Quantifying the vegetative community of a bottomland-floodplain forest within Colorado Bend State Park along the Colorado River

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ABSTRACT

We quantified and analyzed the vegetative composition of a bottomland-floodplain forest along the Texas Colorado River within Colorado Bend State Park. This forest contained three vegetational layers: an upper canopy of larger trees including pecan (*Carya illinoinensis*), green ash (*Fraxinus pennsylvanica*), and cedar elm (*Ulmus crassifolia*); a thick under canopy of shrubby species such as gum bumelia (*Sideroxylon lanuginosum*), with mustang grape (*Vitis mustangensis*) and saw greenbrier (*Smilax bona-nox*) as common lianas; and an herbaceous zone of mostly broadleaf woodoats (*Chasmanthium latifolium*) and Canada wild rye (*Elymus canadensis*). Additionally, native invasive plant species were heavily present in both upper and under canopy areas of the sample area. Of six quadrats where diameter at breast height was recorded for 1,162 trees total, 790 were *Juniperus* trees or shrubs. Woody species in the upper and under canopy areas showed little regeneration, possibly due to dense shade contributed by shrubby species and to populations of whitetail deer (*Odocoileus virginianus*) and feral hog (*Sus scrofa*) in the park. We compared the data collected at Colorado Bend State Park, land that has not been grazed by livestock at least since the land was purchased by the state in 1984, to those of another site along the river which has been continuously grazed for at least 100 years, allowing us to evaluate effects that grazing by livestock has on riparian vegetation. Furthermore, the vegetative composition from this western portion of the Texas-Colorado River can be compared to other bottomland and floodplain forests along rivers in the eastern Cross Timbers and Prairie ecoregion of Texas. *Published online* **www.phytologia.org** *Phytologia 104(4): 49-65 (December 21, 2022). ISSN 030319430.*

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Freshwater ecosystems make up 0.8% of the earth's surface (Cardinale et al. 2020), with 0.58% of earth's surface being rivers and streams (Allen and Pavelsky 2018). Freshwater habitats support a tenth of animal species but are also being degraded by anthropogenic activities (Strayer and Dudgeon 2010). Riparian areas are the ecotonal junctions between rivers and adjacent terrestrial ecosystems (Gregory et al. 1991). They offer valuable resources for humans and other organisms, provide habitats that promote biodiversity (Strayer and Dudgeon 2010), act as corridors for wildlife (Davis and Hardy 2015), and contain adapted vegetation which creates natural buffers between land types (Richardson et al. 2007). Bottomland-floodplain forests are part of deciduous forests that extend into the floodplain of the riparian zone (Vankat 1943). In 1999, it was estimated that more than 60% of the bottomland and floodplain ecosystems that existed in Texas were lost, and that remaining intact forests are endangered (Barry and Kroll 1999).

Globally, river systems have been divided and associated riparian habitat fragmented by more than one million dams (Jackson et al. 2001) with resulting changes in the hydrologic regime and vegetation communities. River bodies have been reshaped by dredging and modified with levees and dams to allow easier navigation for water vehicles and aid in flood control (Jackson et al. 2001; Strayer and Dudgeon 2010). Water slowed by or trapped in a reservoir will lose and not reaccumulate as many sediments and minerals as a free-flowing river with a natural deposition and erosion cycle (Strayer and Dudgeon 2010; Duke 2015). Timing of manual flood releases from dams can also cause issues with riparian ecological processes by disrupting seed dispersal or survival of newly rooted plants (Duke 2015). If the anthropogenic flood regime dominates the ecological timing of floods, terrestrial environments adjacent to rivers may be at risk of degradation.

For centuries, humankind has settled along rivers to utilize fresh sources of running water and nutrient-rich lands as convenient sites for homes, farms, and industries (Strayer and Dudgeon 2010). Settlement along riverbanks results in clearing of forested areas to make room on nutrient-rich riparian land for crops and livestock. Forage crops are often planted in these cleared-forest areas and expand into riparian zones. Nonnative grasses expanding into bottomlands can be problematic as they commonly outcompete native tall grasses that are essential to soil integrity and riverbank stability (Jones-Lewey 2016). Forage crops generally serve the purpose of feeding domestic livestock, the presence and abundance of which often destroys vegetation through overgrazing and creates conditions for runoff and erosion (Texas Parks and Wildlife Department (TPWD) 2017). Manure can introduce bacteria and viruses; rising bacterial levels can degrade water quality while viruses can jeopardize organisms in these environments (TPWD 2017). If fields are treated with fertilizer or pesticides, there is potential for these to leech into the water system through soil, or surface water runoff (TPWD 2017). In the United States, 60-70% of pesticide use is administered by the agricultural sector (TPWD 2017), and aquatic ecosystems in the vicinity are especially susceptible to adverse effects from pesticides. Riparian zones can aid in reducing runoff from entering the river system (Nelle 2015), but only if there is adequate vegetation to create the buffer.

Once humans stop use of a riparian zone it is often left to recover without management. When this happens, invasive species become dominant, and services provided by the natural riparian zone are altered. Common invasive grasses intended for turf or yard cover can serve the same groundcover function in the floodplain understory once established, but do not provide the extent of erosion-protection and bank stability that native tall grasses do during floods (Jones-Lewey 2016). Rangeland brush invasion of Ashe's juniper (*Juniperus ashei*) and Pinchot's juniper (*Juniperus pinchotii*) has been documented for decades in the Cross Timbers ecoregion of Texas, and their encroachment into bottomland forests has caused riparian land to become drier, potentially impeding health of larger hardwood tree species native to these areas (Vickery 1991). As a result of invasive species encroachment, biodiversity of riparian ecosystems is reduced (TPWD 2017).

Due to the many factors working against healthy, natural riparian ecosystems, managed restoration is needed. Before restoration efforts can be made in a riparian area, the vegetative community needs to be quantified and described, so restoration efforts are based on the measured state relative to reference ecosystems that reflect natural vegetative communities within different ecosystems of Texas (Cotton 2017). There are many rivers in Texas, yet proper quantification of forest communities is lacking for a considerable amount of Texas (Diamond et al. 1987). The more information we have on vegetative communities in riparian areas, the better we can compare and potentially develop ubiquitous strategies for preserving and restoring riparian forests.

