RIPARIAN FOREST RECOVERY FOLLOWING A CATASTROPHIC FLOOD ON THE BLANCO RIVER, TEXAS

by

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LIST OF ABBREVIATIONS

Abbreviation

DBH – Diameter at Breast Height

ISA – Indicator Species Analysis

NMDS – Non-metric Multidimensional Scaling

MRPP – Multi-Response Permutation Procedures

1. INTRODUCTION

On May 23, 2015, parts of the Blanco River basin received approximately 250 mm of rain, most of which fell during a period of about 7 hours (Furl et al. 2018). This caused the river to rise to over 13 m, roughly 10 m above flood stage in Wimberley, Texas (NWS 2016). Along with the loss of lives and property, the flood resulted in the loss of numerous riparian trees. Many of the trees were centuries-old *Taxodium distichum* (bald cypress), some dating back to before Spanish colonization (Gaskill 2015). As residents along the Blanco were still cleaning up from the May flood, a second flood occurred on October 30, 2015. The October flood crested at 8 m, destroying more of the riparian buffer (NWS 2016). The floods of 2015 resulted in floodplain stripping in much of the floodway, completely removing vegetation in some areas.

In response to this severe disturbance and the loss of much of the riparian vegetation, ecological processes of secondary succession have begun to take course on the floodplain. During this process, over temporal scales ranging from years to decades (Friedman and Lee 2002), the ecosystem undergoes a transition from bare ground to riparian forest. This transition often follows a somewhat predictable path where fast-growing, full sun-tolerant species are succeeded in dominance by shade-tolerant, slower-growing trees. As trees grow taller and provide more canopy shade to the forest floor, an understory begins to develop. The result, in absence of another major disturbance event, after many growing seasons (decades to centuries) is a riparian forest dominated by large, slow-growing trees with a full canopy and a diverse understory (Egger et al. 2015).

Riparian vegetation is spatially and temporally heterogeneous relative to vegetation tolerances to light, shade, moisture, and riverine-disturbance gradients

(Naiman, Décamps, and McClain 2005). Species composition and diversity vary along a gradient that extends away from the river channel toward the uplands. This vegetation pattern is linked to successional processes following a disturbance. Though these patterns are reasonably well understood, they are not always predictable at local scales because of differences in controlling variables among catchments and climates (Baker and Walford 1995). Succession paths can vary due to various intervening factors, including human-induced changes (e.g. land-use change or flow regulation; Egger et al. 2015) or natural hydro-geomorphological changes (Friedman and Lee 2002). Fluvial processes influence succession by governing processes that drive seed dispersal and vegetation recruitment and establishment (Corenblit et al. 2007). Floods in particular initiate long-term changes in the riparian community (Obedinski, Shaw, and Neary 2001). The process of vegetation removal followed by secondary succession promotes biodiversity (Jansson, Nilsson, and Malqvist 2007; Naiman, Décamps, and Pollock 1993), but can also allow invasion by exotics (Planty-Tabacchi et al. 1996).

This research examines the riparian succession processes occurring on the Blanco River following the 2015 floods in order to understand and predict the post-recovery structure and composition of the riparian forest. This study contributes to the broader knowledge of forest recovery following hydrogeomorphic disturbance and succession, and more specifically provides a case study for Central Texas, an area currently underrepresented in the literature.

2. PURPOSE STATEMENT

The purpose of this research is to evaluate the passive processes of post-disturbance recovery on sites along the Blanco River following the 2015 floods. This study monitors the early-stage recovery processes of the flood-damaged riparian buffer at a variety of sites along the Blanco River to predict the succession trajectory of the floodplain forest.

Early post-disturbance forest composition can reveal new invasions by exotics and can provide clues to the future composition. Exotic invasions during early seral forest development can create problems with forest structure (Fierke and Kauffman 2005), and land managers who are aware of such issues can implement reactive management techniques to correct the problem. In addition, early monitoring of recovery processes can reveal disparities in succession trajectories that could lead to a change in ecosystem functioning. An understanding of succession can inform restoration management, as it provides a reference by which success of restoration can be evaluated (McClain, Holl and Wood 2011). Knowledge of the recovery of the riparian forest can assist landowners and managers to make sound decisions regarding the conservation, restoration, or land-use policy of streamside lands.

3. RESEARCH QUESTIONS, HYPOTHESES, AND CONCEPTUAL FRAMEWORK

This study evaluates the composition and structure of the riparian forest at five sites along the Blanco River which are undergoing recovery following the floods of 2015. This research aims to answer the following question: What are the patterns of early recovery present along the Blanco River following the 2015 floods? This question can be broken down into three research objectives: (1) comparing the riparian structure and composition of five sites along the Blanco, (2) quantifying the percentage of the recovering population that is either recolonizing from the seed bank or resprouting from roots or damaged trees, and (3) identifying local environmental controls that might be influencing riparian recovery within and among the five sites.

My hypothesis was that the recovery patterns will generally follow the patterns outlined in previous succession studies, which demonstrate that fast-growing early pioneers are usually succeeded in dominance by shade-tolerant, long-living species. Because the results of this study reflect a short temporal scale relative to the time passed since the floods (approximately two years), it was expected that the vegetation would be in the primary and the transition phases. During these phases, dominant vegetation consists of species that thrive in full sun and are adapted to become established on disturbed sites (Egger et al. 2015). Because riparian forests are particularly vulnerable to competition by exotics (Nilsson and Grelsson 1995), I felt it was possible that these sites would show evidence of exotic plants establishing.

