in documenting populations and managing it.

Adjoa Ahedor of Rose State College and undergraduate students Bethany Spitz, Michael Cowan, J'nae Miller, and Margaret Kamara investigated transpiration in *Juniperus virginiana* (eastern redcedar) compared to adjacent trees of other species. Although it is native, eastern redcedar's range expansion is threatening Oklahoma's prairie communities because of many factors, which might include higher transpiration than other species.

Bruce Smith of McCloud High School summarizes the status of *Myriopteris lindheimeri* (fairy swords) in southwestern Oklahoma. This fern had been documented in Comanche County in 1942, but over time the lack of additional specimens led the Oklahoma Natural Heritage Inventory to list it as a species that might have been extirpated from the state. In Bruce's article, you will read how, on a visit to Kiowa County, he recently discovered a population of fairy swords that he admits he first confused with another species. His article should alert us that as we take field trips, we could be overlooking populations of rare species, especially if they resemble more common ones.

Jim Estes of the University of Oklahoma reports an unusual number of anthers in *Calypsothecium vialis* (straggler daisy) and describes aspects of its pollination and breeding system in a North Texas population. Native to eastern Mexico and southern and south-central Texas, straggler daisy has spread to the north and was recently documented in southern Oklahoma. It is a shade-loving and mat-forming species that can become very abundant in lawns. This is certainly another plant to watch for in our state.

This issue's Critic's Choice essay was written by Paul Buck for the Botany Bay section of the Fall 1999 *Gaillardia*. Like many articles written by Paul Buck, it encourages us to slow down and notice the myriad interactions taking place right in front of us. This one describes myrmecochory, i.e., ant dispersal of seeds, of two of our earliest spring lawn plants, *Viola* (violets) and *Lamium* (henbit).

Please consider publishing your work in the *Oklahoma Native Plant Record*. It is listed in the Directory of Open Access Journals, is abstracted by the Centre for Agricultural Bioscience International, and can be accessed by researchers around the world.

Gloria Caddell  
Managing Editor

# CHARACTERISTICS OF A BOTTOMLAND HARDWOOD FOREST AT ARCADIA LAKE, EDMOND, OKLAHOMA, WITH SPECIAL EMPHASIS ON GREEN ASH (*FRAXINUS PENNSYLVANICA* MARSHALL)

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*Keywords: emerald ash borer, Fraxinus pennsylvanica, flood*

## ABSTRACT

We characterized the structure and tree species composition of bottomland hardwood forest at Arcadia Lake, Oklahoma County, Oklahoma. Additionally, we quantified the age structure of *Fraxinus pennsylvanica* Marshall (green ash) at the study site in order to establish a baseline dataset in the event that *Agrilus planipennis* (emerald ash borer) invades *F. pennsylvanica* stands in central Oklahoma. Three species, *Salix nigra* Marshall (black willow), *F. pennsylvanica*, and *Populus deltoides* W. Bartram ex Marshall (cottonwood) accounted for over 98% of importance values. These three species were also common in the understory. We found that 95% of *F. pennsylvanica* established following Arcadia Lake reaching pool conservation status in 1987. Arcadia Lake has experienced five sustained flooding events since 1995 that have likely played a role in regeneration at the study site. In particular, we showed that the 1995 event resulted in reduced radial growth in seedlings of *F. pennsylvanica*. Two biotic stressors appear to be influencing *F. pennsylvanica* overstory trees, *Castor canadensis* (American beaver) and *Hylesinus* spp. (ash bark beetle), which will likely enhance the establishment of *A. planipennis* at the study site. We recommend expanding the study of *Fraxinus* spp. forest stands in Oklahoma. Baseline data on *Fraxinus* species prior to an *A. planipennis* range expansion to central Oklahoma can enhance strategies for control and management of this invasive insect by identifying the traits of surviving ash following the invasion.

## INTRODUCTION

Bottomland hardwood forests comprise approximately 10–14% of land cover in Oklahoma (Anderson and Masters 1992; Dooley 2017). Generally, this includes two broad classifications: *Ulmus-Fraxinus-Populus* (elm-ash-cottonwood) in central and eastern Oklahoma and *Quercus-Liquidambar-Taxodium* (oak-sweetgum-cypress) in southeast Oklahoma. Bottomland hardwood forests in Oklahoma represent an

important ecological component that exhibits high biological diversity in both aquatic and terrestrial habitats, and influence flood control ability and water quality (Brabander et al 1985; Anderson and Masters 1992; Rumble and Gobeille 1998).

Previous studies of bottomland hardwood forests along riparian corridors in Oklahoma have highlighted a commonality in terms of species composition but differences in species importance. Rice (1965) documented climax floodplain forest

communities in north-central Oklahoma. He noted *Ulmus americana* L. (American elm) was the most common and dominant tree species across 10 counties. He also noted several other co-dominant species in these mature floodplain forests, including *Celtis occidentalis* L. (common hackberry), *C. laevigata* Willd. (sugarberry), *Juglans nigra* L. (black walnut), *Carya illinoensis* (Wangenh.) K. Koch (pecan), *Sapindus saponaria* L. var. *drummondii* (Hook. & Arn) L.D. Benson (western soapberry), and *Fraxinus pennsylvanica* Marshall (green ash). Hefley (1937) defined the climax floodplain community as *Ulmus-Quercus* (elm-oak) along the Canadian River in Cleveland County. Petranksa and Holland (1980) documented bottomland hardwood forest composition at 13 sites along tributaries of the Washita River. They found that *Salix nigra* Marshall (black willow) and *Celtis* spp. were the most important overstory tree species at their study sites. Rice and Penfound (1956) found *F. pennsylvanica* to be the dominant overstory species at a site in Cleveland County, Oklahoma. Several species that were of higher importance in other studies (Rice 1965; Hefley 1937; Petranksa and Holland 1980) were of minor importance at Rice and Penfound's (1956) site, possibly reflecting differences in stage of succession.

*F. pennsylvanica* was a component of all the previous studies in Oklahoma but varied in its importance. This species is a deciduous angiosperm in the Oleaceae (olive family). *F. pennsylvanica* is predominately found in bottomland forest associations, often with *Salix nigra*, *Platanus occidentalis* L. (American sycamore), *Populus deltoides* W. Bartram ex Marshall (cottonwood), *Celtis* spp., and *Ulmus* spp. (Hoagland 2000; Kennedy, Jr. 1990). According to the United States Forest Service Forest Inventory Analysis (Forest Inventory and Analysis 2018) there are an estimated 163.5 million individuals of *Fraxinus* spp. in Oklahoma greater than

1 cm DBH (diameter at breast height). While *Fraxinus* spp. only account for 3% of stems >1 cm DBH in Oklahoma, these trees are under threat by the non-native emerald ash borer (*Agrilus planipennis* Fairmaire; Coleoptera: Buprestidae, EAB, Figure 1) as it expands its distribution westward in North America.



Figure 1 Adult emerald ash borer (*Agrilus planipennis*; David Cappaert, Bugwood.org <https://www.insectimages.org/browse/detail.cfm?imgnum=2106098>). Creative Commons License (<https://creativecommons.org/licenses/by-nc/3.0/us/legalcode>). No modifications were made of the image.

*Agrilus planipennis*, native to Asia, was first detected in southeast Michigan in 2002 but is believed to have arrived sometime in the 1990s (Herms and McCullough 2014). Forests closest to the epicenter of invasion have experienced more than 99% ash mortality (Klooster et al. 2014). Since the initial detection, EAB has spread to 33 states and four Canadian provinces (Emerald Ash Borer Information Network 2018). In October 2016, EAB was detected in Delaware County, Oklahoma (Oklahoma Forestry Services, <http://www.forestry.ok.gov/>). This wood-boring beetle feeds in galleries under the bark within the phloem and cambium of *Fraxinus* trees (Cappaert et al. 2005). The result of infestation is mortality due to girdling which eliminates the tree's ability to transport sugars and water.

With this potential threat to *Fraxinus* in Oklahoma, there is an immediate need to study existing bottomland hardwood forests that contain *Fraxinus*. Baseline data on the existing structure and dynamics of bottomland hardwood forest communities, prior to an invasion by a non-native species, can provide invaluable information on approaches to control and manage the non-native species and to identify traits of *Fraxinus* trees that survive, known as “lingering” ash (Knight et al. 2012; Koch et al. 2012).

The goal of our research is the establishment of a baseline dataset for a bottomland hardwood forest at Arcadia Lake, Oklahoma County, Oklahoma that has a high density of *F. pennsylvanica*. Research for this paper had three objectives: 1) record the tree species composition in both the overstory and understory, 2) quantify the characteristics of *F. pennsylvanica* structure and growth using standard forestry measurements and dendrochronology, and 3) relate patterns of *Fraxinus* establishment and bottomland hardwood forest structure to repeated flooding at Arcadia Lake. The results reported in this manuscript are part of a long-term study at Arcadia Lake to better understand bottomland hardwood forest succession and dynamics following the formation of the lake during the early 1980s.

## METHODS AND MATERIALS

### *Study Site*

Arcadia Lake (35° 38' 54" N, 97° 21' 47" W) is a man-made lake located in northeast Oklahoma County, Oklahoma. The lake is found at the confluence of the Deep Fork River and Spring Creek. Formation of the earthen dam on the Deep Fork River began in 1980 with the conservation pool being filled by 1987. The United States Army Corps of Engineers maintains a lake surface elevation of 306.6 m (1006.0 ft) that covers 736.5 ha (1820 ac). The lake is managed as a

recreational area, drinking water source for the City of Edmond, and for flood control of the Deep Fork River (U.S. Army Corps of Engineers 2018).

The regional climate (Oklahoma Climate Division 5) is warm-temperate. Mean annual temperature (1901–2017) is 15.7°C (60.2°F) with highest average monthly temperatures occurring in July–August (27.7°C, 81.9°F; 1901–2017) and lowest average monthly temperatures occurring in December–January (3.3°C, 38.0°F; 1901–2017). Precipitation during the year is bimodal, with the highest total monthly precipitation during May (12.9 cm, 5.10 in; 1901–2017) and September (9.30 cm, 3.66 in; 1901–2017) (National Oceanic and Atmospheric Administration 2018).

Soils adjacent to Arcadia Lake are dominated by Stephenville-Darsil-Newalla (3–8% slope) fine sandy loam to sandy clay loam and Harrah (3–5% slope) fine sandy loam. Soils at our specific study site at Arcadia Lake are Easpor loam (0–1% slope). These soils are associated with bottomland/floodplain areas of Oklahoma County and have depths up to 203.2 cm (80 in) to bedrock (U.S. Department of Agriculture Web Soil Survey 2018).

Our study site at Arcadia Lake is located at the northwest section approximately 354 m from the inflow of Spring Creek into Arcadia Lake and is approximately 4.7 ha; the *F. pennsylvanica* stand studied for this paper covers 2.2 ha (47% of total study area).

### *Fraxinus pennsylvanica stand structure and dendrochronology*

During Spring 2016, we began assigning individually identified tree tags to all *F. pennsylvanica*  $\geq 5$  cm DBH. Each tree was tagged with an individually assigned number that allows for continuous monitoring. Tags were nailed to trees at approximately 1.5–1.8 m height to minimize the chance of wildlife removing the tags. Waypoints were recorded using a handheld Garmin GPS for

all tagged trees. We measured DBH (1.3 m above ground level) using a DBH tape measure (cm) on all tagged trees. Tree height was estimated using a Nikon Forestry PRO Laser Rangefinder/Hypsometer.

We estimated the age structure of *F. pennsylvanica* by comparing increment cores (Speer 2010). Approximately every sixth tagged tree ( $n = 65$ ) was cored at 30 cm above ground level using a 5 mm (diameter) Haglof increment borer. One to two cores ( $n = 83$ ) were collected from each tree to get an estimate of tree age at coring height. Increment cores were stored in straws and returned to the TREE (Tree-Ring Ecology & Environment) Lab at the University of Central Oklahoma for processing and analysis.

We mounted increment cores and sanded using progressively finer sandpaper (80–1200 grit) to visualize individual cells under a binocular microscope (Stokes and Smiley 1996). To determine age at coring height of *F. pennsylvanica* and radial growth dynamics, tree-ring widths were measured to the nearest 0.001 mm for each increment core using a Velmex TA Measuring System (Velmex, Inc., Bloomsfield, NY), a binocular microscope, and Measure J2X software (VoorTech Consulting, Holderness, NH). All tree-ring series were crossdated to assign calendar years to each tree-ring using the computer program COFECHA (Grissino-Mayer 2001; Holmes 1983) and graphical visualization.

We used ARSTAN (Cook and Holmes 1986) to create a stand-level standardized tree-ring index for *F. pennsylvanica*. The program allows for different detrending techniques that emphasize a signal of interest in tree-ring series. ARSTAN calculates a standardized tree-ring index by fitting a curve to each tree-ring series. A standardized tree-ring index for each tree is calculated by dividing each tree-ring width by the curve fit value. The stand-level standardized tree-ring index is the average of all individual standardized tree-ring

indices. We applied a 10-year cubic smoothing spline to create a standardized tree-ring index, given the relatively short tree-ring series, in order to understand the patterns of *F. pennsylvanica* growth at the study site.

### ***Bottomland forest structure***

To establish a baseline dataset in the event of EAB invasion, we categorized the bottomland hardwood forest structure and species composition at the study site. Four 150 m transects (oriented southeast-northwest) were established within the 2.2 ha study area in an effort to understand bottomland forest regeneration. At 10 m intervals along each transect, a 1m<sup>2</sup> fixed area plot was established. All seedlings (< 1.3 m height) and saplings (> 1.3 m height; DBH < 8 cm) were counted to estimate stem density and identified to species. Four 0.04 ha fixed area circular plots ( $n = 16$ ) were established along each transect to assess the overstory composition associated with *F. pennsylvanica*. Diameter at breast height was measured for all trees > 8 cm DBH, and each tree was identified to species. We calculated standard descriptive statistics for the overstory composition including tree density (stems/ha), basal area (m<sup>2</sup>/ha), relative density (species density/total tree density x 100), relative basal area (species basal area/total tree basal area x 100), and importance (relative tree density + relative basal area) (Cottam and Curtis 1956; Curtis and McIntosh 1951).

