

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

Chad B. King
Joseph A. Buck
Department of Biology
University of Central Oklahoma
Edmond, OK 73034
Email: cking24@uco.edu

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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* ≥ 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 1m² 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 (m²/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 ^a	83	0.99	0.15	0.92 – 1.00

^aTree-ring index values correspond to the standardized chronology in Figure 4.

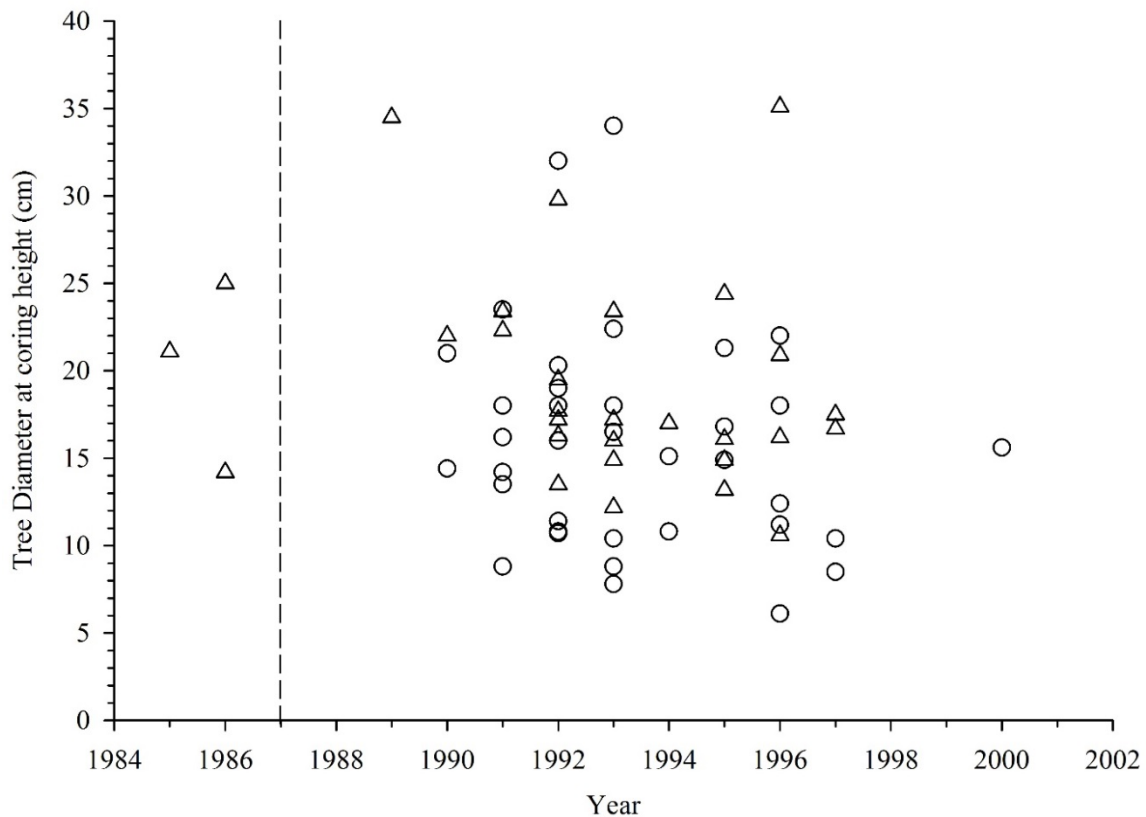


Figure 2 Actual (circles) and estimated pith dates (triangles) and tree diameter of green ash ($n = 65$) at Arcadia Lake, Oklahoma County, Oklahoma. Pith dates were estimated using the method indicated by Speer (2010) for trees in which coring missed the pith. Vertical dash line indicates the year (1987)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