The conceptual framework for this study follows the assumption that the forest composition is determined by the processes of succession, which guide the transition from bare soil or rock to a full-canopy forest (Figure 1). Succession trajectories are determined by the presence of vegetation propagules (seed sources or extant plants), and local geomorphic variables such as location on the floodplain, proximity to the channel, slope, and, substrate.

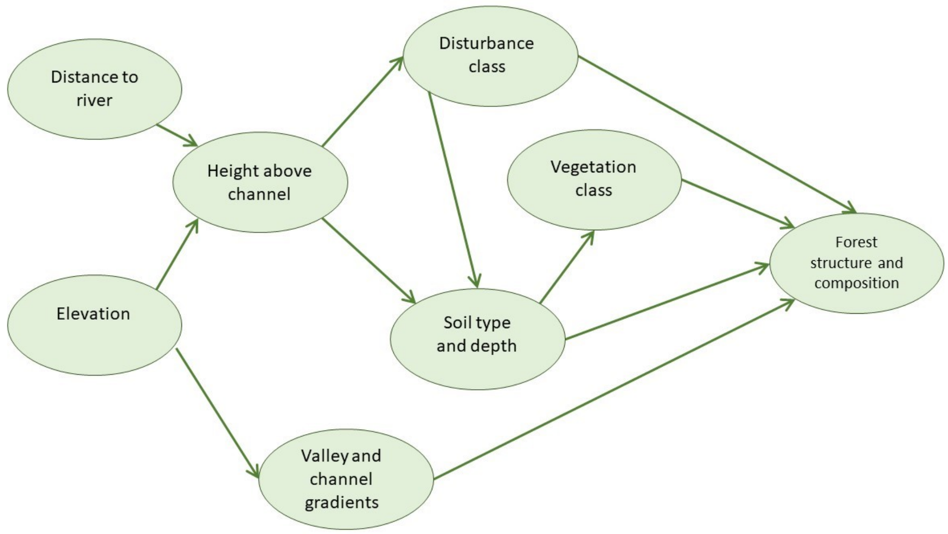

Figure 1. Conceptual model for the study. Forest composition and structure is determined by local geomorphic patterns, extant vegetation, and location on the floodplain.

Forest composition and structure is the dependent variable for this study. The forest composition and structure provide clues that can be used to determine whether the vegetation is structurally and functionally diverse, and whether the riparian forest is under threat from invasion by exotics. Indicators for this variable will be plant establishment status (flood survivors, trees regenerating through resprouting or root-sprouting, or newly established seedlings), and species origin (native and exotic). These compositional and structural factors will be captured using species diversity, relative species density, and relative species abundance. The independent variables are distance to river, elevation, channel gradient, valley gradient, vegetation tolerance classification, and floodplain disturbance classification (further explained in Chapter IV).

4. LITERATURE REVIEW

Following a disturbance as devastating as the floods of 2015, the riparian forest can regenerate through successional processes. Succession models have been created for various rivers in the United States (Table 1), but overall, development of riparian landscapes tends to follow a somewhat predictable path (Figure 2). Clements (1916) first described the causes and processes involved in succession in North America. Since then, landscape ecologists have been further testing and improving his model. Benjaker et al. (2011) and Egger et al. (2015) described succession processes for rivers in western Montana. The authors found that community structure and succession varied with regards to land use, channel structure, and flow regulation. When a site becomes barren (which occurs with floods of sufficient magnitude to cause floodplain stripping; this occurred on the Blanco River), the first species to populate the site are those that grow in full sun. After an increase in vegetation, the community shifts to a transition phase marked by the dominance of herbaceous plants such as reeds and sedges. Within 5-15 years, shrubs become dominant, followed by fast-growing trees which increase shading at ground level. Over time, slower-growing shade-tolerant trees begin to dominate. Finally, barring any additional disturbance, the forest reaches a climax stage marked by long-living tree species.

In some cases, a mature riparian forest is not the climax stage. Studies on the Yellowstone River in Montana (Boggs and Weaver 1994) and the headwater tributaries of the South Platte and Arkansas Rivers in Eastern Colorado (Friedman and Lee 2002) showed that the riparian forests would eventually succeed to grasslands. In still other cases, the late seral forest is composed of the same dominant species as the pioneer stage.

Fierke and Kauffmann (2005) found that black cottonwood (*Populus balsamifera* ssp. *trichocarpa*) was the dominant species in all stages of succession on the Willamette River in Oregon. During establishment, black cottonwoods were associated with willow. As the trees grew larger, an understory began to develop, leading to a vertically diverse riparian forest.

Table 1. Previous Succession Studies in the USA.

Region	***Site***	***Studies***
Great Plains	Yellowstone River, Montana	Boggs and Weaver 1994
Great Plains	Missouri River, Missouri	Bragg and Tatschl 1977
Great Plains	Plum Creek, Colorado	Friedman et al. 1996
Great Plains	Ephemeral tributaries of South Platte and Arkansas Rivers, Colorado	Friedman and Lee 2002
Great Plains	Mississippi River and Tributaries	Hosner and Minckler 1963
Great Plains	Wabash and Tippecanoe Rivers, Indiana	Lindsey et al. 1961
Great Plains	Canadian River, Oklahoma	Hefley 1937
Mountain West	Animas River, Colorado	Baker and Walford, 1995
Mountain West	Kootenai River, Montana	Benjaker et al. 2011; Egger et al. 2015
Northeast	Allegheny River, Pennsylvania	Cowell and Dyer, 2002
Northeast	Cattaraugus Creek, New York	Diggins 2013
Pacific Northwest	Willamette River, Oregon	Cline and McAllister 2012; Fierke and Kauffman 2005, 2006
Pacific Northwest	Hoh River, Washington	Fonda 1974
Pacific Northwest	Tanana River, Alaska	Hollingsworth et al. 2010
Southeast	Congaree River, South Carolina	Meitzen, 2009; Kupfer, Pipkin, and Meitzen 2010; Meitzen and Kupfer 2015
Southeast	Bogue Chitto River, Louisiana	Robertson and Augspurger 1999
Southwest	Sycamore Creek, Arizona	Campbell and Green 1968
Texas - Coastal Plain	San Antonio River, Texas	Bush, Richter, and Van Auken 2006

