Forest Diversity Around Lake Texoma, Oklahoma and Texas

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Abstract
Human-constructed lakes cause local habitat and environmental changes, both during the time of construction and in later years. Later changes can include the flooding regime, microclimate, and species dispersal in adjacent forests. In summer 2011, we sampled eleven areas at five locations at least 15 m from the shoreline of Lake Texoma, Oklahoma and Texas. Lake Texoma is a US Army Corps of Engineers (USACE) lake, formed by the Dension Dam begun in 1938 and completed in 1944. The native vegetation in the area includes grassland, upland oak-hickory forest, and bottomland forest. Using a modified circular-nested-quadrats method we collected data on tree species abundance and diameter at breast height, sapling number, and seedling number. We calculated density, basal area, diversity, and evenness for trees on four stands in upland forest with Quercus stellata dominant and on five stands in bottomland forest, generally dominated by Ulmus americana. These stands seemed to be maintaining themselves, showing reproduction as saplings and seedlings of the dominant species. Salix nigra was the dominant species in two other stands; but it was not reproducing itself so these stands are unlikely to persist as willow stands. Most of the forest stands show evidence of disturbance; several had invasion of Juniperus virginiana and one of the bottomland stands was being invaded by Albizia julibrissin.

INTRODUCTION

Throughout the U.S., many human-constructed lakes have been created for flood control, hydroelectric power, and recreation. Reservoirs have a different configuration of shoreline than natural lakes and a greater perimeter-to-area ratio. The flooding cycle of reservoirs tends to have a longer period of inundation and shorter period of exposure than natural lakes. In natural lakes, the typical period of flood is a brief springtime period. There also can be periods of rapid drawdown and short-term water level fluctuations throughout the year in constructed lakes. Other notable differences include a high degree of shoreline erosion within the first thirty years after lake development (Baxter 1977, Tallent et al. 2011), differences in the depth profile, and differences in the water chemistry. Areas of the newly created shoreline that did not flood before lake creation may periodically flood after its creation, depending on the depth of the lake. The young age of constructed lakes and design factors involved in their construction lead to highly dissected shorelines and a flooding/exposure regimen that differs from natural lakes (Luken and Bezold 2000). Hill et al. (1998), who studied lakes that are regulated for hydropower generation, noted that widely-fluctuating water levels decreased plant species richness, and led to a greater number of exotic species being present. Additionally, the construction process itself can cause disturbance when existing shoreline communities are submerged and destroyed by dam building. The new shoreline is highly erodible for years after lake construction (Hill et al. 1998), and the new shoreline will vary in width depending on the fluctuations in the water level (Nilsson and Berggren 2000). It would be expected that near-shoreline vegetation of a constructed lake would differ from "natural" shoreline vegetation on a naturally-occurring lake. In this study, we examined forested stands occurring at least 15 meters from the shoreline. These forests were presumably undisturbed by USACE activities during actual construction of the dam and lake, but may be changing as a result of altered environmental conditions. The stands surveyed in the current study fell into one of three general types: upland forest (similar to the oak-dominated forests described by Penfound and Rice, 1959), an elm-dominated bottomland forest similar to some described in Rice (1965), and short-lived, black willow (Salix nigra)-dominated stands that likely formed on water-transported sand deposits (Petranka and Holland 1980).

One question that can be asked: how similar are the stands along Lake Texoma (which have suffered recent and continuing disturbance) to the less-disturbed stands described by Rice and Penfound (1959) or Petranka and Holland (1980).

MATERIALS AND METHODS

STUDY AREA DESCRIPTION

Southeastern Oklahoma experiences a continental climate with some moderating influence due to humid air masses from the Gulf of Mexico (The Climate of Oklahoma: http://climate.ok.gov/index.php/site/page/climate_of_oklahoma). It periodically experiences severe drought; 1929-41, 1949-54, 1961-72, and 1975-82 are considered drought years (Rice and Penfound 1959; Tortorelli 1991). More recently, 2001-2002 and 2010-2011 were drought periods (Oklahoma drought years: http://climate.ok.gov/data/public/climate/ok/images/traces/OK-CD00.prcp.Annual.png.). The mean annual temperature for south-central Oklahoma is about 17° C and the average growing season is about 225 days (Arndt, 2003). The average annual precipitation is about 108 cm (The Climate of Oklahoma, http://climate.ok.gov/index.php/site/page/climate_of_oklahoma). South-central Oklahoma, around Lake Texoma, is on the Dissected Coastal Plain geomorphic province, and the soils vary from Grand Prairie Mollisol/Alfisols to Coastal Plain Ultisols (Tyrl et al., n.d.).