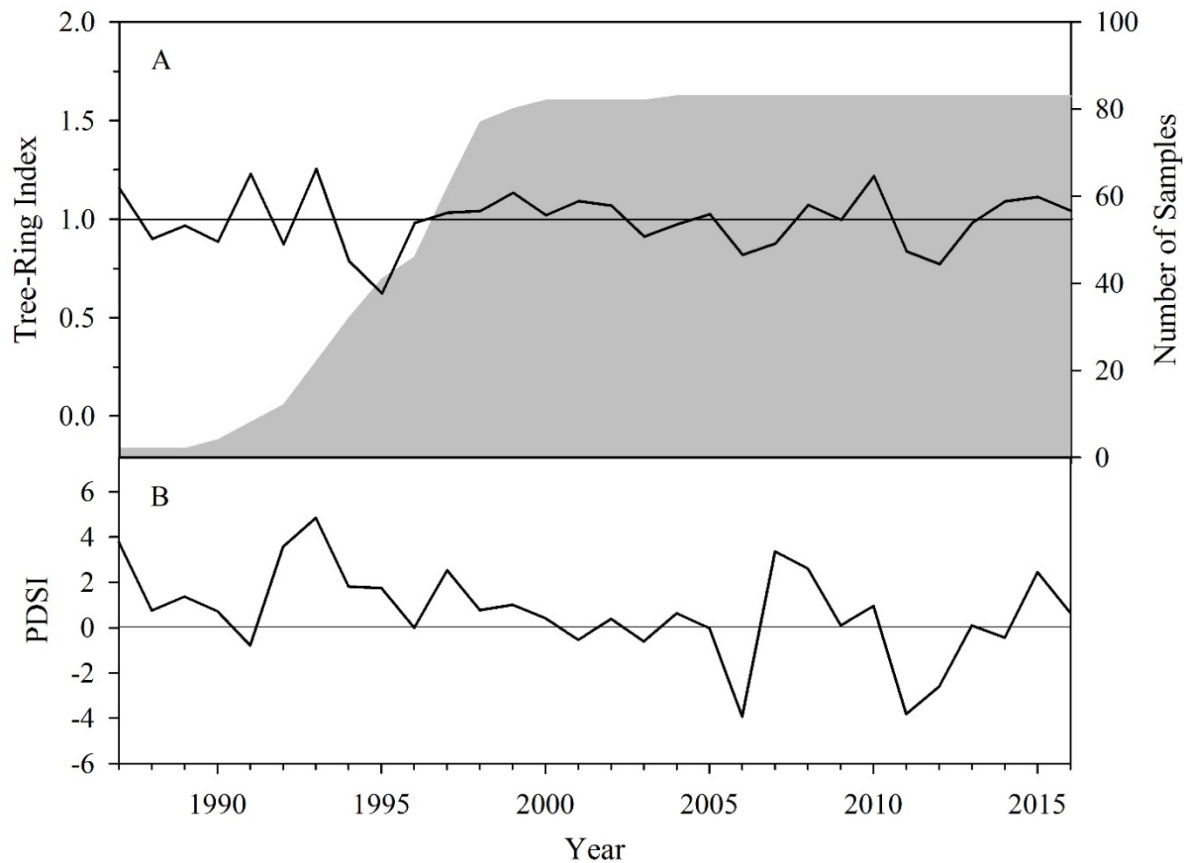


Figure 3 (A) Standardized tree-ring index of *F. pennsylvanica* at Arcadia Lake, Oklahoma County, Oklahoma (1987–2016). Tree-ring index is standardized using the computer program ARSTAN and methods outlined by Cook and Holmes (1986). The standardized tree-ring index has a mean = 1 and is unitless. Index 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 m²/ha) compared to *S. nigra* and *P. deltoides* (see Table 2). *S. nigra* had the highest basal area (10.73 m²/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 ^a	Basal area (m ² /ha)	Relative Dominance ^a	Importance Value ^a	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
Totals		591.7	100.0	25.37	100.0	200.0	458.4	4125.5