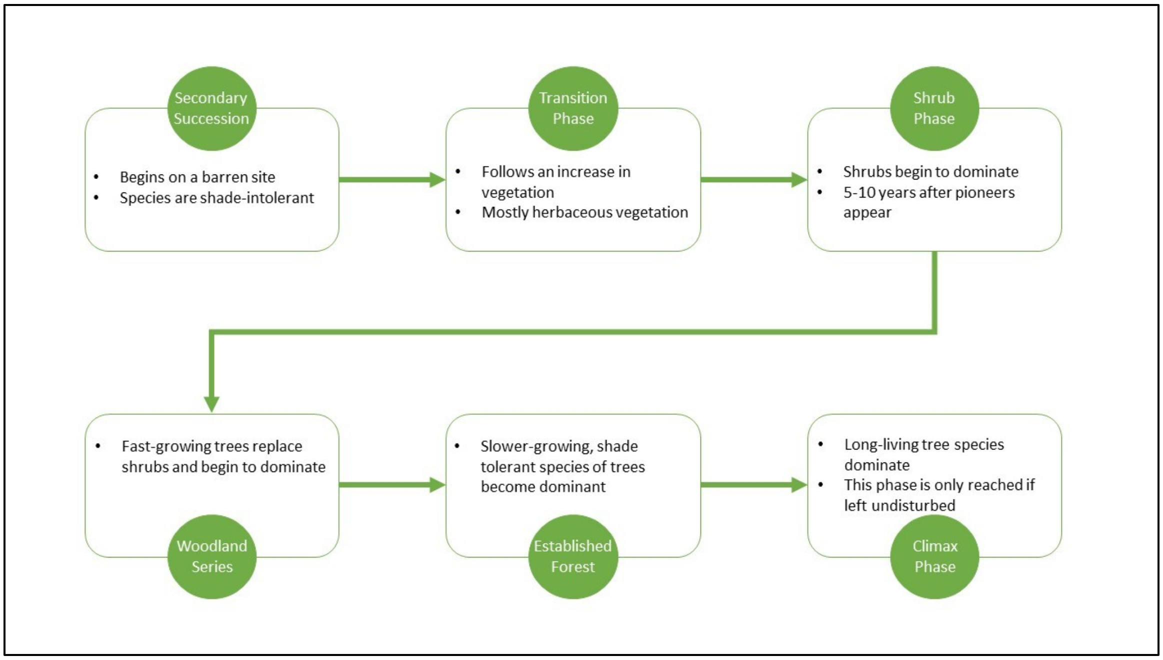

Figure 2. Conceptual Model for Succession Processes. Secondary succession follows a predictable pattern from bare ground to mature climax forest.

Succession patterns are often determined by processes related to hydro-geomorphic disturbance and floodplain development. Floodplain dynamics have substantial influence over the community composition and structure of the riparian forest. In their study of a previously-logged riparian forest in South Carolina, Kupfer, Meitzen, and Pipkin (2010) also found that succession paths can be guided by soil characteristics and flood regimes. Plant establishment can be related to discharge (Friedman and Lee 2002) and frequency of inundation (Kupfer, Meitzen, and Pipkin 2010). The relationships between vegetation and fluvial processes are reciprocal – vegetation influences fluvial processes just as much as fluvial processes affect vegetation (Julian et al. 2016). Vegetation influences hydro-geomorphic processes by aiding sediment deposition and reinforcing banks (Manners, Schmidt, and Scott 2014; Corenblit et al. 2007).

Fluvial disturbance is particularly influential on riparian vegetation. Frequently disturbed communities remain relatively simple in composition, whereas communities that are less frequently disturbed become more complex (Harris 1999). Erosion and subsequent deposition on the floodplain can create new habitat (Clements 1916; Dykaar and Wigington 2000; Hodges 1997). Fluvial processes can result in the establishment of pioneer species through the accretion of previously-inundated abandoned meander landforms (Meitzen and Kupfer 2015) or the erosion of cutbanks and deposition of point bars (Robertson and Augspurger 1999; Meitzen 2009). Hefley (1937) and Ware and Penfound (1949) determined that riparian community composition on the Canadian River in Oklahoma occurs on an elevational gradient extending from the water's edge to a terrace above the bank. The vegetation shifts in this community over time, and succession is related to dune formation associated with spring floods. Hodges (1997) also found that succession was related to sedimentation following floods. In his synthesis on bottomland hardwood forests, Hodges (1997) notes that sedimentation patterns and flood frequencies determine which species become dominant, because they create differences in elevation, soil moisture and other factors which favor some taxa over others.