The U.S. Army Corps of Engineers built the Denison Dam that formed Lake Texoma between 1938 and 1948. Lake Texoma was originally developed for flood control on the Red River; today, it has the additional uses of recreation and power generation (U.S. Army Corps of Engineers History of Lake Texoma: http://www.swt.usace.army.mil/recreat/ViewHistoryMessage.cfm?tblMessages__LakeName=Lake%20Texoma). Prior to construction of the dam, much of the land in the area was farmland or grazed land, with cotton and peanuts being the primary crops (Parks and Barclay, 1966). Construction of the dam inundated several small villages in the area, and pre-dam natural vegetation would possibly been a mixture of grassland, Quercus stellata/Carya texana (post oak/black hickory) forest, and some areas of bottomland forest, based on current vegetation patterns in the area.

In addition to loss of terrestrial habitat in the areas inundated by the lake, the new shoreline would experience disturbance. Typical summer elevation of the lake is between 614 and 619 feet; areas that would not have been close to the banks of the river or in its regular floodplain prior to lake development could be at the water's edge after filling of the lake. Additional disturbance results from periodic flooding. The lake level intermittently rises above 620 feet (often during the rainy period in spring or fall) and three times in the lake's history, it exceeded the 640 foot level, at which point water crests the emergency spillway of the Denison Dam. (The most recent flood period was summer 2007).

STUDY LOCATIONS AND SAMPLING

In June 2011, we traveled to five forested areas located on Lake Texoma; four in Oklahoma and one in Texas. The locations included the Bioscience Area jointly managed by Southeastern Oklahoma State University and the USACE, the Platter Flats Equestrian Area (managed by USACE), Hagerman and Tishomingo Wildlife Reserves (managed by the US Fish and Wildlife Service), and the University of Oklahoma Biological Station. At each area we located at least two forested stands (three for the OU Biological Station) that were near Lake Texoma, but were not immediate shoreline. Stands to be sampled were chosen on two bases: generally representative of a forest type in that area, and with at least one hectare of forest area inside an "edge buffer" of at least 15 meters from trails, forest edge, or lake edge. Within the stand, four to six points were spaced 30-50 meters apart. In stands with four points, the four points formed the vertices of a square; in stands where six points were sampled they were laid out in a rectangular pattern. We used the circular nested quadrat method based on that of Curtis and Cottam (1962): a 0.04 ha quadrat for trees, a 0.01 ha quadrat for saplings, and a 0.004 ha quadrat for seedlings. In each tree quadrat, we tallied all woody plants greater than 9 cm DBH by species and measured the DBH. Saplings were any woody plant smaller than 9 cm DBH and taller than 20 cm. Seedlings were any woody plant shorter than 20 cm, but with the potential to grow to tree height.

We analyzed the circular-nested-quadrat tree data to determine density per hectare, basal area per hectare, relative dominance, and Shannon diversity (using log10), and evenness (Zar, 2010). Density per hectare was calculated by combining data from all points sampled in a stand. Total area sampled was computed (0.16 ha for stands with four samples; 0.24 ha for stands with six samples) and the number of trees (by species and total number) was divided by that area to get density in trees per hectare. Dominance was calculated based on basal area; basal area for each tree was computed ((0.5 * DBH)2 * 3.1415) and basal area of all trees of a species were summed for a single stand. Basal area per hectare was computed by dividing the basal area by the total area sampled per stand. Basal area per hectare was computed for each individual tree species as well as for the entire tree community. Relative dominance was calculated by summing the basal areas per hectare for all species in a stand, and then dividing the basal area of each species by that total and multiplying by 100 to give a percentage. The Shannon-Weiner diversity index (H') was calculated based on proportions: -Σ pi log pi, where pi was the proportion based on number of trees of each species per stand. Maximum diversity (H'max) of a stand was calculated as (log (r) where r was the number of tree species present. Evenness, then, was calculated as ((H'/H'max)*100)

All quadrats from a single location within a stand were combined. We computed both density and basal area for individual species and an overall value for the entire stand. We also computed density and Shannon-Weiner index values for saplings and seedlings, using similar techniques to those used for trees.

Because the sample size was small and data were not normal, correlations between basal area and density, density and diversity, and basal area and diversity were tested using Spearman rank correlations in SPSS (IBM SPSS, 2011).

To examine further the relationship between the eleven forest stands, we performed both Detrended Correspondence Analysis (DCA) and Non-metric Multidimensional Scaling (NMDS) analyses on the relative dominance data for the tree stands, and on the sapling and seedling density data. We used PC-Ord version 3.2 for the analysis (McCune and Mefford, 1997). For the DCA, the axes were rescaled and rare species downweighted; for NMDS, Jaccard's distance measure was used with two axes, and a random starting "seed" (based on time of day) was used.

RESULTS AND DISCUSSION

For ease of interpretation, in both tables and text, upland site numbers will be indicated in plaintext, bottomland sites will be italicized, and willow-dominated sites will be in bold text. Stand 5 (Dead Woman's Pond at Hagerman NWR shares some species with the upland stands, however, I will group it with the bottomland stands because of its position in the ordination analyses.