The Texas Colorado (TXCO) River is the fifth longest river in the state. Yet, the first vegetative analysis of a portion of its riparian zone was not published until 2018, when the woody and herbaceous composition at the Timberlake Biological Field Station (TBFS) was defined (Nelson et al. 2018). The study site at TBFS was a bottomland forest located in the Lampasas Cut Plain along the TXCO River. The forest consisted of three vegetational layers: 1) upper canopy with cedar elm (*Ulmus crassifolia*) and green ash (*Fraxinus pennsylvanica*) as dominant trees, 2) under canopy of heavily browsed lianas, shrubs and smaller trees including saw greenbrier (*Smilax bona-nox*), Texas persimmon (*Diospyros texana*), and western soapberry (*Sapindus saponaria*), 3) herbaceous zone of Canada wild rye (*Elymus canadensis*) and Texas wintergrass (*Nasella leuchotricha*), with sedges and forbs (Nelson et al. 2018). The sampling area was grazed by livestock for ≥ 100 years, frequented by a resident herd of white-tailed deer (*Odocoileus virginianus*), and showed evidence of American beaver (*Castor canadensis*) browsing and girdling trees (Nelson et al. 2018). This herbivory and the hydrological changes to the river could be the causes of the sparce regeneration of the dominant trees, cedar elm and green ash (Nelson et al. 2018).

Colorado Bend State Park (CBSP) was purchased by Texas in 1984 and is located on the TXCO River about 30 km downstream of TBFS (TPWD-History). Domestic livestock have not been present at CBSP since its acquisition by the state. Like many other riparian forests in Texas, little has been done to quantify vegetative communities at CBSP. During part of a field survey to determine diversity of the rodent community within CBSP, six tree species and some herbaceous understory categories, and their percent coverage as habitat were recorded in two transects set in riparian forest (Scales and Wilkins 2003). However, the species of the herbaceous zone were not identified. Ecological site descriptions of forests need more detail and must include canopies and understory (Nelson et al. 2018).

The objectives of the investigation were to quantify both woody and herbaceous species of riparian areas within CBSP and provide ecotonal information regarding the Edwards Plateau and Cross Timbers ecoregions. Additionally, vegetative community composition from CBSP was compared to that of TBFS to evaluate CBSP as a potential reference site for restoration.

MATERIALS AND METHODS

FIELD METHODS

Sampling took place in riparian areas along the TXCO River at CBSP on October 11-13 and 18-20 of 2019. Surveyor measuring tapes were used to set up 12 nonpermanent quadrats (sampling plots) within a stretch of the forest along the west bank of the river. The quadrats measured 50 m by 25 m with the longest side running parallel to the river. Whenever there was not enough bottomland between the river and upland, quadrats consisted of two 50 m by 12.5 m combined sample areas. Sampling began at the River Trail head near the park headquarters and quadrats were set up every 0.2 km. GPS coordinates for the four corners of each quadrat were recorded.

All quadrats were sampled for woody vegetation, any individual with a diameter at breast height (DBH) measurement of ≥1 cm was recorded. To provide the description of the vegetative community, the woody and herbaceous vegetation data from the first six quadrats located closest to the River Trail head were compiled. Herbaceous vegetation was sampled using the step-point method (Bonham 1989) to quantify the species that form the understory. For this method a metal rod is used to strike the ground as the surveyor walks. If the rod strikes a plant, then the plant is identified and recorded; each strike with no plant is recorded as bare ground. The surveyor does not look at the ground until after the rod lands to reduce surveyor bias. A minimum of 500 points were taken at each quadrat for a total of 3,185 total points recorded in the six quadrats.

Woody and herbaceous species were identified and listed with common and scientific names using the taxonomic keys in Diggs et al. (1999), and most were identified to species level. Any unidentifiable plants were labelled as an unknown accompanied by an accurate taxonomic describer. Voucher specimens were collected and deposited in the herbarium at Tarleton State University (TAC).

STATISTICAL ANALYSIS

DBH measurement totals per species were used to calculate area (m^2), which allowed for calculating dominance (m^2/ha). Densities (plants/ha), frequencies, coverages, and relative importance values were found, as demonstrated by Ford and Van Auken (1982), Wood and Wood (1988, 1989), Rosiere et al. (2013), and Nelson et al. (2018). Richness was determined by counting the species present, and Shannon diversity and evenness were calculated using the 'vegan' community ecology package in R Studio (Oksanen et al. 2020).

RESULTS

Three vegetational layers made up the bottomland-floodplain forest: 1) upper canopy of larger trees including pecan (*Carya illinoinensis*), green ash (*Fraxinus pennsylvanica*), and cedar elm (*Ulmus crassifolia*), 2) under canopy thick with short trees and shrubs including *Juniperus* trees and gum bumelia (*Sideroxylon lanuginosum*), with mustang grape (*Vitis mustangensis*) and saw greenbrier (*Smilax bona-nox*) as common lianas, 3) herbaceous zone where main vegetation consisted of native grasses like broadleaf woodoats (*Chasmanthium latifolium*) and Canada wild rye (*Elymus canadensis*), however much of this zone was relatively barren (Tables 1 and 2).

Table 1. Density, dominance, and relative importance values for woody vegetation greater than or equal to one centimeter diameter at breast height of the bottomland-floodplain forest in Colorado Bend State Park, along the Texas-Colorado River.