In the short-term, the effects of a significant disturbance can be devastating to plant communities. Damages can be compounded in communities that have already been exposed to stressors. Frequent exposure to stressors may explain some of the extent of the damage to the riparian forest along the Blanco. Disturbances of all types place stress on plants, and subsequent disturbances can ultimately lead to plant mortality. In the Texas Hill Country, periods of intense drought are known to occur on a regular basis (Smith et al. 2015). In fact, parts of Hays County experienced continuous drought from 2010 to

2015 (NDMC 2017). Drought can affect photosynthesis and flood patterns, causing potentially fatal stress to plants (Obedinski, Shaw, and Neary 2001). It is possible that the prolonged drought of 2010-2015 heavily stressed the riparian forest, significantly increasing its vulnerability to the floods.

In addition to contributing to stress and mortality in vegetation, disturbances also create conditions which are favorable for invasions by exotic species. The combination of frequent disturbances and longitudinal connectivity contributes to the invasibility of riparian zones (Nilsson and Grelsson 1995; Planty-Tabacchi et al. 1996). Exotic species which invade riparian areas are more readily dispersed than exotics in other ecosystem types, mostly due to seed dispersal efficacy or human actions (Catford and Jansson 2014; Reynolds and Cooper 2011). Once established, exotic species can outcompete native species for resources (Nilsson and Grelsson 1995) or change the ecosystem by altering biogeochemistry (Cameron and Spencer 1989; Adams and Saenz 2012) or geomorphology (Manners, Schmidt, and Scott 2014). The dominance of exotics may not always be permanent, however. Exotics that colonize efficiently may not tolerate shade, and in such cases, they will eventually be succeeded by shade-tolerant species (Dewine and Cooper 2008).

Fluvial disturbance can be beneficial to the riparian forest over long temporal scales. Riparian species are well-adapted to floods as a result of life-history strategies and morphological characteristics that allow them to survive inundation. Catford and Jansson (2014) identify numerous adaptations that enable riparian plants to endure submersion, high flow, and anoxia, as well as to disperse easily to ensure their survival. Adaptations such as root structure and reproduction strategy, particularly hydrochory (seed dispersal via flowing water) give riparian plants an advantage in frequently flooded environments (Naiman and Décamps 1997). An experiment by Kui and Stella (2016) found that some riparian species can survive complete burial by sediment, which can happen when floods deposit sediments on the floodplain. Their study indicates that taxa which occur at different stages of succession are adapted to different conditions. This means that disturbances only cause mortality in certain species within a community, while others survive.

Flooding may also increase biodiversity in riparian zones. Floods scour away some plants, creating patches of heterogeneous vegetation, which increases the number of species at a site (Jansson, Nilsson, and Malmqvist 2007). In a study of plant communities along rivers in Denmark, Baattrup-Pedersen et al. (2013) found a positive correlation between low-intensity floods and species richness (number of distinct species) in the floodplain, indicating that floodplain forests benefit from frequent low-magnitude floods. In a similar study, Greet, Webb, and Cousens (2015) studied the effects of floods on riparian sites in the Goulburn-Broken catchment in Australia. They note that species richness of exotics declined following the floods, but native taxa did not decline. Richness of native woody species remained stable, and richness of native annuals increased.

The riparian forest is important because it provides numerous ecosystem services, or benefits to humans from natural ecosystem functions. It can slow floodwaters, cycle and sequester nutrients, and regulate water quality, among many other benefits (Malanson 1993; Naiman and Décamps 1997). Plants are important geomorphic agents in fluvial systems (Gurnell, Bertoldi, and Corenblit 2012), and contribute to the development of floodplain landforms and the moderation of erosion processes (Julian et al. 2016). The canopy provided by riparian forests is one control on light availability within the stream, which in turn governs primary production and other ecosystem processes (Julian et al. 2011; Warren et al. 2016). The longitudinal structure of the riparian zone makes it ideal as a habitat corridor, providing connectivity for faunal taxa and allowing the dispersal of flora (Fremier et al. 2015). A riparian buffer can also counteract changes in inputs of sediment and water brought about by human-induced land-use changes (Jansson, Nilsson, and Malmqvist 2007; Chase et al. 2016).

In areas fragmented by land-use changes, the riparian buffer can have a valuable role in maintaining biodiversity (Fremier et al. 2015). Riparian zones are biodiversity hotspots due to their position on the ecotone between aquatic and terrestrial habitats and their involvement in stream processes relating to sedimentation, stream flow, and large wood (Naiman and Décamps 1997; Naiman, Décamps, and Pollock 1993). Aquatic habitat is highly dependent on riparian buffers, because they control such factors as organic matter inputs, temperature, and light availability within the stream (Vannote et al. 1980; Julian et al. 2011; Warren et al. 2016).

Of the documented ecosystem services provided by riparian forests, the most significant benefit for residents along the lower Blanco River is the moderation of streamflow. Vegetation aids in the reduction of flood magnitudes by providing roughness (Anderson, Rutherford, and Western 2006; Chase et al. 2016; Manners et al. 2015), but not all plants are equal in this respect. Denser vegetation patches that provide foliage at several vertical levels are more efficient at regulating flood magnitudes than vertically open stands (Anderson, Rutherford, and Western 2006; Manners et al. 2015). Manicured lawns are common along the Blanco River, and this might have contributed to the damage from the floods (Furl et al. 2018). These lawns typically consist of short, mowed grass and sparse trees, and reduced or absent vertical connectivity in the riparian zone. The types of plants found on manicured lawns are not generally dense enough to sufficiently slow floodwaters.

Because riparian vegetation provides so many socio-ecological benefits, its conservation is of great importance. Disturbances such as the floods of 2015 create long-lasting ecological changes, but land managers can take steps to restore ecosystem functioning by rebuilding the riparian habitat (Lake, Bond and Reich 2007). Riparian restoration is already occurring on the Blanco River, and successional models like the proposed study can aid in monitoring the ongoing success of such projects (McClain, Holl, and Wood 2011; Winward 2000).