## **RESULTS**

### ***Fraxinus pennsylvanica stand structure and dendrochronology***

To date, a total of 404 *F. pennsylvanica* trees have been individually tagged and measured at Arcadia Lake. The largest diameter was 35.1 cm (mean = 14.0 cm, SD  $\pm$  4.61). The tallest tree was 13.99 m (mean = 9.31 m, SD  $\pm$  2.16) (Table 1).



Table 1 Summary statistics for *F. pennsylvanica* at Arcadia Lake, Oklahoma County, Oklahoma

	N	Mean	SD	Range
Diameter (cm)	404	14.0	4.61	7.00 – 35.1
Height (m)	404	9.31	2.16	2.20 – 13.9
Ring-width (mm)	83	3.55	1.67	1.71 – 6.92
Age (years)	65	23.9	2.84	17.0 – 32.0
Tree-Ring Index <sup>a</sup>	83	0.99	0.15	0.92 – 1.00

<sup>a</sup>Tree-ring index values correspond to the standardized chronology in Figure 4.

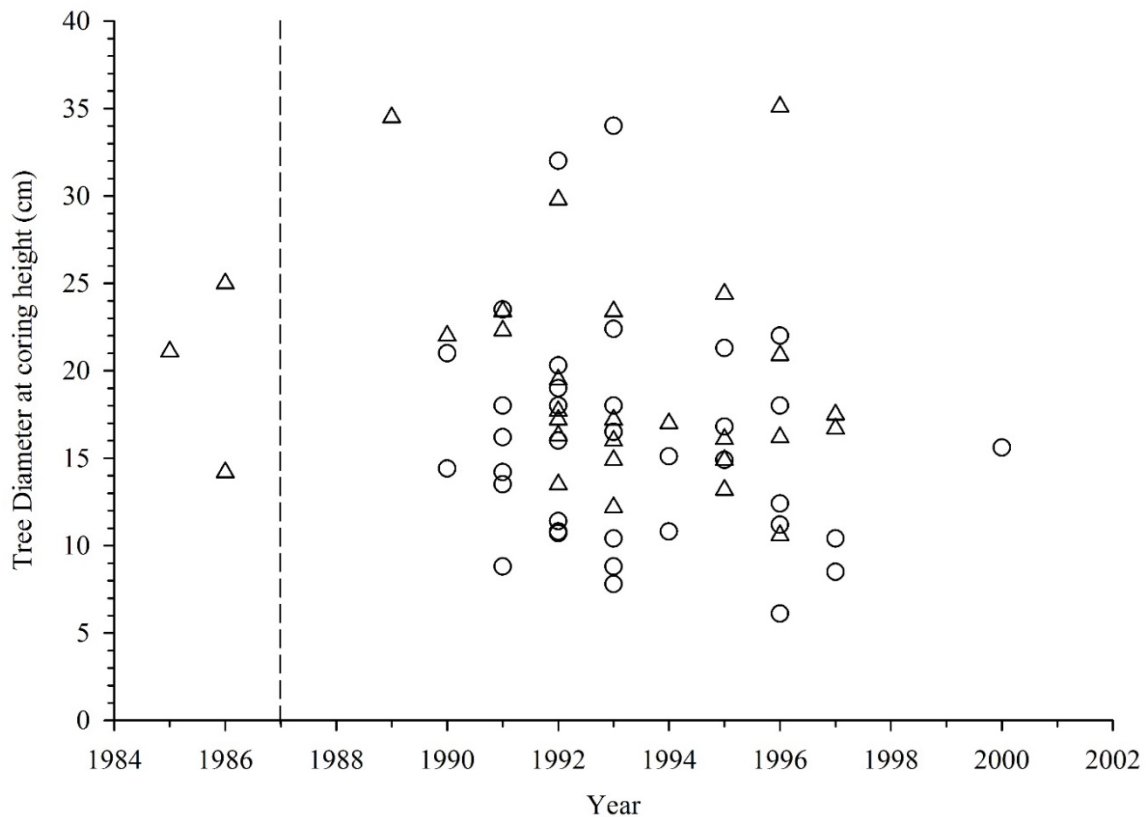


Figure 2 Actual (circles) and estimated pith dates (triangles) and tree diameter of green ash ( $n = 65$ ) at Arcadia Lake, Oklahoma County, Oklahoma. Pith dates were estimated using the method indicated by Speer (2010) for trees in which coring missed the pith. Vertical dash line indicates the year (1987) that Arcadia Lake first reached conservation pool status (306.6 m; 1006 ft) following dam completion.

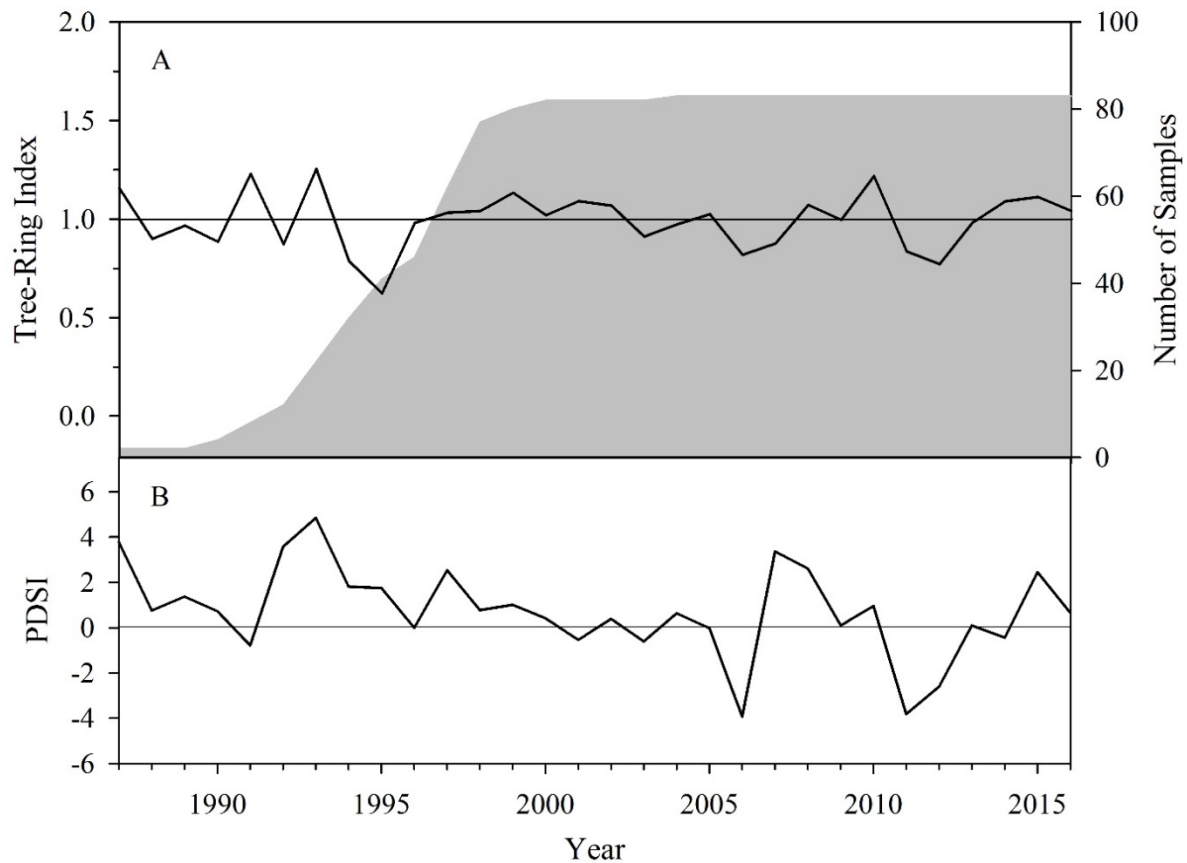


Figure 3 (A) Standardized tree-ring index of *F. pennsylvanica* at Arcadia Lake, Oklahoma County, Oklahoma (1987–2016). Tree-ring index is standardized using the computer program ARSTAN and methods outlined by Cook and Holmes (1986). The standardized tree-ring index has a mean = 1 and is unitless. Index values > 1 indicate above-average annual growth; index values < 1 indicate below-average annual growth. Right y-axis is associated with the shaded area; left y-axis is associated with the standardized tree-ring index. (B) Annual Palmer Drought Severity Index (Palmer 1965) for Oklahoma Climate Division 5 (National Oceanic and Atmospheric Administration 2018). Values above zero indicate above-average annual moisture; values below zero indicate below-average annual moisture.

Eighty-three increment cores from 65 *F. pennsylvanica* trees were analyzed. The oldest *F. pennsylvanica* tree at the 2.2 ha site was 31 years old (estimated pith date = 1985; Figure 2). Three trees pre-dated Arcadia Lake reaching conservation pool level (1987). Approximately 95% of cored *F. pennsylvanica* trees established following Arcadia Lake formation in 1987 (see Figure 2).

*F. pennsylvanica* exhibited variable radial growth based on tree-ring measurements. Below-average growth was documented during the late 1980s and early 1990s (1987–1995; Figure 3). Following 1995, above-average growth occurred in 52% of the years up to 2016. Below-average radial growth after 1995 corresponded with below-average Palmer Drought Severity Index for Oklahoma Climate Division 5

(National Oceanic and Atmospheric Administration 2018).

### ***Bottomland forest structure***

Six species were documented in the overstory at the study site. Three species were identified in the understory (sapling/seedling) that were not present in the overstory (Table 2). Three species, *Salix nigra*, *F. pennsylvanica*, and *Populus deltoides*, had the highest importance values, accounting for over 98% of the importance values in this bottomland forest.

*F. pennsylvanica* had the highest estimated overstory density (271.7 trees/ha) but a lower basal area (6.654 m<sup>2</sup>/ha) compared to *S. nigra* and *P. deltoides* (see Table 2). *S. nigra* had the highest basal area (10.73 m<sup>2</sup>/ha (see Table 2).

*F. pennsylvanica* had the highest seedling abundance with an estimated 1000 stems/ha. *Ulmus* spp. and *Acer saccharinum* L. (silver maple) were the second and third most common in the seedling stage, respectively (see Table 2). Two species documented in the overstory that lacked trees in the understory included *Maclura pomifera* (Raf.) C.K. Schneid. (Osage orange) and *Gleditsia triacanthos* L. (honey locust). *F. pennsylvanica* also had the highest estimated sapling density (250 stems/ha). *S. nigra* and *P. deltoides* were present in the seedling stage but lacking in the sapling stage in the understory.

## **DISCUSSION**

We documented the characteristics of a bottomland hardwood forest at Arcadia Lake, Oklahoma County, Oklahoma. These data are a baseline in the event that EAB arrives in central Oklahoma. *F. pennsylvanica* was the second most important tree species in this forest and demonstrated regeneration in the understory (see Table 2). Other typical bottomland forest species were documented, including *S. nigra* and *P. deltoides*. Our findings were similar to those

for other bottomland forests in the South-Central United States. At a site similar to ours in Texas, Rosiere et al. (2013) documented 15 tree species. We documented nine species at our study site in Oklahoma. Compared to Rosiere et al. (2013), several similar species were noted within our site, including *Ulmus* spp., *G. triacanthos*, *F. pennsylvanica*, *Morus* spp. (mulberry), and *P. deltoides*. Of note from Rosiere et al. (2013) was a very high importance value for *C. laevigata*, which was absent at our study site but can be found in adjacent upland areas around Arcadia Lake (King 2015). The importance value for *F. pennsylvanica* was much lower in Texas (Rosiere et al. 2013) and at a site in Cleveland and Calhoun counties, Arkansas (Lockhart et al. 2010), and it was a minor component in 13 southern Oklahoma bottomland forests (Petranka and Holland 1980).

An exception to the lower *F. pennsylvanica* component in the previous studies is the *F. pennsylvanica*-dominant forest near Norman, Oklahoma (Rice and Penfound 1956). Similar to our results, Rice and Penfound documented low density of *P. deltoides* in the understory even though this species was one of the most important species in the overstory. Possible explanations for the differences in species composition and *F. pennsylvanica* densities may be differences in hydrology and age of forest stands. The Arkansas study site (Lockhart et al. 2010) was along a braided stream, and the Texas study site (Rosiere et al. 2013) was along the Bosque River. Our study site, while located near Spring Creek, was situated along the edge of Arcadia Lake. Lockhart et al. (2010) suggested that their bottomland forest was old-growth which is in contrast to our study site, where very few *F. pennsylvanica* had pith dates prior to 1990.

Table 2 Descriptive statistics for the 2.2 ha bottomland forest at Arcadia Lake, Oklahoma County, Oklahoma. Overstory density is based on trees >8 cm diameter at breast height. Sapling density is based on tree stems <8 cm and >1.3 m height. Seedling density is based on trees <1.3 cm height.