Common name (Scientific name)	**Density (plants/ha)**	**Dominance (m^2/ha)**	**Importance Value (%)**
American elm (*Ulmus americana*)	8.0	4.0	1.6
Black walnut (*Juglans nigra*)	1.3	0.1	0.5
Cedar elm (*Ulmus crassifolia*)	104.0	33.7	5.0
Chinaberry (*Melia azedarach*)	1.3	<0.1	0.5
Green ash (*Fraxinus pennsylvanica*)	38.7	93.8	4.8
Gum bumelia (*Sideroxylon lanuginosum*)	65.3	3.0	4.2
Juniperus spp.	1053.3	2303.1	54.6
Mexican plum (*Prunus mexicana*)	1.3	0.1	0.5
Mustang grape (*Vitis mustangensis*)	44.0	1.4	3.7
Pecan (*Carya illinoinensis*)	28.0	152.7	5.3
Poison ivy (*Toxicodendron radicans*)	1.3	<0.1	0.5
Prairie flame leaf sumac (*Rhus lanceolata*)	2.7	<0.1	1.0
Red mulberry (*Morus rubra*)	2.7	0.1	1.0
Red oak (*Quercus buckleyi*)	1.3	0.7	0.5
Roughleaf dogwood (*Cornus drummondii*)	84.0	2.4	3.7
Rusty blackhaw (*Viburnum rufidulum*)	8.0	<0.1	0.6
Sugarberry (*Celtis laevigata*)	10.7	0.1	2.1
Sycamore (*Platanus occidentalis*)	16.0	31.6	2.6
Texas mountain laurel (*Dermatophyllum secundiflorum*)	2.7	<0.1	0.5
Texas persimmon (*Diospyros texana*)	62.7	1.3	3.7
Western soapberry (*Sapindus saponaria*)	8.0	0.1	1.6
Virginia creeper (*Parthenocissus quinquefolia*)	4.0	<0.1	1.5
Total	**1549.3**	**2628.3**	**100.0**

There were 22 woody species with diameter measurements of ≥1.0 cm sampled in this forest. Of these, 18 were native trees, three were native woody vines and lianas, and one was a non-native invasive tree. Among the native trees, *Juniperus* trees were native invasive species encroaching into the bottomlands. *Juniperus* trees were the most common tree with the highest dominance (2303.1 m^2/ha) and relative importance value (54.6%) of all woody species measured that were ≥1.0 cm in diameter (Table 1). After *Juniperus* trees, cedar elm and roughleaf dogwood (*Cornus drummondii*) were the most common trees. Pecan and green ash had the next highest dominances (152.7 m^2/ha and 93.8 m^2/ha, respectively) and pecan and cedar elm had the next highest relative importance values (5.3% and 5.0%, respectively; Table 1). Mustang grape was a common vine which had a fairly high relative importance value (3.7%), the same importance value as two shrubby species, roughleaf dogwood and Texas persimmon (*Diospyros texana*; Table 1). A single non-native invasive chinaberry (*Melia azedarach*) was recorded in the sample area; however, more were observed along the river outside of the sampling area.

Table 2. Step-point counts to determine species composition of herbaceous and woody vegetation that were less than one centimeter diameter at breast height of the bottomland-floodplain forest in Colorado Bend State Park, along the Texas-Colorado River.

Common name (Scientific name)	**# of hits (%)**
Pteridophytes	
Horsetail (*Equisetum hyemale*)	181 (5.7)
Total Pteridophytes	**181 (5.7)**
Grasses	
Bermudagrass (*Cynodon dactylon*)	4 (0.1)
Broadleaf woodoats (*Chasmanthium latifolium*)	511 (16.0)
Canada wild rye (*Elymus canadensis*)	115 (3.6)
Hairy wood brome (*Bromus pubescens*)	16 (0.5)
Johnsongrass (*Sorghum halepense*)	21 (0.7)
Little bluestem (*Schizachyrium scorparium*)	1 (<0.1)
Switchgrass (*Panicum virgatum*)	5 (0.2)
Unknown grass	43 (1.4)
Total grasses	**716 (22.5)**
Grasslike	
Unknown sedge	39 (1.2)
Total grasslike	**39 (1.2)**
Forbs	
Castor bean (*Ricinus communis*)	1 (<0.1)
Eryngo (*Eryngium leavenworthii*)	1 (<0.1)
Frostweed (*Verbesina virginica*)	10 (0.3)
"Orange-stem" *Euphorbia* sp.	1 (<0.1)
Rubus sp.	2 (0.1)
Slim aster (*Aster subulatus* var. *ligulatus*)	3 (0.1)
Tragia sp.	5 (0.2)
Unknown/small dicot	7 (0.2)
Unknown mint	1 (<0.1)
Western ragweed (*Ambrosia psilostachya*)	3 (0.1)
Wild poinsettia (*Euphorbia heterophylla*)	1 (<0.1)
Total forbs	**35 (1.1)**
Shrubs, lianas, and small trees	
Agarito (*Mahonia trifoliolata*)	1 (<0.1)
American elm (*Ulmus americana*)	4 (0.1)
Bristle greenbrier (*Smilax tamnoides*)	11 (0.4)
Cedar elm (*Ulmus crassifolia*)	43 (1.4)
Green ash (*Fraxinus pennsylvanica*)	1 (<0.1)
Gum bumelia (*Sideroxylon lanuginosum*)	16 (0.5)
Juniperus spp.	18 (0.6)
Plateau live oak (*Quercus fusiformis*)	1 (<0.1)
Mustang grape (*Vitis mustangensis*)	2 (0.1)
Nandina (*Nandina domestica*)	1 (<0.1)
Poison ivy (*Toxicodendron radicans*)	1 (<0.1)
Prairie flame leaf sumac (*Rhus lanceolata*)	2 (0.1)

Table 2 (cont.)

Roughleaf dogwood (*Cornus drummondii*)	13 (0.4)
Saw greenbrier (*Smilax bona-nox*)	93 (2.9)
Sugarberry (*Celtis laevigata*)	1 (<0.1)
Texas mountain laurel (*Dermatophyllum secundiflorum*)	1 (<0.1)
Texas persimmon (*Diospyros texana*)	7 (0.2)
Virginia creeper (*Parthenocissus quinquefolia*)	5 (0.2)
Western soapberry (*Sapindus saponaria*)	1 (<0.1)
Total shrubs, lianas, and small trees	**222 (7.0)**
Bare ground	1992 (62.5)
Total hits	**3185 (99.8)**

