Flood Caused Changes to the Upper Guadalupe River Riparian Forests of Central Texas

O. W. Van Auken and A. L. Ford

Department of Biology
The University of Texas at San Antonio
One UTSA Circle, San Antonio, TX 78249, USA
oscar.vanauken@utsa.edu

allenlford@gmail.com

ABSTRACT

Pre-flood phytosociological measurements were made in eight apparently mature riparian forest communities along the upper Guadalupe River in central Texas. After a high magnitude 100+ year flood in 1978, six communities were revisited and post-flood phytosociological measurements were made to examine flood effects on the riparian forest communities. Some riparian forests were completely destroyed with woody plant trunks snapped or plants uprooted and washed downstream. We viewed these as early successional communities, and did not study them. The flood caused changes in the riparian forest communities we studied previously including reductions in community basal area and density, as well as species basal area, density, and percent cover. Overall, community species composition was unchanged based on Shannon-Weaver diversity values (H'). Species with the greatest reduction in community basal area or density were *Taxodium distichum* (Bald cypress), *Carya illinoinensis* (Pecan), *Ulmus americana* (American elm), *Celtis laevigata* (Hackberry) and *Acer negundo* (Box-elder). Greatest community damage seemed to be related to tree size and bank position. Apparently, the larger the tree or species, the greater the damage sustained in the flood. Larger trees or species at the edge of the river sustained the greatest community change while the smallest ones at greater distance from the river edge had the least change. However, aerial photographic evidence of major river bends, areas that we did not study, suggested that water was so deep and the flood force so great that it cut across the bend removing most trees and vegetation in its path. Published on-line www.phytologia.org *Phytologia 99(4): 226-237 (Dec 18, 2017).* ISSN 030319430.

Key Words: basal area, community structure, density, Edward Plateau, flood damage, floods, Guadalupe River, riparian forest, woody plants.

Understanding community structure and factors that determine structure is a difficult task. Usually more than one force or factor is involved and they could be biotic, abiotic or a combination. Abiotic forces or physical forces such as fires, wind, tidal waves, volcanoes, earthquakes, floods and landslides can have major impacts on plant communities and their component species (Begon et al. 2006). Biotic forces or factors such as herbivory or competition can have similar community effects and usually more than a single force is in play (Begon et al. 2006). All of these forces or combinations can be important in directing community succession (Whitmore 1974; Putz et al. 1983; Begon et al. 2006; Van Auken and Bush 2013).

Riparian forest composition and structure has been studied for many years, including studies in central Texas (Van Auken et al. 1979; Ford and Van Auken 1982). There are spatial gradients that at least partially control the species composition of riparian forests. For example, flood tolerant trees or those requiring more water are close to the river or stream bank and those less tolerant are more distant from the water edge (Bush and Van Auken 1984). Effects of prolonged inundation on tree growth for species on low gradient streams has been well investigated (reviewed by Hupp 1988; also see Johnson et al. 2000). Short term effects of deep, rapidly moving water on woody species and community structure are not as well understood because they occur so infrequently. Some qualitative studies of flood damage have appeared in the literature including mention of complete destruction of all trees in parts of floodplain forests, as well as uprooting, breaking and shearing of stems (Shull 1944; Gardner 1951; Eisenlohr 1952; Hack and Goodlett 1960; Lindsey et al. 1961; Sigafoos 1964; Hallgren 1979; Sullivan 1983).

Recent studies in central and western North America have demonstrated specific flood effects including the importance of floating debris, logs and whole trees (Johnson et al. 2000). In addition, changes in riparian forests on ephemeral streams have been examined (Friedman and Lee 2002). Predictive theories have also been developed that consider various aspects of extreme flood events including water force, material transport, flood frequency and conditions of the floodplain or bank (Dixon et al. 2015).

Early studies of riparian communities did not have much access to or use of aerial photography and overviews of damage to large areas were not easily accomplished, but that has changed (Figure 1, Johnson et al. 2000; Friedman and Lee 2002; Dixon et al. 2015). These studies mainly examined flood effects on early establishing or early successional floodplain species and communities. It has been suggested that temperate floodplain forests are good examples of communities that show a need for chronic, patchy disturbance (Horn 1976). The area of some of these patches may be extensive and show the results of regular destruction which would appear to be cyclic and triggered by periodic high magnitude floods.