5. METHODS

5.1 Site and Situation

The Blanco River lies within the San Marcos River Basin, which itself is part of the Guadalupe River Basin (Figure 3). Most of the 140 km of the Blanco's length flows through the Texas Hill Country; the last few kilometers before its confluence with the San Marcos River flow through the Blackland Prairie (Earl 2007; Smith et al. 2015). The Texas Hill Country lies to the west of the Balcones Escarpment on a portion of the Edwards Plateau which is marked by deep limestone canyons (Earl 2007). The Blackland Prairie is part of the Coastal Plain. Both the Blackland Prairie and the Edwards Plateau have historically consisted of grasslands, but the vegetation of the Edwards Plateau is now in a transition toward an oak-juniper woodland (Wu, Redeker, and Thurow 2001). The climate of the region is subtropical humid, and is prone to cycles of droughts and floods (Earl 2007; Smith et al. 2015). The Blanco River receives most of its rainfall in late spring (May or June) and fall (October), corresponding to the seasons when flooding is most frequent (Earl 2007).

The Blanco River contributes to the Edwards and Trinity aquifers at several locations along its length (Smith et al. 2015). These aquifers supply the cities of Austin, San Antonio, and smaller cities in the vicinity with water resources (Wu, Redeker, and Thurow 2001; Smith et al. 2015). High connectivity to groundwater is a result of the fractured karst landscape and causes spatial intermittence in the river's flow, particularly in dry seasons (Smith et al. 2015).

Data collection took place at five sites along the Blanco River between Wimberley and the confluence with the San Marcos River, including University Camp, Five Mile Dam Park, Blanco Riverwalk Park, Blanco Shoals Natural Area, and Blanco River Village Park. The sites are on public park land managed by Texas State University, the City of San Marcos, and Hays County. Permission to conduct research was obtained from all property managers in September and October 2017.

Texas State University manages University Camp, a park which provides camping and recreation opportunities to students, faculty, and alumni of Texas State University. University Camp is on the Edwards Plateau near Wimberley. The site contains a gently sloping floodplain with thick soils and steeply sloped uplands. Soils at University Camp are primarily composed of fine materials, with some gravels close to the river channel. There is also a vegetated island at the site. Soils on the island differ from those on the riverbank, with large boulders at the upstream end, and gravels and fine material at the downstream end. Prior to the floods of 2015, the riparian zone at University Camp had a full-canopy forest dominated by *Taxodium distichum*. Many of these trees were removed during the 2015 floods. Following the May flood, debris was removed from the floodplain with heavy equipment, resulting in large amounts of exposed soils.

Five Mile Dam Park is along the Balcones Escarpment between San Marcos and Kyle, and is managed by Hays County. The park is popular with families and features large playing fields on the left terrace. Floodplain scouring has taken place below the dam, resulting in a high-water channel which has little to no soil, and a higher vegetated Pleistocene terrace. In some places, the alluvium within the high-water channel has been completely scoured away, leaving exposed bedrock and coarse alluvium. Size classes ranged from fine (clay to coarse sand) to cobbles. At the time of this survey, the river was dry both above and below the dam, however a few remnant pools remained.