Both the DCA and NMDS ordination of the tree stratum showed similar results except for polarity of the subsequent axis. Stands 9, 10, and 11 separated from the other stands. These three stands were all fairly low-density stands and all three had black willow present. (see Figures 1 and 2). The other eight stands tended to group together; however, axis 3 of the DCA did show a minor separation giving two groups: stands 1, 2, 3 and 4 versus stands 5, 6, 7, and 8. This separation seems to be on the basis of a few species-composition differences. The dominance of post oak in stands 1, 2, 3 and 4 is likely the result of this separation; the correlation (Kendall's tau) of post oak with DCA axis 3 was 0.663. This was the single strongest correlation of any species with that ordination axis. The NMDS showed a similar separation but with reversed polarity between the upland and bottomland stands

The Southeastern Oklahoma State University Bioscience area stands were both post oak-dominated upland-type forests (Table 1). The first stand (stand 1, the "lake" stand) had low tree stratum diversity (Table 2). The tree stratum contained post oak, with smaller abundance of white mulberry (*Morus alba*) and American elm (*Ulmus americana*). Tree density was very low. The sapling stratum (Table 3) had large amounts of persimmon (Diospyros virginiana), with smaller amounts of black hickory and American elm. Post oak was absent from the sapling stratum but was abundant in the seedling stratum (Table 4). This location has

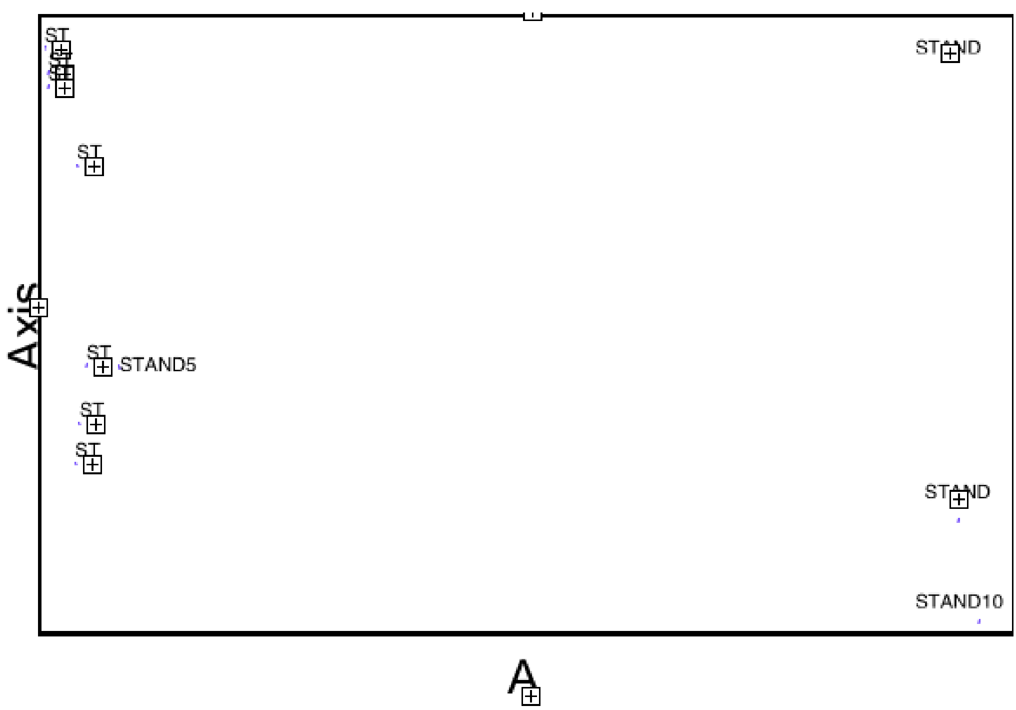

Figure 1. Detrended Correspondence Analysis (DCA) analysis of the eleven Texoma stands. First and third axes are shown because they are the axes giving meaningful patterns. Axis 1 separates stands on the basis of Willow dominance/dominance by other tree species. The left-hand side of axis 3 separates more-upland stands (dominated by post oak – stands 1, 2, 3, 4) from bottomland stands (5, 6, 7, and 8)