Southwestern and central Texas has one of the most varied rainfall-runoff regimes in the United States (Patton and Baker 1976). The rivers occur in bedrock canyons that are deeply entrenched in the Edwards Plateau. The hills are steep, the limestone-derived soils are shallow and the vegetation is comparatively sparse (Van Auken et al. 1979; Kochel 1988). Flood stages have been recorded between 25 and 30 m above normal water levels in some areas (Figure 2, Kochel 1988). On August 1-4, 1978, more than 120 cm of rain from a stalled weak tropical depression (Tropical Storm Amelia) fell on the watersheds of the Medina and Guadalupe Rivers in central Texas (Hallgren 1979; Sullivan 1983). Most of this rain fell during a period of 24 hours causing a major flood. There were 27 deaths in central Texas attributed to the rains and subsequent floods. Normal rainfall for this area is about 81 cm/year, but is highly variable (Arbingast et al.1976; NOAA 2004). The return time for such a flood has been estimated to be several hundred years (Baker 1975; Hallgren 1979; Kochel 1988). Effects of the runoff on the riparian forest communities in some areas were extensive (Figure 1 and 2).Trees greater than 2 m in diameter were up-rooted or the stems were completely shattered with the stem being removed. Others 1 m in diameter were found completely bent-over, parallel to the ground, with vertical splits in the stems (Hallgren 1979; Sullivan 1983).

PURPOSE

The purpose of this study was to identify and quantify changes in the woody vegetation of the upper Guadalupe River riparian forest caused by a high magnitude flood. An additional purpose was to show that the flood caused openings in the tree canopy reduced overstory community cover. The same pre-flood and post-flood riparian communities will be examined to demonstrate the vegetation changes.

METHODS

After analyzing and comparing results of an earlier phytosociological study of the Guadalupe River riparian forest (Ford and Van Auken 1982), we felt there was considerable variability in our data and additional effort would be necessary to understand these forest communities. Consequently, we located and sampled eight additional inner floodplain forest communities to increase our knowledge of this system. These riparian communities were relatively narrow (15-25 m) and relatively steep (slope ~ 21°) usually with agriculture land above the riparian woodland or forest.

Pre-flood sampling. During June and July 1978, phytosociological data was collected from eight riparian communities in Comal, Kendal and Kerr counties in central Texas. All study locations were above Canyon Reservoir, between approximately 50 and 75 mi north or northwest of San Antonio, Texas. We examined the distribution of species and community characteristics on the bank of the inner floodplain, between the river and the grassland or pasture using adjacent 3 x 100 m rectangular quadrats (Van Auken et al. 2005). Basal area, density, cover and species diversity (Shannon and Weaver 1949) were determined and mean values were calculated. Relative values for basal area and density were calculated but are not presented. Relative canopy cover was estimated by visual sighting along a line perpendicular to a level surface at 25 m intervals along the upper edge of each quadrat. Plant species names and identifications were determined using “Vascular plants of Texas” (Correll and Johnston 1979) and confirmed at the United States Department of Agriculture web site (USDA 2016).

Post-flood sampling. During September 1978, six of the original communities were re-sampled (after the flood). Because of community destruction and difficulties getting through the flood debris (Figure 2), a different but equivalent sampling procedure was used (Cottam and Curtis 1956). The point-centered-quarter (PCQ) procedure was used to sample each community. Twenty-five points were sampled at 10 m intervals along a transect line parallel to and approximately 5 m from the river edge. A perpendicular to the transect line was established creating four corners where the perpendicular line crossed the transect line. The point was at the intersection of the two lines. For the woody plant closest to the point in each corner, the species was identified; then, point-to-plant distance, and circumference at approximately 15 cm above ground level were measured and recorded. Only live plants were measured. Basal area, density, cover and species diversity were determined and mean values calculated. Relative values for basal area and density were calculated but not reported. Trees with sapped or broken stems were not counted or measured.

Data analysis. Significant differences between the pre-flood and post-flood communities were determined. Total community mean basal area, density, cover and diversity were compared. Statistical significance of comparisons was determined at the P=0.05 level using paired t-tests (Sall et al. 2012).

RESULTS

Mean total community basal area was reduced 22% (Table 1). Four of the largest species, *Taxodium distichum* (L.) Rich. (Bald cypress), *Carya illinoinensis* (Wang., K. Koch., Pecan), *Ulmus americana* L. (American elm), and *Celtis laevigata* Willd. (Hackberry) had average decreases in basal area of 8-33% (Table 1). The next four species in the table also had large losses in community basal area (Table 1). The remaining species in table 1, low community basal area species, had small or no reductions in basal area.