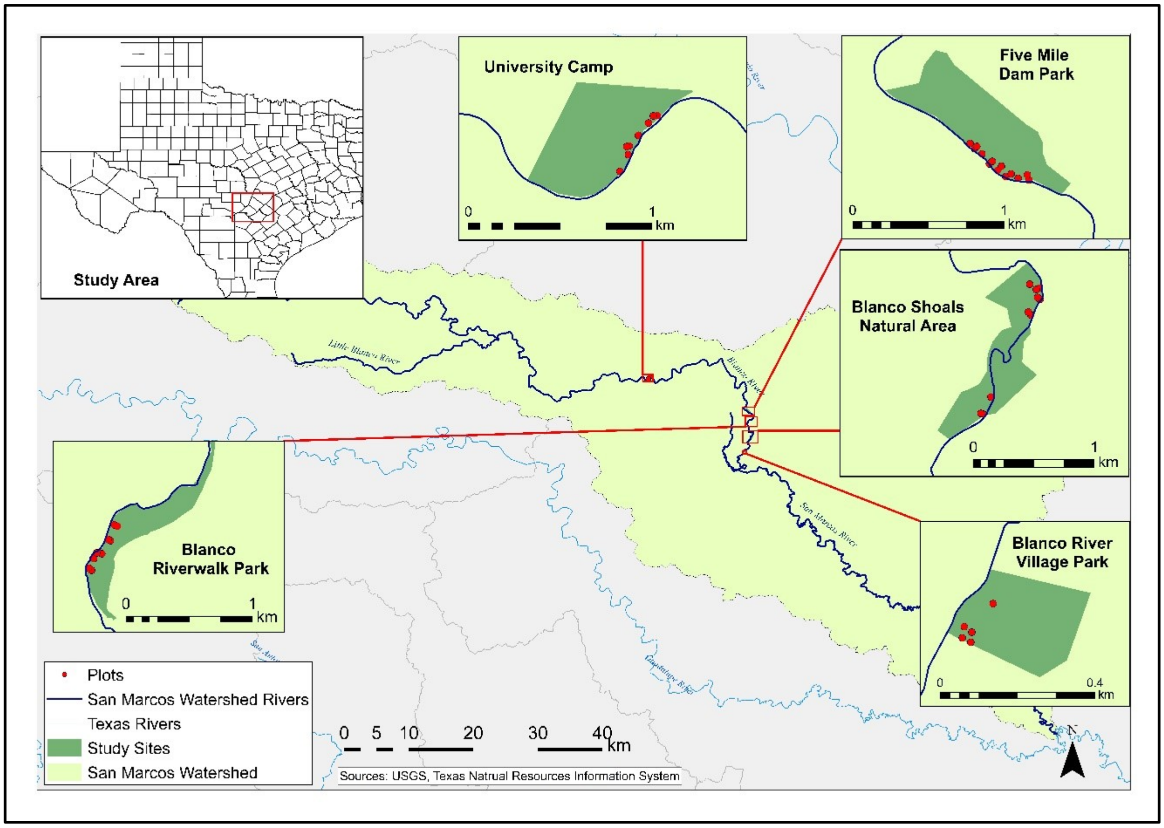

Figure 3. Map of Study Area. University Camp, Five Mile Dam Park, and Blanco Shoals Park are all located along the lower Blanco River, which lies in the San Marcos River watershed.

Blanco Riverwalk Park is just downstream of Five Mile Dam Park. Though it is owned by the City of San Marcos and open to the public, access to the park is limited. Blanco Riverwalk Park is located in a new housing development which has a grid of streets, but very few houses. City workers cannot access the area by vehicle without trespassing across a narrow strip of private land, so maintenance (mowing, etc.) is not done at this time. Due to its remote area and limited legal access, the park has been heavily damaged by off-road vehicles from trespassers. Blanco Riverwalk Park features a wide floodplain that is mostly bare of trees except immediately near the channel. Soils range from fine soils to gravels. There are several islands in the river at this site, though when they were surveyed the river was almost dry and they could be accessed by foot.

Blanco Shoals Natural Area is downstream of Blanco Riverwalk Park on the Blackland Prairie. It features a wide floodplain and a high terrace and is bordered by an apartment complex on one side and agricultural land on the other. For now, it is mostly undeveloped, however plans are in place to increase development and allow for easier public access to the river. Mowing will be restricted to trails and access points as the park is being developed. Blanco Shoals has a point bar along with some ridge-and-swale topography on the floodplain. Soils are coarse on the point bar, but finer on the floodplain. Much of Blanco Shoals was cleared of flood debris, and this process may have damaged some of the extant vegetation that survived the floods.

Blanco River Village Park is located just upstream from the confluence of the Blanco and San Marcos Rivers. Like Blanco Riverwalk Park, vehicular access is restricted. The homeowners' association of a nearby housing development has installed a trail. This site consists of a tall, gently sloping terrace. Flood debris remains at the site, especially where the terrace begins to flatten out as it approaches the river. Soil sizes range from fine to cobbles and are poorly sorted for the most part.

5.2 Data

Data collection took place in the fall of 2017. Because vegetation surveys are most accurate with leaf-on conditions, data collection ceased following the first hard freeze (when leaves dropped), which took place in on December 7, 2017. All data were collected in four weeks from mid-November to mid-December.

Forty-six circular plots (r = 5m) were placed at varying distances from the river (8 at University Camp, 13 at Five Mile Dam, 10 at Blanco Riverwalk, 10 at Blanco Shoals, and 5 at Blanco River Village). Plots were spaced approximately 50 m apart along the channel, with additional plots higher on the floodplain. Plots were preferentially placed in locations with at least one tree in order to get a full picture of the vegetation recovery at a variety of locations on the floodplain. Every effort was made to capture the diversity of species at each site and have each present species represented in at least one plot. Within each plot, diameter at breast height (DBH) was recorded for each woody plant > 1 m height and > 0.5 cm DBH. Woody plants < 1 m tall were counted, but not measured. These small plants were assigned a standard measurement (0.25 cm DBH) so that they could be used to determine basal area and biomass measurements. All woody plants in each plot were identified and species were recorded.

Measurements for distance to river were taken in the field at each plot. Channel width, height above channel, and elevation were calculated in a GIS (ArcMap v. 10.5) using digital elevation models (DEMs) derived from LiDAR at 1 m spatial resolution. Channel gradient (slope of stream from the upstream end of the park to the downstream end) and valley gradient (slope of the floodplain from the upstream end of the park to the downstream end) were calculated from DEMs site-wide for each park.

Substrate properties were determined qualitatively by estimating texture size classifications for each plot. Sizes ranged from fine (including clays to coarse sands) to boulders, and were poorly or moderately sorted at most sites. Eight size combinations were identified, including a class for sites that had no soil, only bedrock (Table 2). Soil size at one site (BS3) consisted of cobbles only (class 7). This site was reassigned to class 6 because a class that only appears on one plot would distort some of the analyses. Soil depth was measured using a 1.2-m length of rebar with a diameter of 1.25 cm. The rebar was hammered into the ground using a rubber mallet until refusal. Maximum soil depth that could be measured using this method was roughly 90 – 100 cm, which left enough rebar for it to be pulled out of the ground. In dryer soils, the rebar had to be pulled out using two hands, so the rebar could only be inserted approximately 90 cm into the ground. In moister soils, the rebar could be inserted further because it was easy to extract with one hand.

Pre-disturbance vegetation class for each site was determined using Texas Ecological Mapping Systems shapefiles from the Texas Parks and Wildlife Department (Texas Parks and Wildlife Department 2014). Various classes of vegetation are represented by polygons which were overlain onto a shapefile of all study plots. Seven classes were identified in the study sites (Table 2). Since the study sites span two ecological regions, Blackland Prairie and Edwards Plateau, naming was somewhat inconsistent. Several plots on the Blackland Prairie were coded as 'urban low intensity,' but similar sites on the Edwards Plateau were coded as 'barren.' The 'urban low intensity' sites may have been misidentified. Because 'barren' is a more fitting description of these sites, I reassigned them to class 6. Two classes, 7 and 3, were found in only one plot each. To avoid issues with the analysis, I reassigned these to classes 6 and 5, respectively.