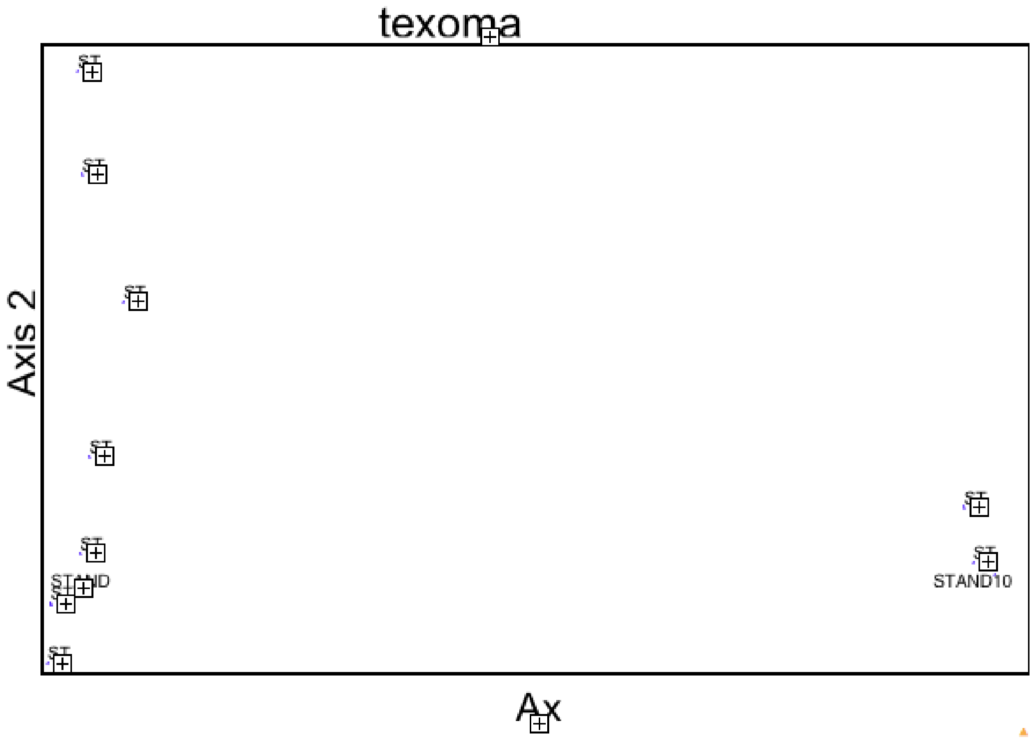

Figure 2. Non-Metric Multidimensional Scaling (NMDS) ordination analysis of the eleven Texoma forest stands. Axes 1 and 2 are shown. Axis 1 separates stands on the basis of Willow dominance/dominance by other tree species. The left-hand side of axis 2 separates more-upland stands (dominated by post oak – stands 1, 2, 3, 4) from bottomland stands (5, 6, 7, and 8). The ordination scores of stands 3 and 4 are so similar that the two stands are superimposed on each other.

experienced recent fire (2006 – C. Buchanan, pers. comm.) and was also flooded in summer 2007. Stand 1 differed in more ways from the other "upland" stands (2, 3, and 4) than they did from each other. Stand 1 had lower basal area, density, and diversity than the other upland stands, likely reflecting its more recent disturbance history.

The second stand sampled at the Southeastern Oklahoma State University Bioscience area had higher diversity in all strata (Table 2, Table 5, Table 6). This stand had a tree stratum dominated by post oak, but it also had white ash (*Fraxinus americana*), Osage orange (*Maclura pomifera*), blackjack oak (*Quercus marilandica*). The sapling stratum included Mexican plum (*Prunus mexicana*), redbud (*Cercis canadensis*), black hickory, and American elm , but was dominated by post oak. Post oak was also the most abundant species in the seedling stratum. This stand was located on a bluff overlooking Lake Texoma, away from the site of the 2006 fire, and it was likely not flooded in summer 2007; we recorded an elevation of 648 meters for this stand and locations with elevations less than 640 meters were the ones flooded.

Both stands at the Platter Equestrian Area (stands 3 and 4) shared similar species composition. Post oak was the dominant tree species, and it was also abundant in the sapling layer and the seedling layer. Both stands also had eastern redcedar (*Juniperus virginiana*) present in the tree layer. The sapling layer also contained possumhaw holly (*Ilex deciduas*), winged elm, and chittamwood (*Sideroxylon lanuginosum*). (Both the holly

Table 1. Relative Dominance values for tree species at the 11 stands sampled. Stands that grouped as upland are numbered in plain text, stands that grouped as bottomland are shown in italic, and willow-dominated stands are shown in bold.

Species:	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	***9***	***10***	***11***
Post Oak	86.81	55.92	76.68	75.31	10.02	8.26	0	0	0	0	0
Blackjack Oak	0	4.4	0.22	0	4.36	0	0	0	0	0	0
Black Hickory	0	2.24	8.36	0	0	0	0	0	0	0	0
American Elm	0.87	9.22	2.44	4.74	26.61	1.7	58.55	24.53	0	0	0
Winged Elm	0	2.20	2.62	3.63	0	0	14.40	3.42	0	0	0
Eastern Redcedar	0	0	13.89	5.50	8.27	0	13.76	11.69	0	0	0
Osage Orange	0	4.99	0	0	10.76	16.84	0	28.81	0	0	0
Sugarberry	0	0.72	0	0	14.27	0	6.10	7.44	0	0	0
Hackberry	0	0	0	0	1.04	0	0	0	0	0	0
Mulberry	1.16	0	0.22	0.46	0	0	4.96	0	0	0	0
Soapberry	0	2.77	0	0	0	0	0	2.25	0	0	0
Persimmon	0	1.06	0	0	0.23	0	0	0	3.17	0	4.10
Plum	0	1.52	0	0	0	0	0	0	1.54	0	0
Honey Locust	0	0	0	0	6.06	0	0	0	2.68	0	2.16
Ash	0	17.13	0	0	0	35.94	1.90	0.23	0	0	0
Mockernut Hickory	0	0	0	0	0.45	0	0	0	0	0	0
Cedar Elm	0	0	0	0	21.80	26.36	0	0	0	0	0
Pecan	0	0	0	0	0.28	0.37	0	8.87	0	72.63	
Bur oak	0	0	0	0	0	3.48	0	0	0	0	0
Cottonwood	0	0	0	0	0	0	0	24.10	0	0	0
Black Willow	0	0	0	0	0	0	0	0	83.08	100	18.45
Box-elder	0	0	0	0	0	0	0	0	0.63	0	0