Of the 40 species in the understory (<1 cm), 28 were native, one was a native invasive, and four were non-native species; seven plant species were not identifiable to species level. There was a substantial presence of horsetail (*Equisetum hyemale*) which had the second highest percentage of herbaceous vegetation (5.7%; Table 2). Broadleaf wood oats (16.0%) and Canada wild rye (3.6%) are native grasses that were main components of the herbaceous zone, and a total of 22.5% of the understory was comprised of grasses. Non-native invasive grasses included Johnsongrass (*Sorghum halepense*, 0.7%) and Bermudagrass (*Cynodon dactylon*, 0.1%; Table 2). While these low percentages of invasive grasses are encouraging, both Johnsongrass and Bermudagrass are described as species that can outcompete other grasses and become dominant in bottomland systems (Elliott 2014). Sedge species were not identifiable at the time of sampling but were likely native and made up 1.2% of the understory (Table 2). Overall, forbs did not contribute much to the herbaceous zone (1.1%), but frostweed (*Verbesina virginica*) was the most common forb species (0.3%; Table 2). There was one non-native herbaceous shrub, castor bean (*Ricinus communis*, <0.1%), which was sampled a single encounter in the study area (Table 2), however established mature stands of castor bean were seen in multiple areas along the riverbank. Saw greenbrier was fairly common (2.9%) in the understory (Table 2) and was notedly climbing and hanging from the upper canopy and shrubby trees in many of the sampling sites, however, individual stems were never thick enough to measure and record DBH in these locations. Cedar elm was the woody species in the understory with the most seedlings (1.4%) and highest sampled regeneration rates (Table 2). *Juniperus* seedlings (0.6%) were the only native invasive woody species sampled. Nandina (*Nandina domestica*, <0.1%) was the only non-native woody shrub and was sampled one time in the study area.

CBSP is located in the Edwards Plateau ecoregion of the TXCO river, and TBFS in the Cross Timbers ecoregion, with CBSP being a possible candidate as a reference site for TBFS. CBSP had shallower soils with bedrock closer to the surface than the sites at TBFS. Vegetation densities, dominances and relative importance values at the sites were directly compared (Table 3). These two TXCO River sites had 15 species in common: 12 were trees, shrubs, or lianas, two were grasses, and one was a forb (Tables 1 and 2; Nelson et al. 2018). At CBSP, *Juniperus* trees yielded the highest density (1053.3 plants/ha), dominance (2303.1 m^2/ha) and relative importance value (54.6%; Table 3), while only one *Juniperus* seedling or sapling was sampled by step-point method in the TBFS herbaceous understory (Nelson et al. 2018). Cedar elm was the woody species at TBFS with the highest density (222.7 plants/ha), dominance (1036.8 m^2/ha) and relative importance value (70.7%; Table 3; Nelson et al. 2018). At TBFS, cedar elm was about twice as dense, three-hundred times as dominant, and had relative importance about fourteen times greater than in CBSP (Table 3). Cedar elm in CBSP had the second highest density (104.0 plants/ha), and third highest relative importance (5.0%) of the present woody species and was also the tree with the highest regeneration (1.4%) in the herbaceous understory (Table 3). Juniper, pecan, and gum bumelia were important in CBSP, but were not at TBFS (Table 3; Nelson et al. 2018). Alternatively, American elm, sugarberry, and western soapberry had high importance values at TBFS, but not at CBSP (Table 3; Nelson et al. 2018).

CBSP had about twice the amount of bare ground step-points (Table 3; Nelson et al. 2018). Broadleaf woodoats and horsetail were sampled often at CBSP but were not sampled at TBFS (Table 3; Nelson et al. 2018). Texas winter grass (*Nasella leuchotricha*) and Bermudagrass were more frequently sampled at TBFS (Table 3; Nelson et al. 2018). At TBFS, grasses made up twice as much herbaceous vegetation in the understory (44.3%; Nelson et al. 2018) than grasses at CBSP. Canada wild rye was almost half (20.6%) of the total grass composition, which is more than five times the amount of Canada wild rye in the understory of CBSP (Table 3; Nelson et al. 2018). Saw greenbrier was nearly twice as common in the CBSP herbaceous zone as it was in TBFS (Table 3; Nelson et al. 2018).

Table 3. Comparison of the Colorado Bend State Park bottomland-floodplain forest to the bottomland forest at Timberlake Biological Field Station (Nelson et al. 2018). Woody vegetation is sorted by five highest densities (plants/ha), dominances (m^2/ha), and relative importance values (%), and top five herbaceous vegetation based on number of hits (%) are compared between the two locations.

	CBSP	**TBFS**
Woody Vegetation Data		
Highest density 1 (plants/ha)	Junipers 1053.3	Cedar elm 222.7
Highest density 2	Cedar elm 104.0	Western soapberry 46.7
Highest density 3	Roughleaf dogwood 84.0	Green ash 45.3
Highest density 4	Gum bumelia 65.3	Sugarberry 25.3
Highest density 5	Texas persimmon 62.7	American elm 24.0
Highest dominance 1 (m^2/ha)	Junipers 2303.1	Cedar elm 1036.8
Highest dominance 2	Pecan 152.7	Green ash 204.9
Highest dominance 3	Green ash 93.8	American elm 37.1
Highest dominance 4	Cedar elm 33.7	Prickly-pear cactus 16.8
Highest dominance 5	Sycamore 31.6	Sugarberry 14.9
Highest importance value 1 (%)	Junipers 54.6	Cedar elm 70.7
Highest importance value 2	Pecan 5.3	Green ash 14.1
Highest importance value 3	Cedar elm 5.0	Western soapberry 4.5
Highest importance value 4	Green ash 4.8	American elm 3.9
Highest importance value 5	Gum bumelia 4.2	Sugarberry 2.9
Herbaceous Vegetation Data		
Highest number hits 1 (%)	Broadleaf woodoats 16.0	Canada wild rye 20.6
Highest number hits 2	Horsetail 5.7	Texas wintergrass 15.2
Highest number hits 3	Canada wild rye 3.6	Bermudagrass 5.0
Highest number hits 4	Saw greenbrier 2.9	Gotthilf Muhlenenberg's caric-sedge 3.4
Highest number hits 5	Cedar elm 1.4	Unknown caric sedge 2.5
	Unknown grass 1.4	Southwestern bristlegrass 2.4
Bare ground	62.5	35.6

Diversity measures were relatively similar between CBSP and TBFS, except for woody richness, which was highest at CBSP with 22 species, compared to 13 species in TBFS (Table 4; Nelson et al. 2018). Herbaceous richness of the forest along the TXCO River was equal at 40 species (Table 4; Nelson et al. 2018). Woody and herbaceous evenness and Shannon Diversity were slightly lower for CBSP than for TBFS (Table 4).

Table 4. Richness, Evenness, and Shannon Diversity comparisons of Colorado Bend State Park bottomland-floodplain forest to the Timberlake Biological Field Station bottomland forest (Nelson et al. 2018).