Riparian forest community density was reduced 26% (Table 2). *Carya illinoinensis*, the species with the highest pre-flood density, changed very little after the flood. Species that were found higher up on the floodplain had little or no change in mean density post-flood (*C. illinoinensis* and *U. crassifolia*). Species found at the river edge had the greatest reduction in density (22-30%, Table 2). However, less common or small floodplain species had little or no change in mean density.

Species richness in the riparian communities was 31 woody species (Tables 2 and 3). Most of the species had low density and basal area. The three tree species with the largest mean species basal area in descending order were *T. distichum*, *C. illinoinensis* and *U. americana* (Table 4). The largest tree measured was a *Taxodium distichum* that had a diameter of 1.15 m. Relative cover was reduced 28% by the flood (from 96±4% to 69±5%, paired *t*-test, $P < 0.05$). Species diversity *(H')* did not change post-flood (2.06±0.34 pre-flood and 2.01±0.35 post-flood, paired *t*-test, $P > 0.05$).

DISCUSSION

Biotic and abiotic forces can have major effects on plant communities (Whitmore 1974; Putz et al. 1983; Begon et al. 2006; Van Auken and Bush 2013). Changes in worldwide plant communities including North American and central Texas plant communities have been going on since prehistoric times. Changes in riparian communities have also occurred in the past and will continue to change in the future (Barbour and Billings 1988; Crawley 1997; Begon et al. 2006; Van Auken and Bush 2013). A successional sequence in these various riparian communities is involved, but fire, wind and herbivory do not seem to be the forces directing the succession. In the riparian woodlands, the major forces influencing the composition and structure of the communities is flood frequency, the time between events, the magnitude of the flood, river bank position and amount of floating debris (Johnson et al. 2000; Friedman and Lee 2002; Dixon et al. 2015).

Curiously, we thought the riparian communities we studied pre-flood were mature communities based on the literature available, the species present and our understanding of these communities at that time (Ford and Van Auken 1982). The riparian communities we examined pre-flood did not include any *Salix* trees (willows) or *Populus* species (cottonwoods) and only a few *Platanus occidentalis* (sycamore). These species are all known or reported to be early successional riparian woodland species (Barbour and Billings 1988; Crawley 1997; Van Auken and Bush 1988). We have not found any studies concerning succession in the central Texas riparian forest communities. However, we speculated that *T. distichum* is an early successional species (Ford and Van Auken 1982).

Since that time, we have not found *Taxodium* juveniles in any of the riparian communities that we surveyed (Van Auken 1988, 1993). Some preliminary studies suggested that *T. distichum* is a high light requiring species (not found below the canopy), indicating that it is an early successional species (Van Auken and Taylor, unpublished). Another species found, *Celtis laevigata*, is a shade tolerant and high soil nitrogen requiring species (typically found below a canopy). Characteristics suggest it is a later successional species, one that would grow in the shade of an overstory canopy (Van Auken and Bush 1985; Bush and Van Auken 1986; Van Auken and Bush 2013) and this current study suggests that as well.

In central Texas, populations of upland species like live oak and Texas persimmon show evidence of recruitment (Van Auken et al. 1980). Conversely, other upland deciduous species like *Quercus sinuate* (Texas red oak), *Q. glaucoides* (Lacy oak), *Prunis serotina* (black cherry), *Fraxinus texensis* (Texas ash), and *Juglans nigra* (black walnut) had few or no new juveniles in the smallest size classes examined (Van Auken 1988, 1993). Therefore, there is little or no recruitment of juveniles of these species into the adult populations.

This lack of recruitment of adults occurs in both upland communities and riparian communities. Possible reasons for this lack of recruitment are changes in local climate, changes in the disturbance regime, increases in herbivore populations, few large carnivores, or episodic establishment that reflect local environmental conditions (Harper 1977; Harcombe and Marks 1978; Beschta and Ripple 2009; Van Auken and Bush 2013). Records do not indicate local climate changes, although they are occurring and will be more obvious in the future (Grunstra and Van Auken 2015). Proximate conditions may be more important such as populations of white-tailed deer in central Texas that have increased dramatically in the last 75+ years (Doughty 1983). These large deer populations have been implicated in the lack of recruitment of various upland deciduous woody species in central Texas (Russell and Fowler 1999, 2002, 2004; Nelson-Dickerson and Van Auken 2016).