Disturbance class for this research was estimated from historic imagery on Google Earth (Table 2). Classes were based the riparian disturbance classification system from Meitzen et al. (2018), which evaluated riparian and geomorphic disturbance on the Blanco following the 2015 floods. Meitzen et al. (2018) identified six categories of riparian disturbance, ranging from no disturbance to complete floodplain stripping. All plots in the present study had at least some obvious riparian disturbance, so no plots were identified for class 1.

Table 2. Classification of Categorical Variables

Disturbance	
1	No disturbance
2	Minimal disturbance
3	Minor disturbance
4	Moderate disturbance
5	Partial floodplain stripping
6	Complete floodplain stripping
Pre-Disturbance Vegetation	
1	Urban low intensity
2	Floodplain hardwood forest
3	Floodplain deciduous shrubland
4	Floodplain herbaceous vegetation
5	Deciduous woodland
6	Barren
7	Open water
Soil Type	
1	Bedrock
2	Fines
3	Fines to gravels
4	Fines to cobbles
5	Fines to boulders
6	Gravels to cobbles
7	Cobbles
8	Boulders

5.3 Analysis

For each plot, relative species density was calculated from the number of individuals per species and standardized by hectare. Basal area was used to calculate relative species dominance, also standardized by hectare. A total of 29 species were identified. Each species was assigned a code for analysis (Table 3). Plots were assigned a code based on site name and a number (Table 4).

Relative dominance and relative density values were divided into two groups, seedlings and resprouts, in order to determine the percentages of the population that are recovering either from the seedbank or from surviving or resprouting trees. Seedlings were classified as < 2 cm DBH and not observed to be resprouting from a damaged tree. Resprouts were recovering specimens observed resprouting from an existing damaged tree or flood survivors ≥ 2 cm DBH. Seedling and resprout density and basal area totals were used to perform simple linear regression against the environmental variables using JMP Pro v. 13.

Three types of statistical analysis were used to analyze patterns of abundance within and among plots using PC-ORD version 6 including non-metric multidimensional scaling, multi-response permutation procedures, and indicator species analysis. Non-metric Multidimensional Scaling (NMDS) determines patterns among communities by comparing similarities/dissimilarities in site composition. This technique is often used to identify plot-level patterns in forest composition (Kupfer, Meitzen, and Pipkin 2010). Prior to analysis, the data had to be adjusted in order to find the best-fitting solution. I added a constant of 1 to the species data, and then log-transformed it (base 10). Three plots (FMD4, FMD5, and FMD13) contained only one species, so they were removed in order to prevent data distortion. Quantitative variables including distance from channel, soil depth, plot elevation, height above the channel, channel gradient, valley gradient, and channel width were tested as joint plots with the analyses.

Multi-Response Permutation Procedures (MRPP) tests the differences in community composition among classes of each categorical variable (soil type, disturbance class, and pre-disturbance vegetation class). Relative dominance is used to calculate MRPP.

Indicator Species Analysis (ISA) compares species abundance among sites, highlighting spatial patterns in dominance of species for classes categorical variables (soil type, disturbance class, and pre-disturbance vegetation class). Each species is assigned a value between 0 and 100 based on its abundance within a given class of a variable, relative to the other classes. A value of 0 indicates that a species is not present at plots in a given class, and a score of 100 means that the species is abundant and exclusive to a class (McCune and Grace 2002).

5.4 Limitations

The main limitation of the proposed study is the relatively short timeline, which is limited to the timeline of completing a master's thesis. The data collection for this study was complete by the end of the second full growing season following the 2015 floods. Because this research covers only early-successional status vegetation, it does not provide a clear picture of future forest composition. Land-use changes, land management practices, and future disturbances can lead to lasting changes in the riparian community make-up (Egger et al. 2015). The small basal area measurements for seedlings compared to larger values of resprouts created a challenge for the statistical analyses.

Table 3. Codes for Scientific Names.

Code	*Scientific Name*	*Common Name*
aceneg	*Acer negundo* L.	Box-elder maple
bacneg	*Baccharis neglecta* Britton	Roosevelt weed
carill	*Carya illinoiensis* K. Koch	Pecan
celtis	*Celtis* spp. L.	Hackberry
cepocc	*Cephalanthus occidentalis* L.	Buttonbush
diotex	*Diospyros texana* Scheele	Texas persimmon
ehrana	*Ehretia anacua* (Terán & Berland.) I.M. Johnst.	Anaqua
eystex	*Eysenhardtia texana* Scheele	Texas kidneywood
forpub	*Forestiera pubescens* Nutt.	Elbowbush
frapen	*Fraxinus pennsylvanica* Marshall	Green ash
iledec	*Ilex decidua* Walter	Possom-haw holly
ilevom	*Ilex vomitoria* Aiton	Yaupon holly
jugmaj	*Juglans major* (Torr.) A. Heller	Arizona walnut
junash	*Juniperus ashei* J. Bucholz	Ashe juniper
macpom	*Maclura pomifera* (Raf.) C.K. Schneid.	Osage-orange
melaze	*Melia azedarach* L.	China-berry
morrub	*Morus rubra* L.	Red mulberry
plaocc	*Platanus occidentalis* L.	Sycamore
popdel	*Populus deltoides* W. Bartram ex Marshall	Eastern cottonwood
progla	*Prosopis glandulosa* Torr.	Honey mesquite
ptetri	*Ptelea trifoliata* L.	Common hop-tree
quevir	*Quercus virginiana* Mill.	Live oak
salnig	*Salix nigra* Marshall	Black willow
samcan	*Sambucus canadensis* L.	American elder
sidlan	*Sideroxylon lanuginosum* Michx.	Gum bumelia
taxdis	*Taxodium distichum* (L.) Rich.	Baldcypress
triseb	*Triadica sebifera* (L.) Small	Chinese tallow
ulmame	*Ulmus americana* L.	American elm
ulmcra	*Ulmus crassifolia* Nutt.	Cedar elm

Table 4. Codes for Plot Names.