	TXCO River (CBSP)	**TXCO River (TBFS)**
Woody Richness > 1.0 cm	22	13
Herbaceous Richness < 1.0 cm	40	40
Woody Evenness > 1.0 cm	0.44	0.59
Herbaceous Evenness < 1.0 cm	0.57	0.66
Woody Shannon Diversity > 1.0 cm	1.37	1.51
Herbaceous Shannon Diversity < 1.0 cm	2.12	2.42

Due to *Juniperus* species' invasive habit, juniper data were removed from Table 1 to show shifted relative importance values of other woody species (Table 5). With junipers removed, Pecan became the species with the highest relative importance value (20.6%), followed by green ash (15.3%), cedar elm (13.0%), roughleaf dogwood (7.9%), and gum bumelia (7.7%; Table 5). Green ash became more important than cedar elm, and roughleaf dogwood became more important than gum bumelia, when juniper data was excluded from woody vegetation calculations (Table 5).

Table 5. Density, dominance, and relative importance values for woody vegetation greater than or equal to one centimeter diameter at breast height of the bottomland-floodplain forest in Colorado Bend State Park, along the Texas-Colorado River when *Juniperus* species data are excluded.

Common name (Scientific name)	**Density (plants/ha)**	**Dominance (m^2/ha)**	**Importance Value (%)**
American elm (*Ulmus americana*)	8.0	4.0	2.4
Black walnut (*Juglans nigra*)	1.3	0.1	0.6
Cedar elm (*Ulmus crassifolia*)	104.0	33.7	13.0
Chinaberry (*Melia azedarach*)	1.3	<0.1	0.6
Green ash (*Fraxinus pennsylvanica*)	38.7	93.8	15.3
Gum bumelia (*Sideroxylon lanuginosum*)	65.3	3.0	7.7
Mexican plum (*Prunus mexicana*)	1.3	0.1	0.6
Mustang grape (*Vitis mustangensis*)	44.0	1.4	6.1
Pecan (*Carya illinoinensis*)	28.0	152.7	20.6
Poison ivy (*Toxicodendron radicans*)	1.3	<0.1	0.6
Prairie flame leaf sumac (*Rhus lanceolata*)	2.7	<0.1	1.2
Red mulberry (*Morus rubra*)	2.7	0.1	1.2
Red oak (*Quercus buckleyi*)	1.3	0.7	0.7
Roughleaf dogwood (*Cornus drummondii*)	84.0	2.4	7.9
Rusty blackhaw (*Viburnum rufidulum*)	8.0	<0.1	1.0
Sugarberry (*Celtis laevigata*)	10.7	0.1	2.8
Sycamore (*Platanus occidentalis*)	16.0	31.6	6.3
Texas mountain laurel (*Dermatophyllum secundiflorum*)	2.7	<0.1	0.7
Texas persimmon (*Diospyros texana*)	62.7	1.3	6.9
Western soapberry (*Sapindus saponaria*)	8.0	0.1	2.0
Virginia creeper (*Parthenocissus quinquefolia*)	4.0	<0.1	1.8
Total	496.0	325.3	100.0

DISCUSSION

Woody Vegetation

The most recent known study that occurred within the park, which provided some information on six woody species, was a rodent survey with two riparian trapping transects (Scales and Wilkins 2003). Specific information about each species is lacking and all are grouped together as "woody plants" which made up the main vegetative cover component (46%) of the habitat being assessed (Scales and Wilkins 2003). Of the trees noted in the rodent survey, black walnut (*Juglans nigra*), red oak (*Quercus buckleyi*), and plateau live oak (*Quercus fusiformis*) were only sampled one time each within the current study's sample area, making them rare in the current riparian forest. Both the red oak and the black walnut appeared to be mature individuals. One plateau live oak seedling was sampled in the step-point surveys, but adult trees were only observed more in upland areas adjacent to the riparian forest. This could indicate a loss of regeneration and reduction in abundance of these species within the last 20 years.

The amount of juniper sampled in CBSP appears to greatly exceed that of other various riparian forests in Texas with documented *Juniperus* presence. In the current study, Ashe's juniper (*Juniperus ashei*) and eastern red cedar (*Juniperus virginiana*) were the two species of juniper identified. Both species are documented by Texas Ecosystem Analytical Mapper (TEAM), however Ashe's Juniper seems to be the more common species of juniper in the Hill Country. Ashe's juniper was a dominant species with an importance value of 20.9±12.7 in creek bottoms in the Cedar Brakes region of the southern Edwards Plateau (Van Auken et al. 1979). In a phytosociological study of riparian forests along the Guadalupe River, Ashe's juniper was limited to the upper portion of the floodplain (Ford and Van Auken 1982); and in a follow-up investigation of flood-caused changes to vegetation along the upper Guadalupe River, Ashe's juniper was present in the riparian forest, but reported as a low-density species (Van Auken and Ford 2017). Along the Sabinal River, Ashe's juniper was a high-density species with a relative importance value of 2.98% (Wood and Wood 1989) and on the Frio River, its relative importance was 2.75% (Wood and Wood 1988). Hall (1952) was perhaps the first account of both species existing and potentially hybridizing in the Edwards Plateau. Eastern red cedar is either not specified or nonexistent in much of the previous riparian work conducted in the Edwards Plateau. Both species have invaded much of the Great Plains of the United States, and are particularly problematic in tallgrass prairie, bottomlands hardwood forest and upland post oak-forest ecosystems in the Cross Timbers (Bidwell et al. 2016).

Pecan, despite lower density, contributed greatly to dominance and garnered a high importance value at CBSP because they were generally larger trees and because their size could be characterized as old growth. Similarly, in a study conducted in the West Cross Timbers ecoregion, pecan was not highly dense, but was the second most dominant tree and of second high relative importance to the bottomland forest along the Bosque River (Rosiere et al. 2013). Results from a study over flooding that caused changes along the Guadalupe River revealed that pecan average basal area decreased post-flood (Van Auken and Ford 2017), which could indicate that while pecans exist and persist in riparian settings, they are moderately intolerant to the regular flooding expected in riparian areas.