Species	Common name	Overstory Density (Trees/ha)	Relative Density <sup>a</sup>	Basal area (m <sup>2</sup> /ha)	Relative Dominance <sup>a</sup>	Importance Value <sup>a</sup>	Sapling Density (stems/ha)	Seedling Density (stems/ha)
<i>Salix nigra</i>	Black willow	213.3	36.05	10.73	42.29	78.34	--	500.4
<i>Fraxinus pennsylvanica</i>	Green ash	271.7	45.92	6.654	26.23	72.15	250.0	1000.1
<i>Populus deltoides</i>	Cottonwood	96.7	16.34	7.690	30.31	46.65	--	83.33
<i>Acer saccharinum</i>	Silver maple	5.000	0.845	0.216	0.851	1.696	41.70	875.0
<i>Maclura pomifera</i>	Osage orange	3.330	0.563	0.035	0.138	0.701	--	--
<i>Gleditsia triacanthos</i>	Honey locust	1.670	0.282	0.045	0.177	0.460	--	--
<i>Morus spp.</i>	Mulberry spp.						41.70	291.7
<i>Ulmus spp.</i>	Elm spp.						125.0	958.3
<i>Acer negundo</i>	Boxelder						--	416.7
<b>Totals</b>		<b>591.7</b>	<b>100.0</b>	<b>25.37</b>	<b>100.0</b>	<b>200.0</b>	<b>458.4</b>	<b>4125.5</b>

<sup>a</sup>Relative density = number of trees in a species/ total number of trees

Relative dominance = basal area of a species/ total basal area

Importance value = relative density + relative dominance for each species

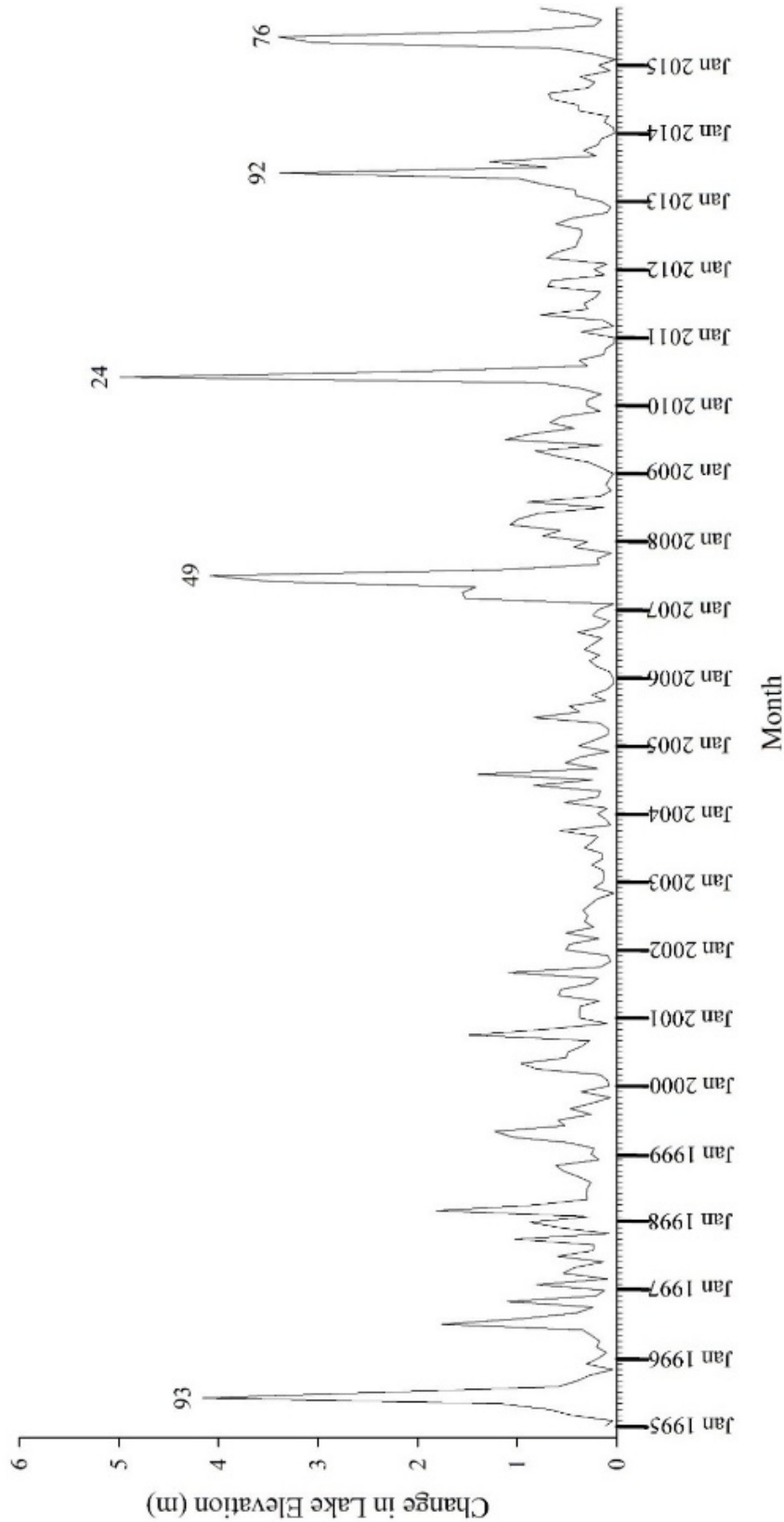


Figure 4 Changes in monthly lake elevation (m) at Arcadia Lake, Oklahoma County, Oklahoma (1995–2015). Change is the difference between the minimum and maximum lake elevation for each month. Numerical values during 1995, 2007, 2010, 2013, and 2015 indicate the number of consecutive days that lake elevation was above conservation pool standard (306.6 m; 1006 ft). Data was accessed via U.S. Army Corps of Engineers Tulsa District Water Control website: <http://www.swt-wc.usace.army.mil/ARCA.lakepage.html>.



Figure 5 Image of the bottomland forest study site along the northwest edge of Arcadia Lake, Oklahoma County, Oklahoma. Photograph was taken April 27, 2018, when lake elevation was 1.1 feet (0.33 m) above conservation pool standard (306.6 m; 1006 ft). The lake edge can be seen in the left-center of the image. Previous flooding height is documented with white arrows approximately 1 m above ground level. Photo by Chad B. King.

Rice (1965) described and documented bottomland forest communities in north-central Oklahoma. He described 10 different bottomland forest communities; three were in Oklahoma County, including *U. americana*, *U. americana-C. laevigata*, and *U. americana-F. pennsylvanica* community types. These were named based on the two species that had importance values >75. Our study site lacked overstory *Ulmus* species. While *Ulmus* was identified in the understory, *S. nigra* and *F. pennsylvanica* were

the dominant overstory species (see Table 2). *Ulmus* species are present around Arcadia Lake (*U. americana*, *Ulmus rubra* Muhl.) but are most often associated with upland areas (King 2015).

One important factor that may be playing a role in the succession of this bottomland hardwood forest is repeated, sustained flooding. Arcadia Lake was formed by damming the flow of the Deep Fork River and, to a lesser degree, Spring Creek. The U.S. Army Corps of Engineers

maintain a conservation pool at 306.6 m (1006 ft) elevation. Precipitation events increase Arcadia Lake levels and cause flooding at our study site. Five pronounced events have occurred since the U.S. Army Corps of Engineers began recording daily lake levels in 1994 (U.S. Army Corps of Engineers 2018). Figure 4 highlights events during 1995, 2007, 2010, 2013, and 2015 that resulted in multiple, consecutive days of lake elevations >306.6 m. These flood events result in several days of standing water that often inundate seedlings and saplings (Figure 5). Lake elevation data also demonstrate that every year between 1995 and 2015 had a period of flooding at the study site. These repeated flooding events maintain bare, moist soil (Scott et al. 1996) that likely contributed to the establishment of *F. pennsylvanica* (see Figure 2) and other bottomland species. We demonstrate that 95% of cored *F. pennsylvanica* established after the lake reached conservation pool status in 1987 (see Figure 2) and suggest that increased moisture availability promoted the establishment of *F. pennsylvanica* and other bottomland tree species.

We also show that approximately 72% of the cored *F. pennsylvanica* trees established prior to the 1995 flood year (see Figure 2 and Figure 4) and ranged in age from 1–10 years old at that time. From April 18, 1995, through July 19, 1995, Arcadia Lake elevation was >306.9 m (1007 ft) and reached a peak of 311.7 m (1022.8 ft) on June 12, 1995. This 93-day flooding event was due to 51.5 cm (20.29 in) of rainfall from April through July, 1995. It is likely that most of the 1–4 year old *F. pennsylvanica* trees were completely inundated with water for several days. This is emphasized by the narrow 1995 tree-ring (see Figure 3) that was formed in the seedlings and saplings during that year. In contrast, dendrochronological work at other study sites near our study site demonstrated wider than average growth rings for 1995 (King

and Cheek 2015; King unpubl. data). This suggests a reduced radial growth rate that is likely attributed to prolonged inundation and reduced photosynthesis during the 1995 growing season. Despite reduced growth rates, these green ash trees survived the 1995 flood. Hosner (1958) demonstrated that *F. pennsylvanica* and *S. nigra* seedlings could survive up to 16 days while inundated. Krinard and Johnson (1981) documented >50% survival of *F. pennsylvanica* and *P. deltoides* seedlings following flooding events during the 1970s along the Mississippi River. In studies that encompassed several species found at our site, Loucks (1971) and Loucks and Keen (1973) found 100% survival of *F. pennsylvanica* seedlings after four weeks of submersion; *A. negundo* L. (boxelder) had increased mortality after the third week; *P. deltoides* had increased mortality in the fourth week of submersion; and *A. saccharinum* had 100% survival after four weeks of submersion. This mirrors the seedling density data in this study (see Table 2) which show higher densities for these same species that are able to survive prolonged submersion. The four highest estimated seedling densities were *F. pennsylvanica*, *Ulmus* spp., *A. saccharinum*, and *A. negundo*. The high frequency of flooding at Arcadia Lake (see Figure 4) likely plays a role in the regeneration of these flood tolerant species while reducing the survival of less flood tolerant species. All of the species documented in our study are classified as intermediate to very tolerant of flooding as mature trees and able to survive flooding or saturated soils up to a minimum of 30 days (Clatterbuck 2005). These periodic flooding events, particularly during the growing season (see Figure 4) are likely influencing regeneration that favors flood tolerant species and maintains the existing species composition.

In addition to flood tolerance, we have found that *F. pennsylvanica* encounters biotic stressors that may make it more prone to

EAB attack at Arcadia Lake. American beaver (*Castor canadensis*) are active and have girdled many *F. pennsylvanica*, *S. nigra*, and *P. deltooides* trees around Arcadia Lake (Figure 6A). We have begun documenting beaver damage and have currently found that 30% of *F. pennsylvanica* trees have some type of beaver damage (King unpubl. data). Native ash bark beetles (*Hylesinus* spp.; Coleoptera: Curculionidae) are also present at Arcadia Lake (Figure 6B). These insects are phloem-feeders and attack recently stressed trees impacted by mechanical damage or disease (U.S. Department of Agriculture Forest Service 1985). These biotic stressors have likely increased the probability for the establishment of a viable EAB population in central Oklahoma.

With the detection of EAB in Delaware County, Oklahoma in 2016 there is an increased likelihood of the continued westward expansion of this non-native beetle to Oklahoma County. Modelled short range dispersal of EAB is on average 20 km per year (Prasad et al. 2010) but long range dispersal is facilitated by humans, often via firewood and wood products that contain undetected EAB. Arcadia Lake has camping areas and does not currently restrict firewood transport (Leon Mixer, City of Edmond Arcadia Lake Supervisor, pers. comm. 4/13/2018). This, and the aforementioned biotic stressors, potentially increase the risk for EAB introduction to the Arcadia Lake area.

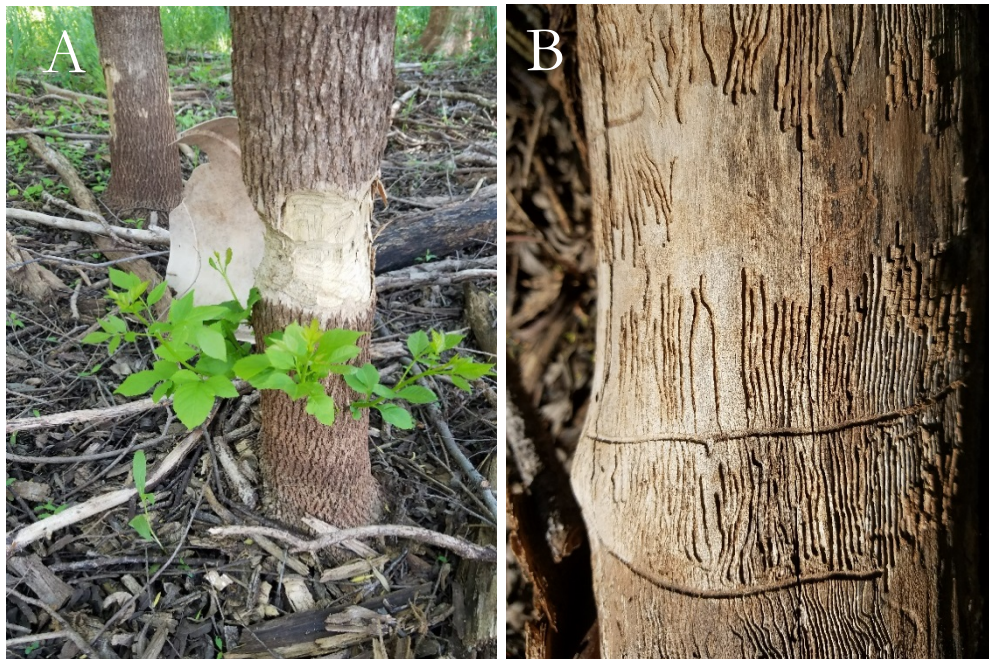


Figure 6 Two examples of biotic stressors on green ash at Arcadia Lake, Oklahoma County, Oklahoma. (A) American beaver activity that nearly girdled this green ash and subsequent sprouting by the green ash. (B) Ash bark beetle (*Hylesinus* sp.) galleries located under the bark of a dead green ash. Photos by Chad B. King.



## CONCLUSIONS

We documented the characteristics of a bottomland hardwood forest at Arcadia Lake, Oklahoma County, Oklahoma with an emphasis on the current age structure of *F. pennsylvanica*. The three dominant species in the overstory were *S. nigra*, *F. pennsylvanica*, and *P. deltoides*. Regeneration of the three overstory species was occurring in this bottomland forest. Frequent flooding of Arcadia Lake since 1995 has sustained this bottomland forest and has likely restricted the establishment of more flood intolerant tree species. The high density of *F. pennsylvanica* and additional biotic stressors at this study site may set the stage for the invasion of EAB in the future. We recommend foresters, scientists, and the public document the locations of *F. pennsylvanica* stands in Oklahoma for further monitoring of EAB infestation.

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## PRESENCE OF *PUERARIA MONTANA* (LOUR.) MERR. VAR. *LOBATA* (WILLD.) MAESEN & S.M. ALMEIDA EX SANJAPPA & PREDEEP (KUDZU VINE) IN TULSA COUNTY, OKLAHOMA

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*Keywords: kudzu, Tulsa County, invasive species, Oklahoma, Pueraria montana*

### ABSTRACT

*Pueraria montana* (Lour.) Merr. var. *lobata* (Willd.) Maesen & S.M. Almeida ex Sanjappa & Predeep (Fabaceae; kudzu) is a deciduous perennial vine native to China. An invasive species that has spread throughout much of the southeastern United States, kudzu covers large open areas, overtops forests, and causes significant ecological and economic damage. Oklahoma has seen a relatively minor impact from kudzu, and previous research indicates a limited (less than 0.04 hectare) presence in Tulsa County. We describe a previously undocumented population of kudzu covering over 6.5 hectares in Tulsa County. We determine the age of this population and its rate of expansion. Documenting and mitigating kudzu populations will likely become increasingly important to protect Oklahoma's native biodiversity.