Table 2. Descriptive statistics at the stand level for the eleven forests at five locations sampled in summer 2011. Stands that grouped as upland are numbered in plain text, stands that grouped as bottomland are shown in italic, and willow-dominated stands are shown in bold.

Stand	*Shannon-Weiner diversity*	*Evenness (percent)*	*Stems/ha*	*BA/ha in* m^2
1	0.2012	42	100.00	13.78
2	0.7472	74	429.16	23.64
3	0.4829	57	606.25	27.86
4	0.5597	72	512.50	22.56
5	0.8286	80	693.75	17.66
6	0.4772	56	512.50	25.29
7	0.5373	64	456.25	32.64
8	0.7541	84	331.25	35.06
9	0.5813	75	206.25	11.05
10	0[1]	0[1]	306.25	27.21
11	0.6213	89	125.00	18.05

[1] This stand had only Salix nigra present in the tree stratum, hence the diversity value of 0.

Table 3. Density per hectare for saplings by species at 11 stands sampled. Stands that grouped as upland are numbered in plain text, stands that grouped as bottomland are shown in italic, and willow-dominated stands are shown in bold.

Stand	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	***9***	***10***	***11***
Persimmon	25	0	0	0	25	0	0	0	325	0	800
American Elm	250	50	0	0	25	25	50	50	0	0	0
Blackjack Oak	25	0	0	0	0	0	0	0	0	0	0
Black Hickory	125	50	25	150	0	0	0	0	0	0	0
Redbud	0	50	0	0	0	0	0	0	0	0	0
Plum	0	50	0	0	0	0	50	0	1325	0	0
Post Oak	0	117	25	350	675	0	0	0	0	0	0
Ash	0	17	25	0	25	500	25	25	0	0	0
Eastern Redcedar	0	0	25	50	300	0	0	0	0	0	0
Possumhaw Holly	0	0	550	300	0	0	25	0	0	0	0
Winged Elm	0	0	50	250	25	0	0	25	0	0	0
Chittamwood	0	0	50	100	0	100	25	0	0	0	0
Mulberry	0	0	0	100	0	0	225	0	0	0	0
Sugarberry	0	0	0	50	100	0	175	175	0	0	0
Honeylocust	0	0	0	25	25	0	0	0	50	0	0
Mockernut Hickory	0	0	0	0	25	0	0	0	0	0	0
Hackberry	0	0	0	0	25	0	0	0	0	0	0
Cedar Elm	0	0	0	0	725	50	0	0	0	0	0
Pecan		0	0	0	0	575	0	50	150	0	25
Albizia	0	0	0	0	0	0	1875	0	0	0	0

Table 4. Density per hectare for seedlings by species at 11 stands sampled. Stands that grouped as upland are numbered in plain text, stands that grouped as bottomland are shown in italic, and willow-dominated stands are shown in bold.

Stand *Species:*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	***9***	***10***	***11***
Post Oak	250	167	2750	2500	1000	0	0	0	0	0	0
Redbud	0	83	0	0	0	0	0	0	0	0	0
Winged Elm	0	0	0	1250	0	0	250	750	0	0	0
Black Hickory	0	0	0	1750	0	0	0	0	0	0	0
Eastern Redcedar	0	0	0	0	250	0	0	0	0	0	0
Mockernut Hickory	0	0	0	0	250	250	0	0	0	0	0
Cedar Elm	0	0	0	0	250	0	0	0	0	0	0
Chittamwood	0	0	0	0	250	0	0	0	0	0	0
Pecan	0	0	0	0	0	750	500	0	0	0	0
Albizia	0	0	0	0	0	0	5500	0	0	0	0
Sugarberry	0	0	0	0	0	0	250	0	0	0	0
Buckthorn	0	0	0	0	0	0	0	500	0	0	0
Plum	0	0	0	0	0	0	0	0	250	0	0
Persimmon	0	0	0	0	0	0	0	0	0	0	500

Table 5. Descriptive statistics at the stand level for saplings in the eleven forests at five locations sampled in summer 2011. Stands that grouped as upland are numbered in plain text, stands that grouped as bottomland are shown in italic, and willow-dominated stands are shown in bold.