Green ash is described as one of three riparian indicator species in Texas and is specifically indicative of regular disturbance attributed to frequent flooding in an area (Duke 2015). Many green ashes at CBSP were close to the river's edge, which corresponds with the species' root system adaptations that allow green ash trees to dominate stream sides and steep riverbank slopes where many species cannot survive (Duke 2015). These extensive root systems also benefit the slopes, which are most prone to direct erosion by the river. Low regeneration rate of green ash was likely due to the fruits and foliage of green ash being highly palatable for many wildlife species (Duke 2015). Herbivory by white-tailed deer, cattle, and beaver, was the apparent cause of low green ash regeneration rates at TBFS as well (Nelson et al. 2018).

One young Chinaberry (*Melia azedarach*) was the only non-native tree >1.0 cm. sampled in CBSP. Chinaberry was introduced from Asia (Jones-Lewey 2016) and listed as a common exotic plant with invasive attributes (Nelle 2015), as it tends to crowd out native species in riparian areas. There is documentation of Chinaberry occurring in many riparian forests across Texas (current study; Nelson et al. 2018; Van Auken and Ford 2017; Rosiere et al. 2013; Davis and Smith 2013; Longfield 2001; Nixon et al. 1991; Wood and Wood 1989; Wood and Wood 1988; Van Auken and Bush 1985; Bush and Van Auken 1984; Ford and Van Auken 1982). Chinaberry may not be as common along the TXCO River in CBSP due to infrequent flooding, as Chinaberry tends to establish after flooding (Bush and Van Auken 1984) and perhaps, because there are few seed sources compared to some rivers.

Some forests in the Cross Timbers contained fewer woody species than the forest at CBSP, only 13 woody species were recorded along the TXCO River at TBFS (Nelson et al. 2018), and 17 woody species were recorded along the Bosque River (Rosiere et al. 2013). Riparian forests from other portions of the Edwards Plateau and Rio Grande Plains yielded higher woody species richness, with 37 on the Leona River and 56 on the Sabinal River (Wood and Wood 1989), 66 along the Frio River (Wood and Wood 1988), and 32 woody species along the Guadalupe River (Ford and Van Auken 1982). In 1993, vegetation of 20 bottomland sites in East Texas were analyzed and revealed presence of 72 woody species, with evenness value ranges from 0.65 to 0.79 (Brooks et al. 1993). Despite having reported lower woody richness, both TBFS and the Bosque River studies had higher evenness values for woody vegetation than CBSP (Nelson et al. 2018) due to the high numbers of junipers in CBSP.

Herbaceous Vegetation

Increased bare ground could be caused by excessive shade and coverage of soil by juniper species (Hoff et al. 2018; Young and Bush 2009). Broadleaf woodoats was potentially the most common species in the understory due to its shade tolerance (Jones-Lewey 2016). Broadleaf woodoats grows readily on slopes and riverbanks, holding soil in place where other soil-stabilizer species may not grow as well (Jones-Lewey 2016) thus preventing excess erosion of the banks. Johnsongrass and Bermudagrass have the potential to become problematic in riparian areas as they can outcompete and replace native riparian grasses (Elliott 2014), potentially increasing erosion rates and degrading nutrient-richness of the soil. Bermudagrass was also present in the understory at TBFS, and likely moved down into the bottomland from nearby fields (Nelson et al. 2018).

Castor bean (*Ricinus communis*), a native to east Africa (Invasive Species Specialist Group (ISSG) 2006), is an escaped ornamental that was recorded once in a step-point sampling area and documented twice outside of our sampling area in large stands on the edge of the TXCO River in the state park. The only other known record of castor bean in riparian areas was along a section of the Frio River, located west of San Antonio in the transitional area between the Edwards Plateau and South Texas Plains ecoregions (Wood and Wood 1988). Here it was described with pecan and honey mesquite as an inner bank stand but was not elaborated on further (Wood and Wood 1988). As an invasive species along rivers, castor bean is problematic for several reasons. Mature castor bean plants rapidly grow to an average of 3 to 5 meters in height and outcompete native species through quickly creating substantial shade and reaching reproductive maturity within the first six months after germination (ISSG 2006). Castor bean is not forage, as its foliage is slightly poisonous, and its seeds are the source of the toxin ricin which can cause illness or death if consumed by any organism; two to six seeds can be fatally toxic to humans and large mammals (ISSG 2006).

Nandina (*Nandina domestica*) is noted as a non-native invasive in the Edwards Plateau, along with *Ligustrum* spp., Chinaberry and Chinese tallow (TPWD 2012). Nandina is native to India and has been reported to escape from cultivation into sandy woods (Diggs et al. 1999). It is possible that Nandina escaped from yards and landscaping from a housing addition located across the river from the park and could become more common in the bottomland overtime.

Hydrology

Indicators of riparian health include an active floodplain, energy dissipation during floods, new plant colonization, stabilizing vegetation, age diversity, species diversity, plant vigor, water storage, and establishment of equilibrium between erosion and deposition (Jones-Lewey 2016). Currently, the TXCO at CBSP is most closely affected by two dams, one located 130 km northwest at Lake O.H. Ivie and the other about 30 km to the south at Lake Buchanan. Dams affect floodplain forests by separating and isolating remnant floodplains, which changes biodiversity in riparian areas (Johnson 2002). The primary disturbance and stressors that influence flood plain forests in semi-arid regions have been associated with river flow where flooding resets the successional cycle (Shafroth et al. 2002; Hardy et al. 2015) and provides critical inundation for wetland adapted plants (Dawson et al. 2017). During droughts and flood flow events, low flow hydrology alters riparian vegetation (Nelson et al. 2018; Hardy et al. 2015). Damming of the TXCO River has caused changes in flood magnitude which can limit the occurrence of wetland-adapted species and turned river flow into a limiting factor that may promote upland species (Alldredge and Moore 2014), such as species of juniper. The TXCO River at CBSP seldom inundates the floodplain forest due to changes in hydrology caused by damming, but when it does flood, the flood flow is so substantial that energy is often not dissipated by vegetation, and this results in an imbalance of erosion and deposition (Nelson et al. 2018). Based on the evaluation system of Jones-Lewey (2016) and riparian health indicators, the portion of the TXCO River at CBSP is in at-risk condition and will need management to reduce encroachment by upland species and restore the forest to a highly functional condition.