### INTRODUCTION

The spread of kudzu, *Pueraria montana* (Lour.) Merr. var. *lobata* (Willd.) Maesen & S.M. Almeida ex Sanjappa & Predeep, and its impact on the environment, economy, and biodiversity has been addressed in many publications. Kudzu is an aggressive species that has the ability to reduce biodiversity, compete for light and space resources with natives (Coiner 2012; Mitich 2000), and kill trees by creating large canopies with its heavy vines (Forseth and Innis 2004). It can fix nitrogen in the soil (Follak 2011), and it has a wide climatic range that promotes its spread (Claytor and Hickman 2015). Claytor and Hickman (2015) assessed the spread of this invasive, non-native species in Oklahoma and stressed the importance of continually updating knowledge regarding this ecologically and economically

detrimental species and its spread within the state. They estimated that kudzu was established in, but limited to, 0.04 hectares in Tulsa County and at least 32.4 additional hectares within the state (Claytor and Hickman 2015). Kudzu has been documented in 28 counties in Oklahoma, mainly in eastern Oklahoma (Oklahoma Vascular Plants Database)(Figure 1), and two locations in Tulsa County. We describe a previously undocumented population of kudzu currently covering approximately 6.5 hectares in Tulsa County.

### STUDY SITE AND METHODS

The Tulsa kudzu site that we describe is distinct from the two locations listed in the Oklahoma Vascular Plants Database (<http://www.oklahomaplantdatabase.org>).



addition to the kudzu records for Tulsa County, which was previously estimated at 0.04 hectares (Claytor and Hickman 2015),

and it demonstrates a need for the documentation and management of kudzu in Tulsa County.

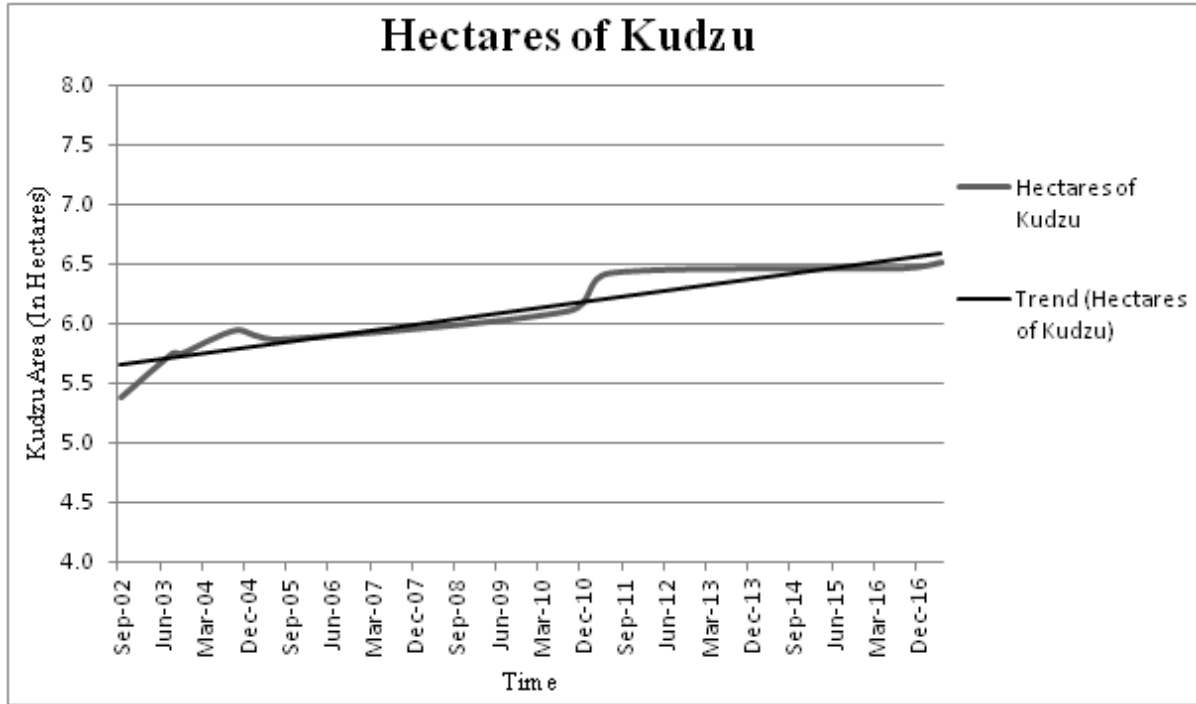


Figure 2 Change in area infested by kudzu using Google Earth Historical Imagery (Google Earth 2018) at the Broken Arrow site

Table 1 Hectares of kudzu present from 2002–2005, 2010, 2011, 2016, and 2017 using Google Earth Historical Imagery (Google Earth 2018)

Google Earth image date	Sep. 2002	Aug. 2003	Oct. 2003	Oct. 2004	Jul. 2005	Sep. 2010	Jun. 2011	Sep. 2016	May 2017
Estimated hectares	5.38	5.75	5.75	5.95	5.87	6.11	6.43	6.47	6.52



Figure 3 Kudzu patch at the Broken Arrow site, August 2017. Photo by Isaac Walker.



Figure 4 Kudzu invasion in field and over trees at the Broken Arrow site, August 2017. Photo by Isaac Walker.

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## COMPARATIVE TRANSPIRATION STUDIES ON THE INVASIVE EASTERN REDCEDAR (*JUNIPERUS VIRGINIANA* L.) AND ADJACENT WOODY TREES

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*Keywords: loblolly pine, bur oak, eastern cottonwood, white mulberry*

### ABSTRACT

Fire suppression and grazing on the Great Plains have resulted in alteration of the grassland ecosystem, including an increase in woody trees. Eastern redcedar (*Juniperus virginiana* L.) is a native but invasive conifer that is rapidly expanding its range in Oklahoma due to human and ecological factors and the ability to tolerate aridity. It is known to reduce soil moisture due to high rates of water uptake compared to neighboring grasses and herbaceous species. The objectives of this study were to compare average amounts of water transpired between eastern redcedar and adjacent woody trees in central Oklahoma to determine how water loss in the conifer compares with other trees in the same locality. Average amounts of transpiration in eastern redcedar were compared with those of loblolly pine (*Pinus taeda* L.), white mulberry (*Morus alba* L.), eastern cottonwood (*Populus deltoides* W. Bartram ex Marshall) and bur oak (*Quercus macrocarpa* Michx.). Three to six branch tips per tree were securely bagged over 24-hour periods, and water collected in each bag was weighed and analyzed. Three to five sampling months spanning two or three seasons were conducted for each comparative study. Results indicated that for winter, spring, and fall, transpiration from eastern redcedar exceeded that from the other tree species. Weather variables such as day length and temperature were found to have strong to moderate effects on transpiration in eastern redcedar. Day length and temperature also had strong effects on transpiration in white mulberry and bur oak, respectively, and humidity had an effect on transpiration in loblolly pine. No reliable or significant effect of weather variables was detected in eastern cottonwood.

### INTRODUCTION

Eastern redcedar (*Juniperus virginiana* L.) is the most widely distributed evergreen in the eastern half of the United States (Smith 2011; Van Haverbeke and Read 1976) and extends into the Great Plains (van Els et al. 2010). In 1950, eastern redcedar occurred

on about 1.5 million acres of Oklahoma (Bernardo 1986). By 1985, the conifer had expanded its range to 3.5 million acres, and by 1994, it had spread to almost 6 million acres of land in Oklahoma (Bernardo 1986; McKinley 2012). This indicates an increase of about 79% in less than 50 years. In 1985, a survey by the Soil Conservation Service

indicated that eastern redcedar, though native, has become invasive and widespread (Snook 1985). In the last few decades, eastern redcedar is rapidly expanding its range in the southern Great Plains primarily due to fire suppression (Bragg and Hulbert 1976), livestock overgrazing (Van Auken 2009; Briggs et al. 2002), and rapid seed germination (Horncastle et al. 2004). It is a pioneer species in old fields and pastures protected from fires. Eastern redcedar is estimated to be currently expanding its range at a rate of 300,000 acres (121405.69 hectares) per annum in the Oklahoma rangelands and prairies (Hung 2012). Although native to the state, it is considered to be drought-tolerant, invasive (Snook 1985; Bihmidine et al. 2010), and well adapted to the semi-arid climate of the state partly due to the presence of scale-like leaves, a thick cuticle, sunken stomata, and fibrous roots typical of conifers.

The fast encroachment of eastern redcedar has raised concern among scientists, land owners, ranchers, water resource managers, and policy makers as a hindrance to water conservation (Hung 2012). The encroachment of eastern redcedar is expected to cause a decline in soil moisture, stream flow, and water supply due to its relatively high water uptake capability compared to native grasses in the same habitat (Huxman et al. 2005). It is estimated that one acre of eastern redcedar trees can absorb up to 55,000 gallons (ca. 208,000 L) of water every year, thereby reducing soil water availability to grasses and other herbaceous species (Briggs et al. 2002).

Research on the effect of eastern redcedar in grassland ecosystems has focused primarily on water use efficiency, impact on soil moisture, and effect on adjacent native grass species (Hung 2012; Awada et al. 2013). However, as a drought-tolerant invader in the semi-arid grassland of Oklahoma, it is important to investigate the amount of water transpired from eastern

redcedar. Previous studies have shown that in loblolly pine (*Pinus taeda* L.), green ash (*Fraxinus pennsylvanica* Marshall), and sunflower (*Helianthus annuus* L.) high rates of transpiration during the day enhanced root absorption at night in the sense that the rate of water intake was largely determined by the rate of water loss (Kramer 1937). The current study was designed to determine the average amount of water transpired from branch tips with intact leaves of eastern redcedar and adjacent trees in four localities in central Oklahoma. The objectives of the study were to 1) compare the average amounts of transpiration in eastern redcedar and adjacent trees in the same habitat and 2) determine how climatic factors such as temperature, humidity, day length, and wind speed affect transpiration in the trees. Results will be useful in understanding the potential amount of water transpired from eastern redcedar. Because most broadleaf deciduous trees in the area are dormant in the winter season, the focus of the study was to assess the level of transpiration in eastern redcedar (and loblolly pine) during the cold seasons, the beginning and end of the warm seasons when deciduous trees are re-foliating or defoliating.

## MATERIALS AND METHODS

Sampling was conducted on trees growing in central Oklahoma at both urban and rural sites. Three deciduous tree species: white mulberry (*Morus alba* L.), eastern cottonwood (*Populus deltoides* W. Bartram ex Marshall), and bur oak (*Quercus macrocarpa* Michx.) and one evergreen conifer, loblolly pine, were selected for the comparative studies, in addition to eastern redcedar. These tree species were sampled because they were growing in the same locality on yards and ranches accessible to undergraduate researchers. A total of four sites were selected, three in Oklahoma County and one in Pottawatomie County. At each site, one to three eastern redcedar

trees were sampled adjacent to one to three comparable trees. The Oklahoma County sites contained eastern redcedar and white mulberry in downtown Oklahoma City (35.4754°N, 97.5330°W), eastern redcedar and eastern cottonwood in urban southeastern Oklahoma City (35.4111°N, 97.5556°W), and eastern redcedar and loblolly pine in rural, wooded southeastern Oklahoma City (35.4249°N, 97.3260°W). Eastern redcedar and bur oak were studied at a site in rural northwestern Pottawatomie County (35.4359°N, 97.0917°W). The investigations were conducted in two parts, a fall study (September–December) of eastern redcedar and bur oak and a spring study (February–June) of eastern redcedar and loblolly pine, eastern cottonwood and white mulberry.

To assess transpiration, clear plastic bags 68.5 cm x 60.9 cm (HDX Waste Basket Liners) were used to enclose branch tips (Robinson and Donaldson 1967). Each bag was examined for holes or open seams prior to use. The mass of each empty bag was estimated ( $W_i$ ; g), and it was tightly secured with twine around three to six branch tips on each tree (Jadrich and Bruxvoort 2011). Branch tips ranged in length from 60–65 cm. Branch tips had approximately 30–40 leaves and needles, except for eastern redcedar that had numerous scales that could not be counted. Leaf surface area was not measured since leaves remained intact on branches, and many were high up on the branches and individual leaves could not be easily measured. Bags securely fastened on branches were left overnight for a 24-hour period, after which they were carefully removed and mass was measured ( $W_f$ ; g). The mass of water ( $W_w$ ; g) collected in each bag was determined by subtracting  $W_i$  from  $W_f$  that is,  $W_w = W_f - W_i$ . Branch tips sampled per tree were varied weekly to achieve greater sampling of each tree. Branch tips high up on a tree were reached by carefully climbing ladders. The same

side(s) of adjacent trees were bagged each time for consistency and to minimize microclimate effect. To assess the potential of condensation inside bags, additional bags were closed and left outside for each sampling event. Condensation was either negligible or completely absent after 24h, particularly after the early morning hours when bags were examined. Because sampling for each tree species at each site was conducted at the same time, the influence of condensation on the results was uniform across species. Experiments were suspended during rainy or windy days to avoid accidental influx of rain water in the bags or puncturing/removal of bags due to excessive wind. The experiment was conducted weekly over three to five months. The local weather (temperature, humidity, wind speed, precipitation, and day length) was recorded for each sampling day by accessing Oklahoma Mesonet Weather reports (Oklahoma Climatological Survey 2017). Following rainfall events, precipitation levels were recorded, but due to persistent rainfall in the spring, there were entire weeks when sampling was suspended. The bagging technique is typically used in classroom demonstrations (Jadrich and Bruxvoort 2011) but has potential for research applications explored here. However, if bags were not firmly secured, they could have been blown away by the wind or punctured. Furthermore, changes in ambient temperature could cause condensation of moisture in the air originally trapped in the bag during bagging. Temperatures were typically mild or low, except for a few sampling days when temperatures were high; thus, condensation in bags due to ambient high temperature was either absent or negligible.