This lack of recruitment has been demonstrated for populations of *T. distichum* (Van Auken 1988), which is similar to trends from floodplain forests in the eastern United States (Sharitz et al. 1990). Reasons seem to be high light levels that are not present below a canopy but would occur in disturbances (Neufeld 1983; Titus 1990). If *T. distichum* is to remain a component in these central Texas riparian forests, disturbances of these ecosystems should continue. Populations of *C. laevigata* in these same riparian communities seem to have large numbers of seedlings and there seems to be recruitment into the adult population. *Celtis laevigata* is shade tolerant and a mature riparian forest dominant species unlike *T. distichum* that appears to be shade intolerant (Van Auken and Bush 1985).

Elevated levels of CO_2 and concomitant increases in temperature will undoubtedly effect the species in this area and the community structure in the future, but how is uncertain. Elevated levels of CO_2 have caused increased levels of photosynthesis in some species, but associated increases in temperature had no effect compared to current temperatures (Grunstra and Van Auken 2015).

Riparian communities in central Texas, like other plant communities will change with disturbances, old communities with large/old *T. distichum* will mostly be destroyed by periodic high magnitude floods (depending on river position and water depth). Thus, the age of old *T. distichum* trees or communities in this area could be used to predict the approximate time for the next high magnitude flood event or perhaps when the previous one occurred, but neither has been done. There are probably other factors to be considered when making predictions, such as sand or gravel bars, chutes, and the cut banks of curves in the river that may be extremely susceptible to flood damage (Figure 1). We found no evidence of damage to the Guadalupe River riparian forest trees due to inundation as in other river systems, perhaps because floods of central Texas Rivers seem to occur and dissipate very quickly (Baker 1975; Hallgren 1979; Sullivan 1983).

Larger trees seemed to experience the greatest damage, which suggests that they are the most susceptible to the force of the flood. The smallest species and individuals would be subject to the lowest water velocity, because of their size and position in the water column. Woody plants with small canopies would also offer the least resistance to the flood water. Debris trapping (Sigafoos 1964; Johnson et al. 2000) would also be reduced because small individuals would be completely submerged and removed from the surface where the floating debris occurs. Larger trees such as mature *T. distichum* trees, were in many cases almost completely covered by the flood waters and subjected to greater water velocities, debris catching and greater stress (Figure 2, see Sigafoos 1964; Johnson et al. 2000). Flood induced changes in riparian forests are difficult to assess and recovery times are uncertain. It is known that high magnitude floods do recur at regular though potentially widely-spaced intervals in this ecosystem, and are apparently an important part of its dynamics. They may even be required if recruitment of early successional species is to occur in these communities.

Recruitment of early successional species in these floodplain forests seems to require light gaps in the forest very much like the light gaps in other forests caused by senility, disease, insects, wind throw and fire (Brewer and Merritt 1978; Garwood et al. 1979; Putz et al. 1983; Begon et al. 2006; Van Auken and Bush 2013). High magnitude floods do in fact reduce cover and create gaps; they also recur at predictable, though widely-spaced, intervals in this ecosystem (Baker 1975; Kochel 1988), and are apparently an important force and part of the dynamics of this ecosystem.

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Table 1. Flood induced changes in community mean basal area (m^2/ha) for 11 of the highest basal area riparian species found in the Guadalupe River riparian forest. Scientific names, common names, pre-flood, post-flood and % changes are presented. Total pre and post-flood mean basal areas are significantly different* (paired *t*-test, $P<0.05$).

		BASAL AREA (m^2/ha)		
SPECIES	**NAME**	**PRE-FLOOD**	**POST-FLOOD**	**% CHANGE**
Taxodium distichum	Bald cypress	61.1	44.1	-33
Carya illinoinensis	Pecan	24.1	22.0	-8
Ulmus americana	American elm	3.6	2.9	-19
Celtis laevigata	Hackberry	3.3	2.4	-27
Platanus occidentalis	Sycamore	2.1	1.9	-10
Morus rubra	Red mulberry	1.1	0.3	-63
Acer negundo	Box-elder	0.9	0.8	-12
Ilex decidua	Possum-haw	0.6	<0.1	-86
Cornus drummondii	Dogwood	0.1	0.1	0
Ulmus crassifolia	Cedar elm	0.1	0.1	0
Diospyros texana	Persimmon	<0.1	<0.1	0
Others (20 species, see Table 3)		1.6	2.1	+31
Total*		98.6±19.2	76.5±18.3	Mean = -22

Table 2. Flood induced changes in community mean species density (plants/ha) for 11 of the highest density riparian species found. Pre-flood, post-flood and % changes are presented. Total pre- and post-flood mean densities are significantly different* (paired *t*-test, $P<0.05$).