Herbivory

CBSP has significant populations of white-tailed deer and feral hogs (*Sus scrofa*). During the research, white-tailed deer were observed in the park multiple times, and rooting by feral hogs was also documented. Because state park land is protected and disturbance is minimized by the state, many animal species find sanctuary in the park's boundary, to the point where they become problematic to the environment. Abundance and activities of both white-tailed deer and feral hogs can cause habitat degradation and low regeneration rates of woody species (TPWD 2012) and are likely contributors to low regeneration of woody species, general lack of forbs, and the large percentage of bare ground in the CBSP understory.

White-tailed deer hunting is permitted within the park in specific, assigned areas and only by application and acquisition of a hunting permit by drawing. In past hunting seasons, there have been three different intervals to hunt deer: an antlerless and spike period, a regular period for either sex, and a youth only period for either sex (TPWD-Texas Public Hunt System). These three intervals combined in 2020 consisted of only 18 days. During this short amount of time allotted for hunting in the state park, bag limits were three white-tailed deer per drawn applicant. Additionally, hunters drawn for deer hunts were not limited on the number of feral hogs, aoudad (*Ammotragus lervia*) and other exotic mammals they could take (TPWD-Texas Public Hunt System). There is not information available reporting the numbers of these wildlife species taken per season within the park. The Texas Conservation Action Plan (TCAP) for the Edwards Plateau region states deer in the region are insufficiently harvested, leading to high deer populations and extreme herbivory (The Nature Conservancy 2004), notably on hardwood seedlings (TPWD 2012). Of the woody species recorded in CBSP, cedar elm, poison ivy (*Toxicodendron radicans*), roughleaf dogwood (*Cornus drummondii*), saw greenbrier and Virginia creeper (*Parthenocissus quinquefolia*) are preferred first-choice browse for white-tailed deer (TPWD 2009). Additionally, junipers are among the woody species that are a least utilized for browse (TPWD 2009; Wright et al. 2002). White-tailed deer have become a native problematic (TPWD 2012) species in many parts of Texas, especially in the Hill Country which supports the largest population of white-tailed deer in the state (TPWD-Hill Country).

Feral hogs are a non-native invasive (Schlichting et al. 2015) ungulate that are widespread across the state and exhibit foraging behaviors that degrade riparian habitat, which they tend to prefer over upland habitat (Wagner 2004). Two factors contribute to feral hogs quickly becoming problematic: versatile diets and high fecundity. In the Rolling Plains ecoregions of Texas, feral hog diets were analyzed throughout each of the four seasons (Schlichting et al. 2015). Natural vegetation like grasses, forbs, roots, tubers, browse, and mast made up 56.15% of the feral hog annual diet, and agricultural crops essentially made up the remaining portion (42.21%) of the diet (Schlichting et al. 2015). In pristine bottomland forests, where agricultural crops have not been planted in monocultures, established native grasses like broadleaf woodoats and Canada wild rye become valuable forages for grazing and browsing wildlife (Rosiere et al. 2013). Near the Lampasas Cut Plain, soils are deeper and limestone-derived, and CBSP soils within the sampling area are either frequently flooded, deep, loamy Westola, or stony, shallow Eckrant (Web Soil Survey). Rooting and wallowing by feral hogs increase the likelihood of soils eroding more quickly. Feral hog activity along the river also decreases regeneration rates of woody species and causes damage to riverbank stability through increasing erosion rates (Nelle 2015).

Native Juniper Invasion

The floodplain forests of larger rivers, like the TXCO River, should contain truly mesic woody vegetation and mostly exclude upland species (Van Auken et al. 1979), but the forest at CBSP faces encroachment by Ashe's juniper and eastern red cedar. The extent of Ashe's juniper in Texas before European settlers arrived is debated, but the presence of these trees in the Edwards Plateau was described in reports from early explorers (TPWD 2017). Eastern red cedar proliferation and range began to increase into the Cross Timbers in the mid-1900s (Hoff et al. 2018). The juniper invasion in Texas is the result of anthropogenic actions and is directly tied to fire suppression on degraded land (Leis et al. 2017). *Juniperus* species are some of the first to establish in areas degraded by agriculture and where fire is suppressed (TPWD 2017). Prescribed burning currently only occurs on one park trail near an upland savannah (TPWD-Park Trails). It is most likely that fire suppression, lack of brush management, and absence of subsequent management or restorative measures following the park's agricultural history have contributed to the invasion of native junipers.

Ashe's juniper and eastern red cedar can be distinguished by the growth pattern of the trunk where Ashe's juniper characteristically has multiple trunks sprouting from the base, while eastern red cedar typically has one single trunk (Diggs et al. 1999). Another trait that can help differentiate these two species is the shape of the abaxial leaf glands: abaxial glands of Ashe's juniper are round and often conspicuously raised, whereas abaxial glands of eastern red cedar are more elongated or elliptical and not conspicuously raised (Diggs et al. 1999). At CBSP, several individuals of each species were identified using these characters, however multiple individuals exhibited cross-species characteristics. Hybridization and introgression occur when Ashe's juniper and eastern red cedar are both present (Diggs et al. 1999), and hybrid swarms of Ashe's juniper and eastern red cedar reportedly occur in Texas, specifically in the Edwards Plateau (Hall 1952). Hybridization could be occurring within CBSP since many of the sampled individuals had trunk and abaxial gland characteristics that were mixed between Ashe's juniper and eastern red cedar. Junipers cause significant problems for native species (Diggs et al. 1999) by competing for plant-growth resources (Corbett and Lashley 2017; Yager and Smeins 1999; Vickery 1991) and may have allelopathic attributes which could affect surrounding vegetation (Young and Bush 2009; Stipe and Bragg 1989).