The total amount of water collected (transpired) was organized into tables for each investigation and analyzed using PASW Statistics ver. 18.0 for Windows - Predictive Analysis SoftWare (SPSS, Inc. 2009). Normality tests were conducted to

determine the appropriate analysis (parametric or non-parametric) for each dataset. Due to the small sample size in each investigation (< 50), Shapiro-Wilk test was conducted instead of K-S test. Ghasemi and Zahediasi (2012) reported that Shapiro-Wilk test is more reliable in testing data with a small sample size of fewer than 50. The eastern redcedar and loblolly pine data were analyzed using a t-test of the hypothesis that these species experience equal transpiration rates after conducting Levene's test for equality of variances. The remaining comparison involved significantly non-normal data, and differences were tested using Mann Whitney U tests (SPSS Inc. 2009; Zar 1996). The significance level (alpha) was set at 0.05 for all statistical analyses. Correlations between weather variables and transpiration for each

comparison investigation were determined by conducting paired samples t-tests using SPSS (SPSS, Inc. 2009).

## RESULTS

### *Tests for Normality*

Results of the normality tests (Shapiro-Wilk tests) indicated that for the spring study most of the data were normal (as significance levels were higher than 0.05) except for white mulberry, and eastern redcedar compared with eastern cottonwood (Table 1). The Shapiro-Wilk test also indicated that for the fall study data obtained for eastern redcedar were not normal (p-value = 0.017) and bur oak data were normal (p-value = 0.097) (see Table 1). Transpiration rates for eastern redcedar growing with loblolly pine were normal.

Table 1 Results of Shapiro-Wilk Normality Tests for data obtained for all comparison studies. Significance level (P-value) = 0.05. P-values greater than 0.05 indicate normal data; less than 0.05 indicate not normal data.

	Statistic	Degrees of freedom (df)	Significance Level (p-value)
<b><u>Spring</u></b>			
Eastern redcedar	0.935	13	0.401
White mulberry	0.814	13	0.010
Eastern redcedar	0.897	9	0.237
Loblolly pine	0.857	9	0.090
Eastern redcedar	0.750	15	0.0001
Eastern cottonwood	0.948	15	0.495
<b><u>Fall</u></b>			
Eastern redcedar	0.850	15	0.017
Bur oak	0.900	15	0.097

Table 2 Results of parametric and non-parametric tests at 0.05 significance level for testing mean transpired water. F = Fisher's statistics, t = T-value, DF = degree of freedom, CI = confidence interval, U = U-value, N = sample size, P = probability value/significance level, - = not applicable. P-value > 0.05 indicates dataset not significantly different.

Statistical Analysis	Investigation	Mean/Mean Ranks	F	t	DF	95% CI of difference	U	N	P-value
<b>Parametric</b>									
<u>Means</u>									
Levene's Equality test of variances	Eastern redcedar & Loblolly pine	90.54g : 49.92g	0.413	-	16	-	-	9 : 9	0.53
Independent samples t -test	Eastern redcedar & Loblolly pine		-	2.392	16	4.63 - 6.62	-	18	0.29
<b>Non-Parametric</b>									
<u>Mean Ranks</u>									
Mann-Whitney U test (Exact sig.)	Eastern redcedar & White mulb.	15.85g : 11.15g	-	-	-	-	54	26	0.125
Mann-Whitney U test (Exact sig.)	Eastern redcedar & Cottonwood	21.67g : 9.33g	-	-	-	-	20	30	0.0001
Mann-Whitney U test (Exact sig.)	Eastern redcedar & Bur oak (fall)	14.07g : 16.93g	-	-	-	-	91	30	0.389

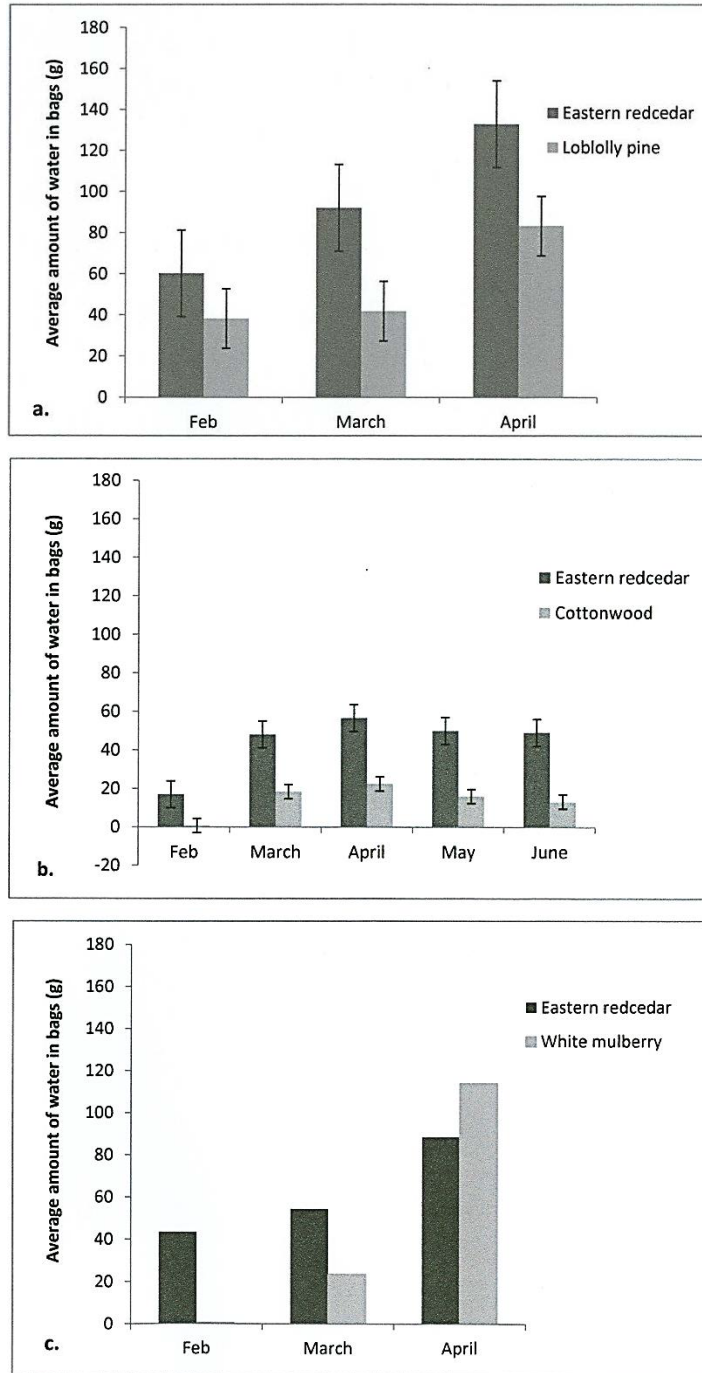


Figure 1 Average monthly transpiration measured in the spring study for (a) comparison study between eastern redcedar and loblolly pine conducted in rural southeastern Oklahoma City, (b) comparison study between eastern redcedar and eastern cottonwood conducted in urban southeastern Oklahoma City, and (c) comparison study between eastern redcedar and white mulberry conducted in downtown Oklahoma City. Bars represent means of water collected for all trees during the sampling period. Standard error bars represent distribution of overall data obtained for three trees per species (a & b). Bars without error bars represent means of water collected for one tree per species (c). All sites were located in Oklahoma County.

***Spring Study: eastern redcedar and loblolly pine, white mulberry and eastern cottonwood***

The variances of eastern redcedar and loblolly pine did not differ significantly (Levene's test:  $F = 0.413$ ,  $p = 0.53$ ,  $df = 16$ ). The mean amount of water transpired did not differ between these species (t-test:  $t = 2.392$ ,  $p = 0.29$ ,  $df = 16$ ) (Table 2). The mean amount of water transpired by eastern redcedar was 90.54 g; whereas, the mean for loblolly pine was 49.92 g. Results of Mann-Whitney tests indicated that the difference in mean transpiration was not significant between eastern redcedar and white mulberry ( $U = 54$ ,  $N = 26$ ,  $p = 0.125$ ) but was significant between eastern redcedar and eastern cottonwood ( $U = 20$ ,  $N = 30$ ,  $p = 0.0001$ ) (see Table 2). Average monthly transpiration increased steadily in all trees from winter to spring (Figure 1a - c).

Eastern redcedar transpired on all sampling days at all three sites, and its average transpiration was also higher than that by eastern cottonwood in each month from February to June (see Figure 1b). In the comparisons of total transpired water between eastern redcedar and either loblolly pine or eastern cottonwood, 64% and 70% respectively of the total amounts of water transpired were obtained from eastern redcedar (Table 3). In the spring, significant effect was detected between day length and transpiration in eastern redcedar (Figure 2), and white mulberry (Table 4). Humidity also had some effect on transpiration in loblolly pine, but no effect was detected in the remaining tree species, including eastern redcedar (see Table 4). Results on precipitation were inconclusive due to very small sample size.

Table 3. Total amounts of water transpired over entire sampling periods and overall percentages of total water mass sampled from eastern redcedar alone. N = number of sampling days.

Comparison	N	$W_w$ - Total mass of water in bags (g)	Percent of total water transpired from Eastern redcedar (%)
Eastern redcedar & Loblolly pine (spring)	9	1264	64
Eastern redcedar & Eastern cottonwood (spring)	15	1086	70
Eastern redcedar & White mulberry (spring)	13	981	50
Eastern redcedar & Bur Oak (fall)	15	1920	68

Table 4 T-test paired samples correlations showing effects of weather variables on transpiration during the spring and fall studies. N = number of sampling days, \* = P-value  $\leq$  0.05, \*\* = P-value  $\leq$  0.01, \*\*\* = P-value  $\leq$  0.001, \*\*\*\* = P-value  $\leq$  0.0001, - = not recorded.

Weather Variables	Spring N = 9		Spring N = 13		Spring N = 15		Fall N = 15	
	Eastern redcedar	Loblolly pine	Eastern redcedar	White mulberry	Eastern redcedar	Eastern cottonwood	Eastern redcedar	Bur oak
<b>Day length</b>	0.205	0.27	0.762**	0.933**	0.616***	0.237	0.206	0.335*
<b>Temperature</b>	0.278*	0.099	0.225	0.101	0.414**	0.256	0.278	0.71****
<b>Humidity</b>	0.209	0.672*	0.052	0.082	0.047	0.009	0.111	0.131
<b>Wind Speed</b>	0.351	0.245	0.111	0.226	0.101	0.133	-	-
<b>Precipitation</b>	0.022	0.038	0.035	0.135	-	-	-	-



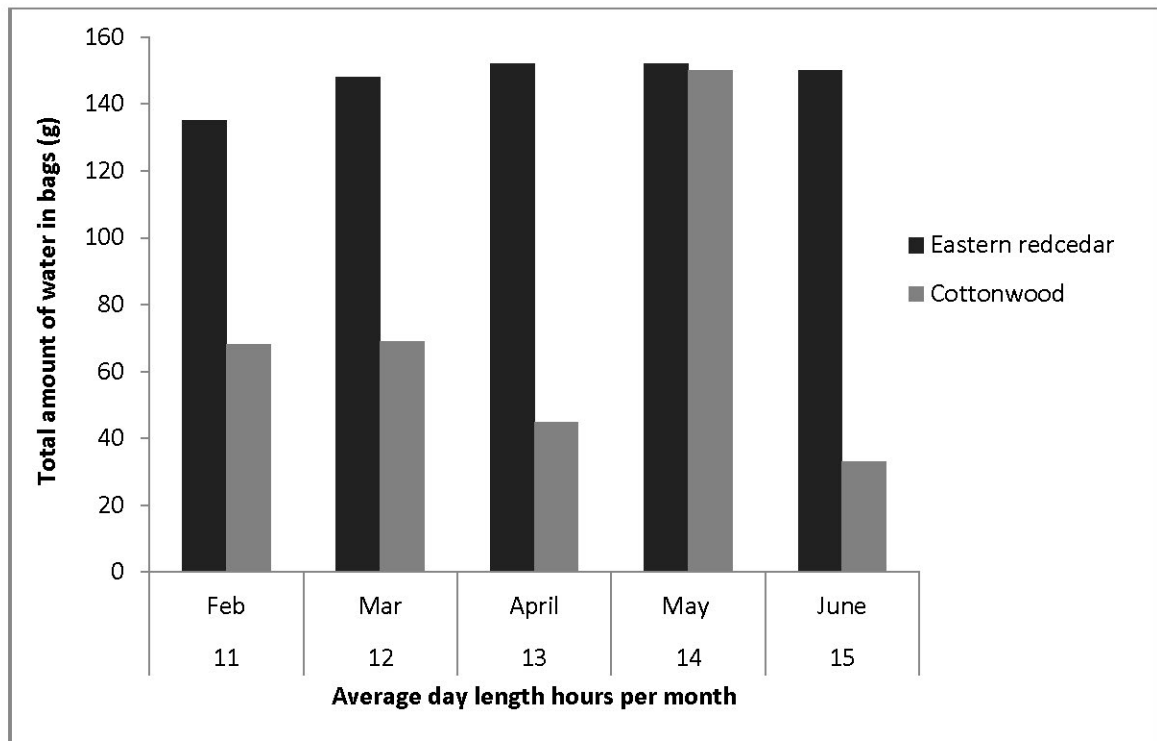


Figure 2 Effect of increasing day length on transpiration as observed in comparison study between eastern redcedar and eastern cottonwood in urban southeastern Oklahoma City

***Fall study: eastern redcedar and bur oak***

Results of Mann-Whitney U tests indicated that the ranks of median transpired water were not significantly different between eastern redcedar and bur oak ( $U = 91$ ,  $N = 30$ ,  $p = 0.389$ ) (see Table 2). However, similar to the spring study, eastern redcedar transpired throughout the entire sampling period (Figure 3) and 68% of the total amount of water sampled in the entire study came from eastern redcedar (see Table 3). In eastern redcedar, transpiration was very low at high temperatures  $\geq 90^{\circ}\text{F}$  ( $32^{\circ}\text{C}$ ) but moderate at warm temperatures ranging from  $77\text{--}88^{\circ}\text{F}$  ( $25\text{--}31^{\circ}\text{C}$ ) (Figure 4). In the winter when the temperature fell below freezing at  $29^{\circ}\text{F}$  ( $-1.7^{\circ}\text{C}$ ), transpiration decreased in eastern redcedar to similar levels observed in the

summer when temperatures were at  $90^{\circ}\text{F}$  and  $94^{\circ}\text{F}$  ( $34^{\circ}\text{C}$ ), respectively. In the late summer at high temperatures, transpiration in bur oak was very high, but as temperature decreased in the fall, transpiration decreased quickly as trees defoliated until transpiration completely stopped when temperatures reached below  $44^{\circ}\text{F}$  ( $7^{\circ}\text{C}$ ) and trees became dormant. Thus, temperature had a significant effect on bur oak but not on eastern redcedar (see Table 4). Day length was also found to have an effect on transpiration in bur oak but not eastern redcedar (see Table 4). As day length decreased from summer through fall, transpiration decreased in both bur oak and in eastern redcedar (see Figure 4 and Table 4). Effect of humidity and precipitation were not tested.