	DENSITY (plants/ha)		
SPECIES	**PRE-FLOOD**	**POST-FLOOD**	**%CHANGE**
Carya illinoinensis	229	227	-1
Celtis laevigata	141	103	-27
Acer negundo	139	96	-30
Ulmus americana	63	46	-27
Taxodium distichum	58	45	-22
Cornus drummondii	55	46	-26
Ilex decidua	43	31	-28
Diospyros texana	40	29	-27
Platanus occidentalis	13	12	-8
Morus rubra	15	10	-33
Ulmus crassifolia	12	12	0
Others (20 species, see Table 3)	328	176	-46
Total*	1124±171	833±112	*Mean* = -26

Table 3. Other species found in the Guadalupe River riparian forest including common names and type of woody species. These species are low basal area and low density species.

Species	Common Name	Vegetation Type
Vitis mustangensis	Mustang grape	Vine
Sapindus drummondii	Soapberry	Tree
Parthenocissus quinquefolia	Virginia creeper	Vine
Ptelea trifoliata	Skunk-bush	Shrub
Fraxinus americana	White ash	Tree
Cephalanthus occidentalis	Buttonbush	Vine
Maclura pomifera	Osage orange	Tree
Juglans nigra	Black walnut	Tree
Sideroxylon lanuginosum	Gum bumellia	Tree
Prosopis glandulosa	Honey mesquite	Tree
Melia azedarach	Chinaberry	Tree
Toxicodendron rydbergii	Western poison ivy	Vine
Quercus virginiana	Live oak	Tree
Amorpha fruticosa	Bastard indigo	Shrub
Callicarpa americana	American beautyberry	Shrub
Juniperus asheii	Ash juniper	Tree
Salix nigra	Black willow	Tree
Ailanthus altissima	Tree of heaven	Tree
Smilax bona-nox	Cat-brier	Vine
Tilia ameracana	Carolina basswood	Tree

Table 4. Flood induced changes in mean species basal area (cm^2/plant) for seven selected riparian species, including the four highest community total basal area species. Pre-flood, post-flood and % changes are presented.

		MEAN BASAL AREA	
SPECIES	**PRE-FLOOD**	**POST-FLOOD**	**% CHANGE**
Taxodium distichum	11,478	9,450	-18
Carya illinoinensis	992	845	-15
Ulmus americana	878	938	+7
Ulmus crassifolia	315	271	-14
Celtis laevigata	245	247	+1
Cornus drummondii	13	11	-15
Diospyros texana	5	6	+20

Figure 1. Photographs of damage to the riparian forest of the Medina River. Top figure is ground level and shows the removal of the tops of all *Taxodium* trees on the river edge. The middle and bottom figures are aerial photographs showing a number of different kinds and amounts of damage to the floodplain forest. In most cases parts of the riparian forest were completely removed or destroyed by the flood. The middle picture (aerial photograph), lower, central part shows all of the *Taxodium* trees with branches removed and apparent total removal of any forest on the right side of the photograph. Bottom picture (aerial photograph), lower center, next to the river shows *Taxodium* trees down or apparently washed away as the flood waters washed over the river edge. Photographs taken from Sullivan 1983, with permission.

Figure 2. Examples of damage to *Taxodium distichum* and the riparian forest of the Guadalupe River after the 1978 Guadalupe River flood. Upper left, a mature *Taxodium* tree apparently undamaged with uprooted trees or broken stems on the bank of the river. Upper right, two mature *Taxodium* trees with tops removed. Lower left, piles of debris on the river bank with a large *Taxodium* tree standing in the approximate center with a large, broken limb caught in the upper branches approximately 16 m (63 ft.) above ground level. Lower right, large *Taxodium* tree with the two large top stems broken off and removed. Two broken or uprooted trees are at a diagonal in the photograph. Photographs were taken by the senior author.