In CBSP, junipers were dense and dominant, creating thick shrubby masses close to the river. Eastern red cedar can shade out herbaceous vegetation (Hoff et al. 2018) and dense canopies of Ashe's juniper can reduce proliferation and species diversity of understory vegetation (Young and Bush 2009), to the point where the herbaceous zone can be nonexistent under larger juniper trees (Yager and Smeins 1999). Ashe's juniper and eastern red cedar also use water year-round and are drought-tolerant species (Caterina et al. 2014). Eastern red cedar has been shown to flexibly exploit deep soil water during drought and switch to shallow water sources when available (Eggemeyer et al. 2009). Both species of juniper utilize water excessively which can cause soils to dry out and competitively exclude vegetative species which need wetter soils (Vickery 1991). Junipers' scale-like leaves create substantial leaf area which can intercept up to 95% of precipitation specifically in a completely closed canopy of eastern red cedar (Caterina et al. 2014). While most studies on adverse effects of junipers have focused on exploitative competition for resources, interference competition utilizing allelopathic compounds has been observed. One study's finding suggested that Ashe's juniper affected the germination of side-oats grama (*Bouteloua curtipendula*) through the release of allelopathic compounds (Young and Bush 2009), and phytotoxins from eastern red cedar potentially decreased the germination of finger coreopsis (*Coreopsis palmata* Nutt.) in another study on allelopathic properties (Stipe and Bragg 1989).

Ashe's juniper, eastern red cedar, and other shrubby invasives can be managed in multiple ways, but if left unmanaged, these trees will negatively impact the riparian ecosystem, and potentially change forest succession into an abnormal juniper dominated system (Bidwell et al. 2016). The aquatic portion of a riparian ecosystem is especially susceptible to pesticides because they can inadvertently and easily enter the water system where they decompose into more toxic compounds and harm other organisms (TPWD 2017), therefore herbicides are not an ideal treatment for selective brush management along rivers. Prescribed fire might be an option for managing juniper encroachment into riparian forests, as these methods can be applied in small amounts or in coordination to limit collateral effects on native species (Nelle 2015). Seedlings and small eastern red cedar trees are fire-intolerant and would normally be removed by low-intensity surface fires if fires had not been suppressed across much of the country (Hoff et al. 2018). However, larger junipers become difficult to kill even with prescribed fire, while also increasing the risk of wildfires (Hoff et al. 2018) that persist long enough to reduce or eliminate more tolerant species. The combination of individual mechanical removal, which could be limited to felling of larger junipers and prescribing fire to small shrubs and trees could be effective in areas that are encroached upon. Focused brush management with these two methods would minimize soil disturbance and potential damage to other woody species. While these junipers do not resprout after cutting or burning (Diggs et al. 1999), reapplication to new growth from the seed bank or follow-through of any form of management is crucial for control of invasive species.

Successional Stages of the Forest at CBSP

When this property became a state park, decades of anthropogenic activities and disturbances were halted, and a preservation management regime was started by the state. Junipers, which were reported in the Edwards Plateau as early as the 1950s (Hall 1952), were preserved within the park area by extension. Each seral stage in the process of succession affects the microenvironment through cover and shade, organic litter, and chemical output, so that the most adaptive species outcompete and encroach on already present species of that given microenvironment (Vankat 1943). In 2019, the area sampled at CBSP was relatively undisturbed, lacked evidence of recent larger disturbances such as fire or recent flooding, and as a result, junipers had invaded into climax riparian forest. In the Balcones Canyonlands Preserve, about 70 km southeast of CBSP, Ashe's juniper growth rates ranged from 0.6 in (1.5 cm) to 1 in (2.5 cm) per decade (O'Donnell 2020). Eastern red cedar with 6 cm to 8 cm DBH trunks are estimated to be around 20 to 30 years old (SRS Forest Service). Given these estimates, the average DBH of junipers in CBSP would indicate that their invasion into the riparian forest began within the past two to three decades.

Riparian zones in the Edwards Plateau can be characterized by the following upper-canopy communities: bald cypress (*Taxodium distichum*) and sycamore (*Platanus occidentalis*), pecan and sugarberry, and elm (*Ulmus* spp.; Wagner 2004). Bald cypress, pecan, and sugarberry were listed as dominants in a floodplain forest along the Guadalupe River in the Edwards Plateau and considered to be representative of climax conditions for this area (Ford and Van Auken 1982). Bald cypress was not sampled or observed along the TXCO River at CBSP, sycamores and sugarberry were not common, pecan was dominant, and cedar elm was dense. The proposed climax community for a remnant bottomland hardwood forest in the Cross Timbers was a sugarberry-cedar elm-green ash community (Barry and Kroll 1999), which was similar to the cedar elm-green ash community reported in the bottomland forest at TBFS (Nelson et al. 2018), and to the sugarberry-cedar elm-pecan community of the mixed-hardwood bottomland forest on the Bosque (Rosiere et al. 2013). Cedar elm and sugarberry are components of and often become dominants in climax forest (Jones-Lewey 2016; Van Auken and Bush 1985). Old growth individuals of pecan, cottonwood (*Populus* spp.), willow (*Salix* spp.), and sycamore (*Platanus* spp.) are often dominant trees (Barbour et al. 1987) but are moderately to highly intolerant pioneer species that can persist into climax bottomland forest (Rosiere et al. 2013). TEAM reports the sample area adjacent to the river predominantly as floodplain hardwood forest: upper canopy can consist of cedar elm, sugarberry, American elm, pecan, plateau live oak, bur oak, western soapberry, Arizona walnut, and green ash; and the understory can include mesquite, gum bumelia, roughleaf dogwood, red mulberry, Texas persimmon, and possumhaw. This floodplain hardwood forest type potentially represents the original vegetation along this part of the TXCO River, as our data reflects the existence of remnants of this forest type within the riparian zone.

CONCLUSIONS

The quantification of this bottomland-floodplain forest provided the first description of woody and herbaceous communities along a portion of the TXCO River in CBSP. The sampled area indicated a degraded habitat dominated by invasive plants and overly abundant wildlife. The plant assemblages of the bottomland-floodplain forest at CBSP indicate that the ecological services of erosion prevention, river stability, and protection from runoff are likely no longer adequately provided. For this reason, CBSP cannot be recommended as a reference site for restoration at this time. Mechanical removal of large junipers paired with prescribed fire treatments to smaller trees and shrubs are restoration strategies that could facilitate or maintain species composition of the remnant climax forest that is currently threatened by juniper invasion. Additionally, reduction of excessive populations of white-tailed deer and exotic ungulates, especially feral hogs, in creek areas of the Edwards Plateau would ease utilization on herbaceous forage species. Should these management practices be implemented, and the remnant plant species restored to a more historical balance, CBSP may serve as a reference site for riparian forests in the Edwards Plateau-West Cross Timbers ecocline.

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