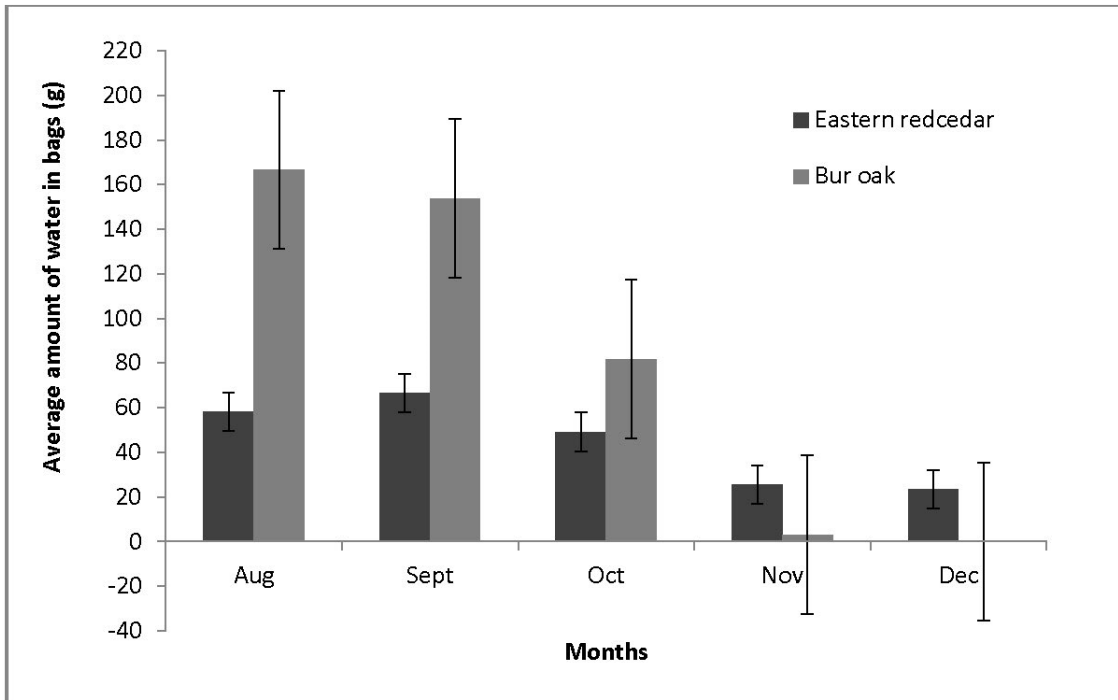


Figure 3 Average monthly transpiration measured for eastern redcedar and bur oak in the fall study in rural northwestern Pottawatomie County. Bars represent means of water collected for all trees that month. Standard error bars represent distribution of overall data obtained for three trees per species.

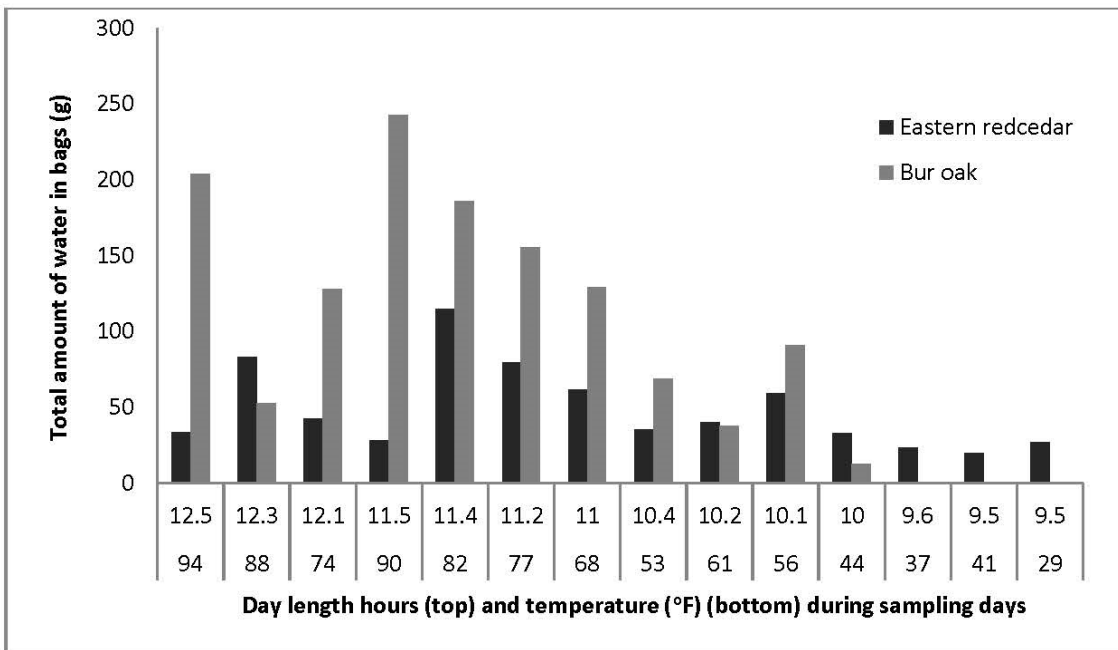


Figure 4 Combined effect of decreasing average daily temperature and decreasing day length hours on transpiration observed in the comparison study between eastern redcedar and bur oak during fall in rural northwestern Pottawatomie County

## DISCUSSION

Results of the study indicated that eastern redcedar transpired throughout the entire study period and more than observed in adjacent trees including loblolly pine (see Table 3). This may be partly due to the presence of stomata on both surfaces of the numerous scales (reduced leaves) of eastern redcedar. Although stomatal counts were not conducted in this study, leaf anatomical studies of a related species, western juniper (*Juniperus occidentalis* Hook), revealed stomatal distribution on both abaxial and adaxial surfaces of the scales with the majority of stomata occurring on the adaxial surface and near the margins (Miller and Shultz 1987). Unlike deciduous trees, transpiration in eastern redcedar did not greatly increase during the warm growing seasons but remained low to moderate even when seasons changed (see Figures 1 and 3). A study by Eggemeyer et al. (2009) on depth of water uptake in eastern redcedar growing in Nebraska using stable isotopes of hydrogen and oxygen revealed that in the winter, water uptake occurs from deeper levels of the soil below 0.9 m due to unfavorable low and extreme temperatures in upper soil profiles. However, in the warm seasons, water uptake in eastern redcedar occurred at the shallow soil levels between 0.05 – 0.5 m. Uptake of water from the upper soil profiles during the warm seasons was associated with an increase in fine shallow roots (Eggemeyer et al. 2009). It has also been reported by Lawson (1990) that adults and seedlings of eastern redcedar are known for their fibrous and extensive root system that spreads widely in shallow and rocky soils. Furthermore, eastern redcedar is known to develop some form of deep penetrating taproot when growing in good soils, thereby enhancing water uptake from deeper levels and transpiration (Hung 2012). The ability for eastern redcedar to utilize soil water at variable depths in response to

seasonal temperatures may account for the low to moderate amounts of transpiration of eastern redcedar observed in all the comparison investigations in the current study. Awada et al. (2013) also observed significant seasonal variability in transpiration in eastern redcedar with minimal transpiration observed in the winter from December to February when ambient temperatures fell below 0°C. Similarly, in the present investigations, very low average amounts of transpiration were sampled for eastern redcedar during the cold months of February (see Figures 1a–c), November, and December (see Figures 3 and 4). However, the highest average amounts of water sampled from eastern redcedar were in April at the beginning of spring (see Figures 1a–c) and September at the end of summer (see Figure 3).

Average amounts of transpiration were also highest for loblolly pine, white mulberry, and cottonwood in April (see Figures 1a and c). Low transpiration was observed for loblolly pine in February compared to eastern redcedar. In general, average transpiration was observed to increase in March (see Figures 1a–c) when trees were leafing out. The results further show that eastern redcedar and loblolly pine (both conifers and evergreen) transpired in February when the deciduous trees were either dormant or lacked matured leaves. The trace amounts of water sampled for eastern cottonwood and white mulberry in February may have been due to condensation after a spike in ambient temperature on one sampling day (see Figures 1b and 1c). Hydrogen isotopes used to determine water uptake from different soil levels in loblolly pine in North Carolina revealed that similar to eastern redcedar, water uptake during spring through fall occurred primarily in the upper soil profiles; whereas, in winter, water uptake occurred at lower soil profiles (Retzlaff et al. 2001). Our data suggest that eastern redcedar and loblolly pine may have similar water uptake

strategies (Eggemeyer et al. 2009; Retzlaff et al. 2001), as evident in the consistent amounts of water collected in the bags throughout the sampling period (see Figure 1a). The effect of humidity on transpiration in loblolly pine (see Table 4) supports its predominant southern distribution in the USA where average humidity may be higher than that on the grassland due to the forest ecosystem, coastal climate, and higher annual precipitation.

Awada et al. (2013) reported that in the winter, daily average air temperature was a major factor limiting transpiration in eastern redcedar followed by precipitation and photosynthetic active radiation. In that study, a slight increase in transpiration in eastern redcedar was measured in the months of March and April when environmental conditions improved as photosynthetic active radiation, temperature, and precipitation increased. Awada et al. (2013) further observed significant regression estimates between transpiration in eastern redcedar and daily air temperature when temperatures were above 0°C (32°F). Despite the limited sampling events of our current spring investigations, temperature was found to have a significant effect on transpiration in eastern redcedar (see Table 4). Similarly, day length had an effect on transpiration in eastern redcedar in the spring (see Figure 2 and Table 4). Therefore, it can be inferred from the results obtained that as day length increased from February to June, associated with an increase in temperature, transpiration increased in all trees, especially in eastern redcedar (see Figure 1). In late August through late September when day length was long (11.0–12.5 hours), transpiration was much higher in bur oak than in the adjacent eastern redcedar. However, as day length decreased (from October), transpiration drastically decreased in bur oak, and by late November and early December, negligible amounts were recorded. Eastern redcedar, on the other

hand, maintained a consistent moderate to low transpiration even when day length decreased to 9.5 hours in early December. Despite the uneven sampling events for both spring and fall studies, the t-test paired samples results suggested that overall, day length and temperature are two weather variables that affected transpiration in eastern redcedar (see Table 4). Thus, further research will be necessary to better understand the combined effects of weather variables on transpiration in eastern redcedar.

In conclusion, the success of eastern redcedar in the semi-arid grassland may be due to multiple factors, including drought-tolerance (Hung 2012), long growing season (Awada et al. 2013), water uptake strategies (Eggemeyer et al. 2009), and the effect of day length and temperature on transpiration, as observed in this study. Considering the mild and short winters, coupled with early spring typical of Oklahoma weather, transpiration in eastern redcedar appears to span all seasons. Transpiration is moderate during warm seasons but low during hot or cold seasons. Thus, overall, annual transpiration in eastern redcedar may be higher than in adjacent trees due to the consistent low to moderate transpiration all year round, regardless of season.

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## NEW RECORD OF *MYRIOPTERIS LINDHEIMERI* (HOOK.) J. SM. IN KIOWA COUNTY, OKLAHOMA

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### ABSTRACT

*Myriopteris lindheimeri* (Hook.) J. Sm. (fairy swords; Pteridaceae) is an apogamous fern of the southwestern United States. Fairy swords are native to Arizona, New Mexico, Texas, and Oklahoma. The only two records in Oklahoma are from Comanche County: F.B. McMurry in 1942 and J.B. Beck with C.J. Rothfels in 2017. In this article, I report a new sighting from Kiowa County, describe the species, and explain how it can be distinguished from other southwestern Oklahoma species in the genus.

### INTRODUCTION

*Myriopteris lindheimeri* (Hook.) J. Sm. (fairy swords; Pteridaceae), formerly *Cheilanthes lindheimeri* Hook. (Grusz and Windham 2013), is a fern of the southwestern U.S. that occurs in Arizona, New Mexico, Texas (Windham and Rabe 1993), and Oklahoma (Hoagland et al. 2004-present). The species has been classified as rare by the Oklahoma Natural Heritage Inventory with a SH rank (Oklahoma Natural Heritage Inventory 2018). The only occurrences in Oklahoma were reported from Comanche County (Hoagland et al. 2004-present) in 1942 and 2017. The 2017 specimens were deposited at the herbaria of the University of Oklahoma, University of Michigan, University of Duluth, and Wichita State University. A third sighting in Kiowa County in 2013 and 2016 is reported in this article. I will give a technical description of *M. lindheimeri* and describe general locations where it has been seen and collected. I will also include a simple dichotomous key to six southwestern Oklahoma species of *Myriopteris*.

### METHODS AND MATERIALS

On March 18, 2013, my wife and I visited Lindheimer's Mountain (Figure 1) on the campus of Southwest Baptist Youth Camp in Kiowa County. I made two collections of what I thought were *Myriopteris rufa* Fée most likely because the blades appeared tomentose. To my surprise, both specimens were *M. lindheimeri*. On April 23, 2016, I visited the same location and again found a population (Figure 2) of what I thought was *M. rufa*. I made several collections, and once again I had made the same identification mistake as I did in 2013. Knowing how rare *M. lindheimeri* is, and knowing that the only record of its occurrence was in Comanche County, it took me by surprise. The 2013 and 2016 specimens will be deposited in the herbaria of the University of Oklahoma, University of Central Oklahoma, and Oklahoma State University. The exact location of the collection is not reported because of the status of *M. lindheimeri* as a species of conservation concern in Oklahoma.