Stand	*Shannon-Weiner diversity*	*Evenness*	*Stems/ha*
1	0.4366	72	425
2	0.719	92	333
3	0.4525	54	750
4	0.8370	88	1375
5	0.7235	69	2800
6	0.4920	70	1250
7	0.3959	44	2450
8	0.5663	81	325
9	0.3674	61	1850
10	0[1]	0	0
11	0.0590	20	825

[1] Stand had no saplings present.

Table 6. Descriptive statistics at the stand level for seedlings in the eleven forests at five locations sampled in summer 2011. Stands that grouped as upland are numbered in plain text, stands that grouped as bottomland are shown in italic, and willow-dominated stands are shown in bold.

Stand	*Shannon-Weiner diversity*	*Evenness*	*Stems/ha*
1	0[1]	0	250
2	0.2764	92	166
3	0[1]	0	2750
4	0.4601	96	5500
5	0.6020	86	2000
6	0.2442	81	1000
7	0.2559	43	6500
8	0.2923	97	1250
9	0[2]	0	250
10	0[3]	0	0
11	0[4]	0	500

[1] Stands had only Post Oak present, hence the diversity value of 0.
[2] Stand had only Plum seedlings present, hence the diversity value of 0.
[3] No seedlings present.
[4] Stand had only Persimmon seedlings present, hence the diversity value of 0.

and chittamwood are unlikely to reach tree size at maturity). Stand 4 also had black hickory present in both the tree and sapling layers. These sites grouped with the other "upland stands" in the ordination analysis, probably because of their abundance of post oak. Sites 2, 3, and 4 showed similar basal area per hectare and density, although they differed in diversity index and evenness.

The two stands sampled at Hagerman differed in species composition and abundance. Dead Woman's Pond (stand 5) had a species composition superficially similar to that of upland forest, because of the presence of post oak and hickories. However, in the ordination analyses it tended to group with other stands best described as "bottomland" (stands 6, 7, and 8). Stand 5 had the highest tree density (993 trees / ha) and lowest basal area per hectare of all stands sampled, and was difficult to traverse because of the high density, large number of saplings, and high abundance of greenbriar (*Smilax* spp.). The dominant tree species included American elm, cedar elm (*Ulmus crassifolia*), sugarberry (*Celtis* spp.), and post oak. Eastern redcedar was also present. In the sapling layer, mockernut hickory (*Carya alba*) was abundant, along with cedar elm, chittamwood, and eastern redcedar. Possibly, stand 5 can be seen as having characteristics reflecting both upland and bottomland forest. Based on topographic position, I would have described it as "upland" forest, but the presence of some species with more of a bottomland affiliation seem to have caused it to group with sites 6, 7, and 8.

Haller's Haven (stand 6) was more similar in composition to bottomland forest, with ash dominant in the tree stratum. Cedar elm and Osage orange were also present.

Post oak was also absent from this stand. The sapling layer had highest abundance of pecan (*Carya illinoiensis*) and white ash. The most abundant seedling species was pecan, but mockernut hickory was also present. This stand had lower tree and sapling density than the Dead Woman's Pond stand, with higher basal area/ha – fewer, but larger trees. This stand also showed evidence of recent flooding: woody debris covered the forest floor. There was more debris than would be expected from shed branches from the trees present, and some of it showed evidence of being stripped of bark and affected by submergence in water. Given its topography, it was certainly flooded in 2007 and may have flooded more recently than that.

Stands 7 and 8 sampled at the OU Biological Station were similar. Both were sampled in the location set aside as the "Ecological Area." These stands are similar in species composition and abundance to the "riparian" bottomland forest type as described by Petranka and Holland (1980). However, both these stands were experiencing some invasion; both had eastern redcedar present, and stand 7 (the first of the Ecological Area stands) had a large individual of Albizia (*Albizia julibrissin*) present (not included in samples but observed), and Albizia was abundant in the sapling stratum. These stands had the highest basal area of all stands in the study. Stands 6, 7, and 8 varied in density, evenness, and diversity.

The last three stands (9, 10, and 11) were more similar to each other and different from all the other stands, according to the ordination analysis. All three stands had low density values (300 or fewer trees per hectare) and stands 9 and 11 had low values for basal area per hectare. These three stands had black willow present. In stands 9 and 10 it was the dominant species, but in stand 11 pecan was dominant. Species composition was considerably different from that of other stands.

The Shannon Diversity Index values for the tree layers ranged from a low of 0 (stand 10 had no woody species other than black willow) to a high of 0.8255 (Stand 5 – Dead Woman's Pond at Hagerman NWR). Diversity was not significantly correlated with either density per hectare (Spearman correlation, n=11, correlation=0.214, p=0.527) or basal area per hectare (Spearman correlation: n=11, correlation =-0.036, p=0.915) . There was also no clear pattern in differences of diversity by forest type – for example, forests dominated by post oak did not show significantly lower or higher diversity than forests dominated by other species.