^aRelative 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

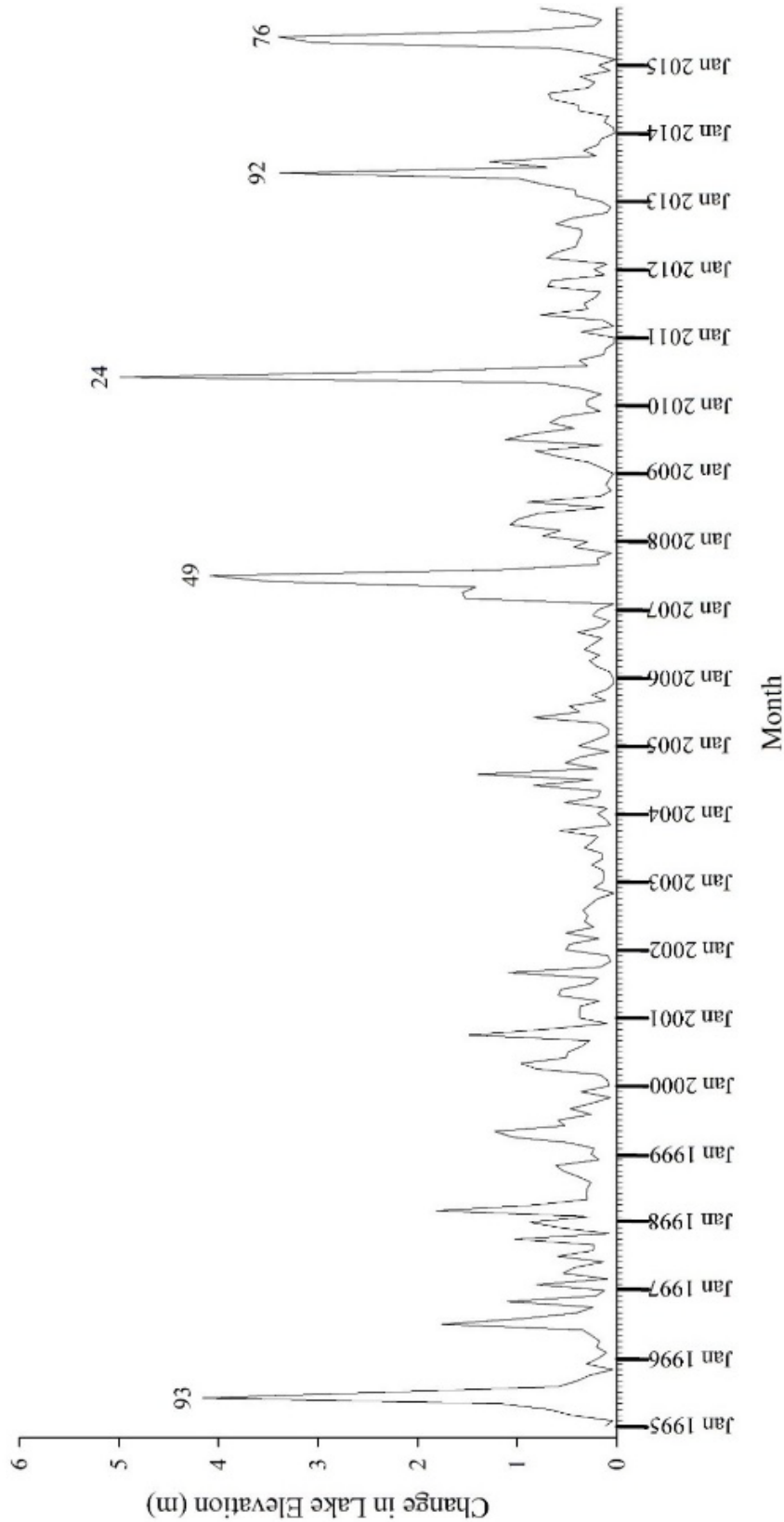


Figure 4 Changes in monthly lake elevation (m) at Arcadia Lake, Oklahoma County, Oklahoma (1995–2015). Change is the difference between the minimum and maximum lake elevation for each month. Numerical values during 1995, 2007, 2010, 2013, and 2015 indicate the number of consecutive days that lake elevation 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.

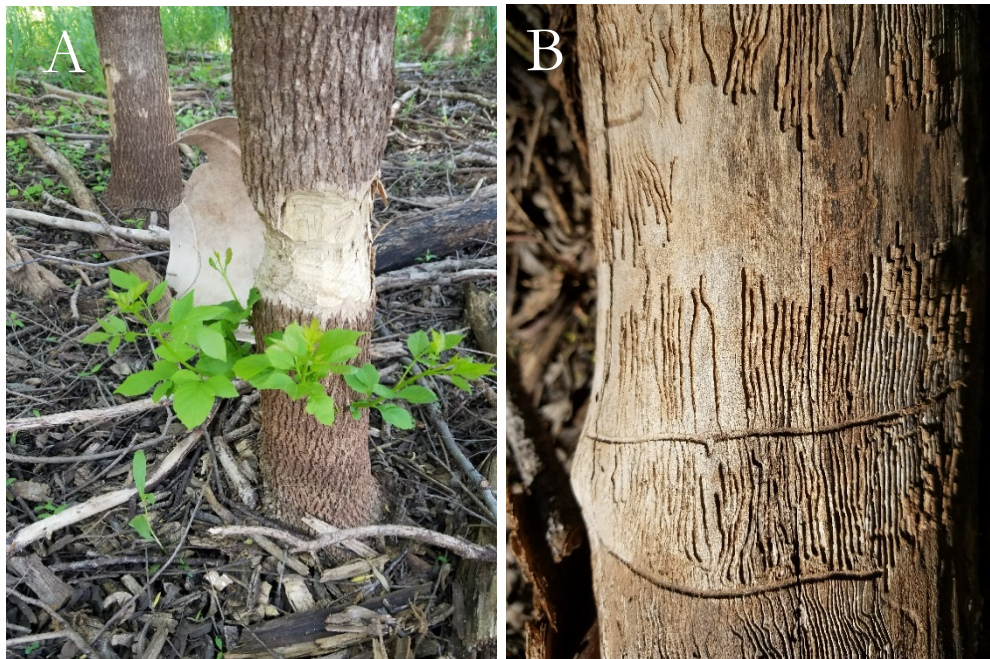


Figure 6 Two examples of biotic stressors on green ash at Arcadia Lake, Oklahoma County, Oklahoma. (A) American beaver activity that nearly girdled this green ash and subsequent sprouting by the green ash. (B) Ash bark beetle (*Hylesinus* sp.) galleries located under the bark of a dead green ash. Photos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