## MYRIOPTERIS IN OKLAHOMA

*Myriopteris* in Oklahoma is composed of eight species that were formerly in the genus *Cheilanthes* (Grusz and Windham 2013). The eight species are typically separated by presence or absence of rachis scales and whether the fronds are clustered or separated on the rhizomes (Figures 2, 3, 4, and 5). Six of the eight species can be found on rocky slopes and ledges in the Wichita Mountains: *M. gracilis* Fée, *M. lanosa* (Michx.)

Grusz and Windham, *M. rufa* Fée, *M. tomentosa* (Link) Fée, *M. wootonii* (Maxon) Grusz and Windham, and *M. lindheimeri*. Neither *M. alabamensis* (Buckley) Grusz and Windham nor *M. scabra* (C. Chr.) Grusz and Windham have been reported to occur in the Wichita Mountains. Both occur mainly on limestone rock; *M. alabamensis* is a northeastern Oklahoma species reaching its western limits in Murray County, and *M. scabra* has only been sighted in Murray County.

## DESCRIPTION OF *MYRIOPTERIS LINDHEIMERI*

**Plants** growing in open rock crevices or rock overhangs or rocky ledges (see Figure 2; Figure 6). **Rhizomes** long creeping, fronds separate. **Fronds** all alike, 3.1-29.5 cm long, mostly erect; vernation noncircinate. **Stipes** straight or curving, brown; scales conspicuous. **Blades** oblong-lanceolate to ovate-deltate, 1.5-4 cm wide, 2-13 cm long, 3-4 times pinnately compound at the base; pinnulets or ultimate segments beadlike at the base; adaxial surfaces green, falsely appearing tomentose (the hairs have their origin from the ciliate scales that grow between the lobes of the ultimate segments from the abaxial surfaces to the adaxial surfaces); abaxial surfaces obscured by scales with ciliate margins. **Rachis** brown; scales conspicuous. **Costae** on adaxial surfaces green, obscured by scales. **Revolvate margins (false indusia)** hidden or partially hidden by scales (Figure 7). **Sori** continuous.

## KEY TO SOUTHWEST OKLAHOMA LIP FERNS, *MYRIOPTERIS*

1. Rachis and stipe scales absent; segmented hairs present.
  2. Ultimate segments beadlike. .... *M. gracilis* (= *Cheilanthes feei*)
  2. Ultimate segments not beadlike. .... *M. lanosa* (= *Cheilanthes lanosa*)
1. Rachis and stipe scales present; segmented hairs absent.
  3. Rhizomes short creeping. Fronds clustered, erect in center to ascending to descending on the outside.
    4. Scales on abaxial surfaces of costae conspicuous, margins crose-dentate. Blades about 6 times longer than wide. .... *M. rufa* (= *Cheilanthes eatonii*)
    4. Scales on abaxial surfaces of costae inconspicuous, margins entire. Blades about 4 times longer than wide. .... *M. tomentosa* (= *Cheilanthes tomentosa*)
  3. Rhizomes long creeping. Fronds separate, mostly erect.
    5. Adaxial surfaces of blades glabrous. Revolvate margins (false indusia) on abaxial surfaces of blades conspicuous, not hidden by scales. .... *M. wootonii* (= *Cheilanthes wootonii*)
    5. Adaxial surfaces of blade glabrous, but appearing tomentose (the hairs on the adaxial surface originate from the abaxial surfaces and grow between the lobes of the ultimate segments to the adaxial surface). Revolvate margins (false indusia) on abaxial surfaces of blades inconspicuous, hidden or partially hidden by scales. .... *M. lindheimeri* (= *Cheilanthes lindheimeri*)



## DISCUSSION AND CONCLUSIONS

Currently *M. lindheimeri* is assigned a state rank of SH plant by the Oklahoma Natural Heritage Inventory (Oklahoma Natural Heritage Inventory 2018). SH plants are thought to be "possibly extinct or extirpated" in Oklahoma. With the two new sightings in Comanche and Kiowa counties, the status of the species will be upgraded to S1 (Amy Buthod, Oklahoma Natural Heritage Inventory, personal communication). S1 means the species is critically imperiled, with fewer than five populations. This is good news.

The number and size of the populations in the area in which it has been found are also important to conserving *M. lindheimeri*. The 2017 Wichita Mountains National Wildlife Refuge collection by Beck with Rothfels is from a single population of two small patches with at least 100 leaves (James Beck, Wichita State University, personal communication). I have no idea how many populations are on Lindheimer's Mountain; it is a large area that needs to be traversed on both sides. The picture taken in April 2016 is of a relatively large group of fairy swords. The population I visited in November 2018 (which may be the same population as the one located in 2016) is about 6 m<sup>2</sup> with nine groups about the size of those pictured in Figure 6. The area needs more visits to document the size of the population(s).

In conclusion, I am glad that Frank McMurry explored the Wichita Mountains and made a record of *M. lindheimeri*. Nice job J.B. Beck and C.J. Rothfels for successfully searching and finding *M. lindheimeri*, for the first time since 1942. It must have been an exciting day. Good news, it still lives in the Wichitas! Finally, I am glad we found it "thriving" in Kiowa County. Hopefully, additional populations will be

found, its known range will be extended in both counties, and it will be found in other southwestern Oklahoma counties. I suggest Quartz Mountain Resort and Headquarters Mountain Hiking Trail in Granite (both in Greer County) as good areas to search. Let me know; I am ready.

## ACKNOWLEDGMENTS

Thanks to Clayton and Christie Carlisle for giving me access to the Southwest Baptist Youth Camp. You have been very kind. Thank you reviewers, including Amy Buthod, for your time and additions. Thank you, Dr. Caddell, for your additions, editing the article, patience, and allowing me to publish my findings.

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Figure 1 Lindheimer's Mountain (name given by the author), Southwest Baptist Youth Camp, near Quartz Mountain Resort. Photo by Bruce Smith.



Figure 2 *Myriopteris lindheimeri* (= *Cheilanthes lindheimeri*), fairy swords, growing under a granite rock overhang on Lindheimer's Mountain, Southwest Baptist Youth Camp. Note the long stretching rhizome, separate erect fronds, and adaxial surfaces appearing tomentose. Photo taken by Bruce Smith.



Figure 3 *Myriopteris wootonii*, beaded lip fern. Rhizomes long creeping, fronds separate. Photo by Bruce Smith.



Figure 4 *Myriopteris rufa*, Eaton's Lip fern, on Headquarters Mountain Hiking Trail in Granite, Oklahoma. Note the clustered fronds and the white hairs on the blade surfaces. Photo by Bruce Smith.



Figure 5. *Myriopteris tomentosa*, woolly lip fern. Rhizomes short creeping, fronds clustered. Photo by Bruce Smith.



Figure 6 *Myriopteris lindheimeri* growing in an open granite rock crevice on Lindheimer's Mountain, Southwest Baptist Youth Camp. Photo by Bruce Smith.



Figure 7 Abaxial surfaces of *M. lindheimeri* (top) and *M. wootonii* (bottom). Note the revolute margins (false indusia) hidden or partially hidden by scales on *M. lindheimeri*. Photo by Bruce Smith.

## ANTHER NUMBER, ANTHER APICAL APPENDAGES, AND POLLINATION BIOLOGY OF *CALYPTOCARPUS VIALIS* LESSING (HELIANTHEAE: ASTERACEAE)

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*Keywords: secondary pollen presentation, pollen-dome, reproductive system, bordered patch butterflies, invasive species*

### ABSTRACT

The numbers of disk floret anthers of *Calyptocarpus vialis* in Wichita County, Texas form a consecutive series of one to four; four anthers (71%) and three anthers (27%) were most common. Three anthers is an unusual, perhaps singular, number for Asteraceae. These florets also have four-lobed corollas. The extruded pollen-mass is enclosed by a vaulted dome created by apical appendages of the anthers that are lanceolate and inflexed. Pollination appears to be via autogamy (*sensu stricto*) for disk florets and (considering each head as a single blossom) facultative autogamy and allogamy (both geitonogamy and xenogamy) for the ray florets.

### INTRODUCTION

*Calyptocarpus vialis* Lessing (straggler daisy, horseherb, or horse herb) is native to eastern Mexico and perhaps as far north as Bexar and Medina, or even Travis, counties in Texas (Nesom 2011). It has spread eastward and become established in all the Gulf Coast states (Strother 2006; Nesom 2011), and Nesom recorded its presence in the Desert Southwest, Arkansas, South Carolina, Illinois, and western Mexico. He also clearly documented the species' recent migration north to the Red River where it was collected in Grayson County. The species has since been reported in Oklahoma (Singhurst et al. 2012; Ryburn et al. 2018), and it may be more widespread in the state. Migration may be partly attributable to the use of straggler daisy in the landscape-trade as a shade-loving groundcover and/or climate change.

Collections of the species from Texas are geographically spotty except in the south and south-central counties; however, it appears to be exceedingly under-collected throughout the state. In the Rolling Plains, the species is known from Tom Green (Nesom 2011), Wichita (this report), and Taylor (Anna Saghatelyn, pers. comm., 19 October 2018) counties. Based on Nesom's map (2011), straggler daisy occurs in all the vegetation areas of Texas (Correll and Johnston 1970) except the High Plains and the far western reaches of the Trans-Pecos Mountains and Basins (Nesom 2011).

Straggler daisy is now one of the most abundant, invasive lawn plants in Wichita County, Texas, especially, but not exclusively, in shady locations. In deep shade under Shumard oak (*Quercus shumardii* Buckley), two live oak species (*Quercus fusiformis* Small; *Quercus virginiana* Mill.), and American elm (*Ulmus americana* L.), its

measure of cover is often close to 100%. It is less dense, but still abundant, in the shade of sycamore (*Platanus occidentalis* L.), sugarberry (*Celtis laevigata* Willd.), and western soapberry (*Sapindus saponaria* L. var. *drummondii* (Hook & Arn.) L.D. Benson).

### ANTHER NUMBER AND FLORAL MORPHOLOGY IN *CALYPTOCARPUS VIALIS*

Five is, by far, the most common anther number among genera in the Asteraceae, although some taxa have only four (Barkley et al. 2006). Disk florets from specimens of *Calyptocarpus* in Mexico were reported to have either four or five anthers (McVaugh and Smith 1967; McVaugh 1984), and Gibson (2013+) observed both these numbers in Williamson County, Texas. Although the anther number was not listed by the authors in the *Illustrated Flora of North Central Texas* (Diggs et al. 1999), the illustration by Linny Heagy in the text displayed four anthers.

During a public event at River Bend Nature Center in Wichita Falls in 2014, I used heads of *C. vialis* in an exhibit to demonstrate magnification of plant parts using a Zeiss stereo-microscope—the small heads (diameter 6–9 mm: apex to apex of opposing rays) of straggler daisy were examined (along with its leaves) with the naked eye, a hand lens, and then the microscope at various powers of magnification. Elementary-aged students observed previously dissected heads and verbally described them, including the unusual achenes and the ray and disk florets. All the heads were taken from plants growing in soil within the Ruby N. Priddy Conservatory. The disk florets that the students examined had only three anthers per floret. These plants had been introduced from a local native plant nursery, perhaps from a single ramet.

To determine if this unexpected number of anthers was a singular horticultural sport,

in 2014, I surveyed fresh heads from a number of local populations in northern Wichita County and from specimens collected from the same areas in the Bebb Herbarium (OKL). Anther numbers formed a consecutive series from one to four, but not five.

To determine the proportion of each anther number in early fall of 2018, a 0.5 km transect along Park Street, Burkburnett, Texas was sampled. The species was personally known to be especially abundant along this street. Flowering heads of *C. vialis* were collected from populations growing along the verge of the street (utility easement of the lot) of every other street address, beginning with an exceptionally large population at 412 Park, east along the south side of the street, and then the alternate addresses on the north side of the street. If five distinct colonies were present, then one open head was taken from each colony. If a single continuous population was encountered, five heads were taken at five-step intervals. If fewer than five distinct colonies were present, then one head was taken from each available colony, with fewer than five collected for that site. If a site lacked *Calyptocarpus*, the sampling method was maintained, and no counts were made for that “plot.” Side streets were not counted as lots. Both mown and non-mown plants were sampled, as were plants in shady and sunny sites. The heads were dissected fresh, and the anther-numbers were determined. If anther number could not be determined from a plant (i.e., a head had completed its flowering phase), then it was discarded and not replaced, unless another head was present on the sampled stem. When an anther number of fewer than four was recorded, a second count from another floret in the sampled head was made to confirm the count. All those counts were confirmed. In sum, 63 heads included florets whose anthers could be tallied.

Sampled specimens along the transect revealed disk florets with two, three, or four

anthers, with four (71.43%) and three (26.98%) being the most common numbers (Table 1). I have been unable to find reports of composite genera with three anthers per disk floret in *Flora of North America* (Barkley et al. 2006).

Even though an earlier collection revealed one head with one anther per disk floret, no one-anthered heads were collected in this sample, and only one head (1.59%) had two anthers. The two anthers of this head were not fused and were opposite one another; whereas, the anthers were fused in those florets with three and four anthers. It seems likely that the one- and two-anthered florets are developmental anomalies rather than regular occurrences.

All of the heads that were in anthesis from five discrete plants were examined to determine if the number of anthers varied within plants. The number of anthers varied (three versus four) among the plants, but the numbers of anthers among all the disk florets of single heads and all the heads on a single plant were identical with respect to anther number, implying genetic control, but the sample size was small.

The range of anther numbers per disk floret obviously differs between populations in Mexico and central Texas and those in this study from Wichita County. It is unknown whether anther number decreases

along the SE to NW distributional axis for *C. vialis*, or if lower anther numbers occur (but have not been recorded) throughout the species in Texas and Mexico, or if the plants in Wichita County differ in the range of anther numbers from other populations in the state. Because these counts were obtained in late October and early November, perhaps some plants produce fewer anthers in the autumn.

All of the disk florets sampled in Wichita County had four corolla lobes; whereas, the populations sampled by McVaugh and Smith (1964) and McVaugh (1984) in Mexico and Gibson (2013+) in Texas were four- and less commonly five-lobed. In their description of *C. vialis*, Correll and Johnston (1970) reported five lobes for the corollas of disk florets. Therefore, I conclude that the number of corolla lobes also decreases from south to north.