In general, sapling and seedling data suggested that most stands are replacing themselves. However, several stands are likely undergoing a change over time: stand 10 had a sapling diversity of 0; no saplings were present. In stand 9, the species present in the sapling layer (plum, pecan, and honeylocust) generally differed from those in the tree layer, and in stand 11, persimmon was a dominant species in both the sapling and seedling layers, even though it was in low abundance in the tree layer. Stand 7, at the OU Biological Station, was experiencing invasion by Albizia. The low sapling diversity observed at this stand is the result of a very large number of Albizia saplings crowding out other species. The other stands varied widely in sapling diversity; stand 4 (at Platter) had the highest sapling diversity. Data from the seedling layer (Table 6) is less revealing because of the small size of the seedling quadrats and limited diversity of seedlings present. Stands 1 and 3 had only Post Oak present in the seedling stratum.

Ordination of the seedling and sapling data was complicated by the fact that there were relatively few saplings and seedlings, and some stands could not be included in the analysis because of the absence of these data. What analyses were possible showed similar patterns to the tree data ordination, with stands 9, 10, and 11 separating from other stands.

Comparing the stands sampled in this study with published information about other, presumably less-disturbed Oklahoma forest shows some similarities of species composition. Rice and Penfound (1959) examined upland forests throughout Oklahoma. They described two types of oak-dominated upland forest in South Central Oklahoma: a savannah-like "open" forest, and the more dense "cross timbers" forest. The dominant species were post oak, hickories (*Carya tomentosa, C. texana*), and Juglans microcarpa (little walnut; Rice and Penfound called it western walnut), but they also noted the presence of elms (*Ulmus americana* and *U. alata*), sugarberries (predominantly *Celtis reticulata*), and chittamwood (*Sideroxylon lanuginosum*) on stabilized dune sites (Rice and Penfound 1959). The upland forest in the areas of south-central Oklahoma that we sampled was most like the "open" upland forest Rice and Penfound described. Cross timbers forest is denser and has lower species diversity: Bragg et al. (2012) noted that original cross timbers forest was mostly post oak and blackjack oak (*Quercus marilandica*), with few other species. They also noted that this forest has changed considerably in the past 200 years because of fire suppression.

Southern Oklahoma seems to have two general types of bottomland forest: a short-lived black willow-dominated forest that can develop rapidly on exposed sandbars and sand flats, and a more diverse "riparian" forest dominated by a variety of species. Rice (1965) surveyed bottomland forest in north-central Oklahoma. American elm tended to be the dominant species. Other species present included sugarberry (*Celtis laevigata*), hackberry (*Celtis occidentalis*), soapberry (*Sapindus drummondii*), pecan, and black walnut (*Juglans nigra*). He also noted that woody vines were abundant, with twelve species being present. Our stands 5, 7, and 8 had high relative dominance of American elm, and Celtis species were also present. Petranka and Holland (1980) delineated two "zones" of bottomland forest– a willow zone and a riparian zone. The willow zone had much lower species richness and had numerous "weedy annuals," which suggested recent disturbance. Petranka and Holland concluded that this community was unlikely to persist. For the riparian zone, sugarberry, hackberry, elms, soapberry, box-elder (*Acer negundo*), pecan, bur oak, green ash, and Shumard oak (*Quercus shumardii*) were the dominant species. Many of these were the same species as found in our stands 6, 9, and 11. In the willow zone, black willow was the dominant species, with American elm and eastern cottonwood (Populus deltoides) also present. They also noted the presence of numerous woody vines (Petranka and Holland 1980). These forests were similar to two of the "types" delineated by Dale et al. (2007) for an extensive study of bottomland forest in Missouri, Arkansas, and Louisiana. Their group 9: "sugarberry/pecan/American elm" was similar in species composition to our stands 7 and 8. They also noted the presence of numerous woody vines. Additionally, they described a low-diversity "black willow" community that was strongly dominated by *Salix nigra*. In their study, American elm was increasing in many forests that were selectively logged as it is not a harvested species (Dale et al. 2007). While the forests we studied around Lake Texoma had not experienced recent logging, American elm was a major species in stands 5, 7 and 8.

Penfound et al. (1965) suggested that there had been "very rapid" succession at Lake Texoma. Within twenty years of the lake's filling, researchers described some unusual communities that had developed along the shores of Lake Texoma (Penfound et al.. 1965, Parks and Barclay 1966). These including one community dominated by vines such as Smilax bona-nox (saw greenbriar), *Passiflora incarnata* (purple passionflower), *Strophostyles* sp.(fuzzybean species), *Rubus trivialis* (southern dewberry), and *Vitis cinerea* (graybark grape). The density of vines seemed to increase between 1960 and 1965, and then declined sharply afterward (Parks and Barclay 1966). Often these communities seemed to be short-lived and it was implied they were atypical for the region. Penfound et al. (1965) suggested that it was possible some of these communities may have been succeeding to a sort of bottomland forest; they reported individuals of box-elder and black willow invading the area. Johnson (1984) resampled some areas that had shown black willow dominance in the early 1960s; in 1983 these stands had become considerably more diverse and now supported sugarberry, persimmon, Osage-orange, pecan, white mulberry (*MORUS ALBA*), honeylocust (*Gleditsia triacanthos*), American elm, buttonbush (*Cephalanthus occidentalis*), and cottonwood. This forest composition is similar to that of our stand 11, which is near a willow-dominated area, and is also similar to our stand 9, which contained some black willow but a mixture of other species. Johnson (1984) suggested that there is a hackberry-persimmon stage that follows the black willow forest. Parks and Barclay (1966), working in Marshall County, OK, described four community types they observed, including further evidence of a vine-dominated community similar to that described by Penfound et al. (1965). In addition to that community, they found willow forest, "mixed" forest (mostly "upland" trees), and abandoned cropland. They noted that most of the soils in the area were derived from river sand.

The greatest differences within the stand types around Lake Texoma were in species composition and in the comparison of the tree and sapling strata. Stands 1, 2, 3, and 4 were dominated by post oak, and in general, the sapling stratum reflected the pattern of the tree stratum, suggesting these stands will replace themselves over time. These sites varied more widely in terms of Shannon diversity, evenness, density, and basal area per hectare than any other group. Stand 5 groups with the other "bottomland" stands (6, 7, and 8) on the basis of the ordination analyses, however, it also had unique characteristics. This stand perhaps can be seen as a stand sharing characteristics with both upland and bottomland forest. The other stands that were grouped as "bottomland" in the ordination analysis (stands 6, 7, and 8) varied in species composition. Stands 7 and 8 had the highest basal area of all stands in the study. In general, the bottomland stands showed a tendency to replace themselves (the dominant tree-stratum species were also present in the sapling and/or seedling strata); however, stand 7 did show invasion from the non-native *Albizia julibrassin*. Stands 9, 10, and 11 grouped together in the ordination analysis, because they all had black willow present as a dominant species. Stands 9 and 11 were very similar in Shannon diversity and evenness, despite differing somewhat in species composition. Stand 10 had only black willow present, and only in the tree stratum. No willow seedlings or saplings were found in any stands, and (Johnson, 1984) noted that willow stands around Lake Texoma tended not to replace themselves.

Many Oklahoma forests are fire-adapted (upland stands more so than bottomland stands). According to Burton et al. (2010), the average fire-return time for Eastern Oklahoma hardwood forests before European settlement was from 2 to 10 years. Most of these fires happened during the dormant season (late winter fires). With fire suppression, species composition, diversity, and density change, it is possible for non-native species to invade because shade-tolerant and fire-intolerant species, many of which are non-native, are able to survive the changed conditions (Burton et al. 2010) When fires do happen, they tend to be larger and more damaging (Burton et al. 2010). It seems the fire at Hagerman NWR in summer 2011 would be an example of this.

Lack of fire also affects species composition. Burton et al. (2010) described reductions in oak density, and increases of fire-intolerant, shade-tolerant species including winged elm, eastern redcedar, Mexican plum and blueberry (Vaccinium arboreum) in areas where fire had been absent. We noted that in a number of the forested areas, elms and eastern redcedar were in high abundance, as well as being present in the sapling stratum. It seems likely that with continued lack of fire, eastern redcedar will continue to spread.

This study shows that despite the presence of Lake Texoma for some sixty years, upland stands in the area around the lake are more or less maintaining themselves, in that the sapling and seedling stratum contain the same species as the tree stratum. This is also true of the elm-dominated bottomland forests. The lake does not seem to have as great an influence as we originally predicted – we first thought that perhaps the upland forest sites near the lake would show an increase in mesic species in their sapling and seedling strata. The one group of forests that are unlikely to reproduce themselves over time, and will be replaced by other vegetation, are the willow-dominated stands. No saplings or seedlings of willow were found on either stand where they dominated the tree stratum. Johnson (1984) noted that stands sampled in the 1960s and found to contain willow forest were no longer willow-dominated; persimmon, pecan, and other species took over. Shelford (1954) observed that after about 18 years, willows began to "decline in vigor," suggesting these forests would be replaced by other species.

Although most of the stands sampled do seem to be replacing themselves, there are still concerns about management. One of the bottomland-type stands (stand 7) was experiencing invasion by Albizia. It is possible that this is still at a stage where removal of the seedlings, saplings, and mature trees reduce the likelihood of this species to spread to other areas of the stand and reduce its competition for light with other, native, species.

To manage these stands, regular prescribed burns on the upland stands (possibly coupled with directed removal of potentially-invasive species, like eastern redcedar) could help to restore the stands to a more undisturbed-like state. In the bottomland stands, removal of and monitoring for invasive species, such as Albizia could prevent future changes in stand diversity or species dominance that could be caused by invasion of non-natives

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