The adaxial surfaces of the corolla lobes of the Wichita County plants are highly and densely ornamented with turgid papillae; these protuberances are yellow. The papillae are restricted to the adaxial surfaces; they are difficult to discern in herbarium specimens, and they were not discussed in any descriptions of the genus with which I am familiar.

Table 1 Distribution of anther numbers from samples of *Calyptocarpus vialis* from a transect in Wichita County, Texas. Five flowering heads were sampled from the street verge of each sampled address on Park Street in the city of Burkburnett. The survey was completed from late October to early November.

<i>anther number</i>	<i>individuals</i>
5	0
4	45
3	17
2	1
1	0
0	0



The number and form of ray florets, however, differed among and within the heads of single plants: Numbers of ray florets per head ranged from two to nine. Apices of the rays in this survey were either acute or broadly obtuse, and the number of teeth ranged from zero to five (the latter number on only one ray among five rays from one head on one plant). The teeth on a single ray often varied in size. This is in contrast to Correll and Johnston's (1970) description, which indicated that the rays are "equally 5-toothed." Gibson's (2013+) account indicated that most rays were two to three lobed (perhaps equivalent to teeth in this account and in Correll and Johnston's description) with a few, apparently, entire (in Gibson's description, "unlobed" was included in parentheses). In addition, with the exception of one head, the apices of the rays observed in this study were more appropriately referable to "teeth" rather than "lobes." It is possible that the numbers of teeth per ray diminish from south to north, but additional analysis would be necessary to determine if that is the case.

#### **ROLE OF APICAL APPENDAGES OF *CALYPTOCARPUS VIALIS* ANTHERS**

The anthers of the disk florets of *C. vialis* dehisce introrsely, and sweeping hairs on the distal surface of the style extrude the pollen-mass upward and out of the anther tube as per Proctor and Yeo's (1972), Yeo's (1993), and Carlquist's (1976) general descriptions for some genera in the family. However, rather than being presented in an open-cup formed from the appendages as described by Carlquist, in this species the inflexed appendages combine to form a closed, dome- or cap-like covering (hereinafter in this account referred to as a "pollen-vault" or "vault") over the pollen-mass. The entire pollen crop from the anthers was swept into the vault, rather than

incrementally (Proctor and Yeo 1972). Small (1915) recorded other composite genera with appendages that are inflexed. However, I did not locate any descriptions that implied a pollen-holding function for any other genera of the family.

The pollen-vault is formed as a result of the lanceolate appendages being curved inward (rather than outward) and fitting together closely. Therefore, the pollen is not immediately and readily available to foragers or for deposition on the stigmas of the ray florets. It was not visually apparent to this viewer, whether the margins of the appendages coalesced or cohered or were just closely fitted. However, judging by how readily they separated during dissection, I concluded that they were merely close-fitting (immature appendages were observed to be distinct). The yellow pollen, therefore, might be accessible to insects at the seams of the vault. In the heads with only two anthers, the pollen was only partially covered. That might result in the more ready deposition of pollen on styles of ray florets.

#### **POLLINATION BIOLOGY OF *CALYPTOCARPUS VIALIS* IN NORTHWEST TEXAS**

A sod of *C. vialis* was isolated in a Plexiglas-covered indoor terrarium to monitor achene-set in the absence of potential pollinators and to observe floral behavior. All heads that were already open and flowering or fruiting were excised. Newly-opening heads ( $n = 10$ ) were observed daily for one week. The plants in the sod failed to thrive indoors, and nine of the ten heads opened but shriveled within three weeks, and of the nine, six were both shriveled and brown. None of the nine exhibited fully developed achenes, though melanin did form in many of the flat, unfilled ovaries (three-week duration). Only one head formed achenes that appeared mature (expanded in all three dimensions,

dark brown). All of the achenes that appeared normal were from ray florets. None of the disk florets from that head produced mature achenes. I do not believe any conclusions regarding pollination can be drawn from this experiment.

Based on observations of capitulum development in the field and the terrarium-grown plants, when the flower buds open, on the first day of anthesis, the pistillate ray florets of blossoms of *C. vialis* emerge first from the buds, often in the late afternoon, but also other times throughout the day. This is equivalent to protogyny (Faegri and Pijl 1966; Proctor and Yeo 1972), presumably favoring cross-pollination. In all examined *Calyptracarpus*, the styles of this whorl of florets are oriented more or less radially, even though the flattened achenes are tangentially oriented. Pollen-carrying floral visitors could deposit pollen on these stigmas at any time after opening. I was unable to determine directly if nectar was being produced by the ray florets.

The outermost whorl of disk florets opens throughout the second- or third-day of anthesis; however, the pollen is not exposed until later in the same day. The centrally-positioned limb of the ray florets' styles is, at this time, in close proximity to or even in contact with the pollen-vaults of the disk florets. However, the vault's closure clearly restricts pollen transfer, thereby effectively extending the period of protogyny. In the field, many of the ray stigmas appear devoid of pollen, but a few have scattered grains and in a few older heads, the tips of the styles of ray florets exhibited a mass of pollen.

The anthers of the disk florets ultimately grow and project through the pollen-mass and from the vault. In some heads, the styles emerge from the apex of the vault, and in others, one style branch breaks through one lateral suture and the other through an opposite suture. In the latter instance, the styles were pollen-coated; in those that emerged from the apex, some

bore pollen along the stigmatic lines, but others seemed to be pollen-free. Clearly the tubular disk florets of *C. vialis* exhibit a delayed secondary pollen presentation (cf. Small 1915; Yeo 1993; Leins and Erbar 2006). However, many (probably most) of the emergent stigmas are already self-pollinated, and all those stigmas that emerged laterally are covered with self-pollen. Within a capitulum, pollination of the ray florets of the head could also occur at this time.

During the study period (late summer and autumn) in North Texas, the heads were visited by dipterans, mostly syrphid flies, throughout the day and by small lepidopterans from about 1100 hours until 1800 hours. The visitors were not collected, and it is unknown if any carry *C. vialis* pollen. [The author is aware of J. W. McSwain's retort that not all flower visitors are pollinators (Robbin Thorp, pers. comm.; Otto Solbrig, pers. comm.).] The lepidopterans probed the florets, as though they were foraging for nectar, which is the only evidence of nectar production in these populations. Parsons (2018) reported that straggler daisy is a host for caterpillars of bordered patch butterflies (*Chlosyne lacinia*), but none were observed in Wichita County. Small butterflies were cited as anthophilous visitors at the Lady Bird Wildflower Center in Austin (2018); that listing did not mention syrphids. Straggler daisy was introduced into Wichita County and to potential pollinators that may differ from those available in Mexico and southern Texas and earlier in the season in North Texas.

The pollination system of *C. vialis* appears to be facultative autogamous-allogamous facilitated by the described secondary pollen presentation. This inference could be tested in insect exclusion- and artificial pollination-studies. The pollen-vault assures that the disk florets have the potential for self-pollination, all the while preventing immediate pollination of

ray florets by the pollen of disk florets from the same blossoms. Thus, the more numerous disk florets appear to be primarily autogamous. The pistillate ray florets acquire pollen from disk flowers in the same head (autogamous) [It is often useful in terms of pollination and reproductive systems to consider the composite head as a single “blossom” (*sensu* Faegri and Pijl, 1966; Proctor and Yeo, 1972).], different heads on the same plant (geitonogamous), or heads from a different plant (xenogamous). A facultative reproductive system such as this could be advantageous for an invasive species that spreads into a new area with a different set of pollinators. However, pollination of straggler daisy appears to rely on available indigenous insects rather than a few specialized anthophilous insects. This dual pollination system may be useful in mat-forming species such as this with many heads of the same genotype in close proximity (Estes and Brown 1973). Geitonogamy must be commonplace in this species. In field observations, all of the fruiting heads studied bore a full array of the cuneate-shaped, two-spined achenes.

### CONCLUSIONS

The floral morphology of the northwestern Texas populations of *Calypsocarpus vialis* is distinctive from those reported from south-central Texas and Mexico with regard to the numbers of anthers (from four and five in the south to three to four in Wichita County) and the numbers of corolla lobes of disk florets (from four and five in the south to four in Wichita County). The highly ornamented faces of the corolla lobes have not been previously described in any floras or generic descriptions of this species seen by this author.

Although definitive breeding studies were not accomplished, it appears that the species is largely self-pollinated. It is unclear if the northerly migration and presumed

self-fertilization are correlated with the decreasing anther number; reduction of pollen production with decreasing anther number would be compatible with those features. Pollen retention by the pollen-vault produced by the apical anther appendages also appears to favor self-pollination.

### ACKNOWLEDGMENTS AND COLLECTIONS

Specimens collected by Estes in 2014 are deposited at the Robert Bebb Herbarium (OKL). A count of three-anthers was confirmed by Ronald J. Tyrl for a specimen from the Herbarium. Synantherologists John Strother and Bruce Baldwin at the University of California; Luc Brouillet, Université de Montréal; and Linda Watson, Oklahoma State University, all kindly responded that each was unaware of any composites that regularly produce three anthers per floret.

Dr. Anna Saghatelyn, McMurry University in Abilene, Texas, generously provided her observations and collections of *Calypsocarpus vialis*. Dr. Richard Kazmaier, West Texas A&M University, provided an interesting discussion of the abundance of *C. vialis* in Terrell County, Texas, and he had not noted the plant in the Panhandle, albeit, he had not searched for it.

I am grateful to Assistant Librarian and Interlibrary Loan Director Ms. Ashlee O’Rourke and all the staff of the Burkburnett Public Library for provision of their services and library loans. The Sooner Xpress/Interlibrary Loan provided copies of journal articles on line that were essential to the conduct of this study.

The original anther-counts of three were from a plant grown in a glasshouse at River Bend Nature Center in Wichita Falls, Texas and made in conjunction with a number of young visitors during an open-house event at the Nature Center.

Three anonymous reviewers made several substantive suggestions that greatly

aided interpretation of this paper, and I am deeply appreciative of their contributions.

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*Critic's Choice Essay***MYRMECOCHORY**Reprinted from *Gaillardia*, Fall 1999

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As I write, rain rattles against the window, driven by a cold northwest wind. The sky is overcast and the low, scudding clouds warn that winter is still here.

Not long ago an interesting word came to mind. Let me share it with you: *myrmecochory*. What a strange and unusual word. I know you wonder why it would pop into one's head.

It was early winter and I was sitting on the edge of the porch watching birds vigorously competing for the abundant seed in the feeder hanging from the bur oak. What dumb animals! If they had any brains they would know by now that the supply is unending. However, it was another of those special Oklahoma days. Clear, warm sunlight, a gentle breeze from the south, temperatures well above those of 24 hours earlier - you know what kind of day I mean. When one is not surprised to find dandelions flowering in the lawn.

The base of the corner pillar surrounding the porch does not sit tightly against the concrete deck. The small gap on one side has been accepted with the thought the resulting ventilation might help keep the wood dry. But on that day the base was enclosed with a bright green wreath of lush, young, spring-like vegetation, a veritable garden of foliage. Examination showed it was 100% *Lamium amplexicaule*, dead-nettle or henbit - whatever name you prefer, a common, beautiful, but oft-despised prolific lawn weed. Such a mass

of young plants must have been the result of a large cache of seeds. The moment I saw that growth I thought "What a beautiful example of myrmecochory". The word means "dispersal by ants". Here the seeds of *Lamium* had been gathered by ants, laboriously transported through the grass of the lawn, across the drive, up the side of the house, across the porch, and into the hollow pillar. For what reason would ants go to all that trouble? The answer discloses an interesting story.

Myrmecochory comes from Greek, with myrmeco- meaning "ant" and -chore, "to spread". In this case in reference to seed dissemination by ants, one of many dispersal mechanisms ranging from autochory, dispersal by the plant itself, to zoochory, a variety of approaches utilizing animal agents. But there is more. One cannot help but wonder why ants go to the expense of gathering, transporting, and accumulating large quantities of seeds and then apparently abandoning them. What is in it for the ants?

At the next opportunity, gather some henbit seeds and examine them under low magnification, anywhere from 15 to 45 times. The small, brownish, hard, and apparently inedible seed is evident. Notice however, one end is capped by a mass of light-colored, fleshy tissue surrounding nearly half the seed. This lump is rich in nutritive compounds, primarily fats and proteins. These masses are

gathered and stored by animals as a future food source. As you know, botanists have a name for everything. This structure is called an *elaiosome*.

Let us not concern ourselves with what part of the plant produces this clump of food. That is another story. The fact is, ants collect henbit seeds and carry them to their nests where they gnaw off the elaiosomes for their food value. The problem the animals then face is what to do with the waste material, in this case, seeds. At my house they dumped their debris under the porch pillar, not far from the nest entrance, in a *Lamium* trash pile. It was there, under favorable conditions, the seeds germinated and produced that lush ring of vegetation.

Think a moment. Have you ever observed an ant hill surrounded by a ring of *Viola* (violet) seedlings? It is not an uncommon occurrence. If so, you have encountered the phenomenon of myrmecochory; that circle of young plants represents the colony dump. But wait. In the case of violets that is only half the story. In this genus myrmecochory serves as secondary seed dispersal. Primary dispersal is autochorous, with exploding fruits scattering seeds around the plant, frequently as far as a meter.

For you doubting Thomases, let me make a suggestion. First locate some healthy *Viola* plants. Observe them until you locate maturing fruit and then, on a calm day, to eliminate wind as a factor, spread white paper around the plants (poster or butcher's paper will do) and record the distance you find the seeds from the parent plant. If you are fortunate (and observant) you will see seeds suddenly appear as they are thrown from the capsules (fruits). Use the opportunity to examine seeds under magnification. The elaiosomes are evident.

There are other Oklahoma wildflowers with either exploding fruit or elaiosomes on the seeds. Why do you suppose we call *Impatiens*, that common member of the Balsaminaceae, "Touch me not"? Also, take time to closely examine the seeds of *Corydalis* for external structures.

I hope these comments regarding the strange word *myrmecochory* will open some eyes to one of the unusual botanical phenomena taking place in our yards. But do not stop here. There are numerous other unique events and relationships to be discovered out there. Start looking for some.

O.N.P.R.

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