Site Name	***Code***
Blanco Riverwalk Park	BRW
Blanco River Village Park	BRV
Blanco Shoals Natural Area	BS
Five Mile Dam Parks	FMD
University Camp	UC

6. RESULTS

This chapter will report the results of the statistical analyses. First, descriptive statistics and linear regression will be used to explain relationships between resprout and seedling density and environmental variables. Next, NMDS, MRPP, and ISA results will be used to explain patterns among species.

6.1 Descriptive Statistics

Among the 46 plots, mean diversity was 5 species with a standard deviation of 2.3 (Table 5). Relative density ranged from 51 trees/ha to 31,082 trees/ha. Mean relative density was 2,181 trees/ha. Mean relative dominance was 4.3 m^2/ha, but was < 1 m^2/ha for most plots. Because resprouts and surviving trees were larger in size than seedlings, they made up 98% of the basal area. Total basal area for resprouts and survivors was 202 m^2. Seedling basal area totaled 4 m^2. On the other hand, 89% of the density consisted of seedlings because they were far more frequent than resprouts and survivors. Seedlings totaled 89,682 trees/ha, while total density of survivors was 10,650 trees/ha.

Table 5. Diversity and Abundance for Each Plot.

Plot	*Diversity (# of species)*	*Relative Density (# of trees/ha)*	*Relative Dominance (m^2/ha)*
FMD1	3	152	0.3
FMD2	4	2,191	0.2
FMD3	5	1,529	2.0
FMD4	1	764	0.6
FMD5	1	51	2.5×10^{-4}
FMD6	2	204	1.8×10^{-3}
FMD7	2	204	0.3
FMD8	4	917	0.2
FMD9	2	102	0.3
FMD10	2	713	0.3
FMD11	4	306	0.5

Table 5. Continued.

Plot	*Diversity (# of species)*	*Relative Density (# of trees/ha)*	*Relative Dominance (m^2/ha)*
FMD12	3	764	0.5
FMD13	1	51	0.4
BRV1	5	3,516	0.2
BRV2	5	357	0.4
BRV3	4	31,082	0.2
BRV4	6	713	0.2
BRV5	6	6,726	0.1
BRW1	4	2,803	4.6×10^{-2}
BRW2	3	1,019	0.2
BRW3	2	204	0.3
BRW4	6	815	3.3
BRW5	3	1,631	9.0
BRW6	7	3,159	1.0
BRW7	4	306	2.4×10^{-2}
BRW8	4	357	0.1
BRW9	2	1,427	3.5
BRW10	3	153	0.1
BS1	3	1,987	3.8×10^{-5}
BS2	2	255	2.7×10^{-2}
BS3	2	4,586	0.1
BS4	9	2,446	0.7
BS5	5	510	0.1
BS6	7	561	13.3
BS7	7	3,312	1.0
BS8	6	4,841	78.6
BS9	6	2,191	3.4×10^{-2}
BS10	8	3,567	0.2
UC1	3	764	0.1
UC2	7	1,376	4.6
UC3	10	3,159	45.1
UC4	8	3,516	0.1
UC5	9	1,936	0.2
UC6	5	1,274	0.1
UC7	5	510	0.4
UC8	8	1,325	0.6
Mean	**5**	**2181**	**4.3**
Total	**29**	**100,332**	**169.4**

6.2 Linear Regression Relationships

There were no significant linear regression relationships, however a few weak patterns emerged. Linear regression of seedling and resprouts density and basal area resulted in weak positive correlations between seedling density and soil depth (r = 0.39), seedling basal area and soil depth (r = 0.3) seedling density and height above the channel (r = 0.17), and resprouts basal area and height above the channel (r = 0.17). Weak negative correlations were found between resprouts basal area and channel width (r = 0.26), resprouts density and channel width (r = 0.24), resprouts basal area and distance from the channel (r = 0.2), seedling density and distance from the channel (r = .022), seedling basal area and channel width (r = 0.2), and seedling density and distance from the channel (r = 0.2). No relationships were found between seedling density and channel width or elevation, seedling basal area and distance from channel, elevation, and height above the channel, resprouts density and elevation or height above the channel, and resprouts basal area and soil depth or elevation.

Seedling densities and basal areas were highest in the most disturbed plots (disturbance classes 5 and 6; Table 6). Resprout basal area was highest in disturbance class 2, and resprout density was highest in disturbance class 4. Both resprout density and resprout basal area were highest in vegetation class 2 (Table 7). Seedling density was highest in vegetation classes 2 and 6. Seedling basal area was highest in classes 2 and 4. Seedling density was highest in soil type 4 (Table 8). Both seedling basal area and resprout basal area were highest for soil type 2. Resprout density was highest in soil types 2, 3, and 4.

Table 6. Distribution by Disturbance Class

	2	*3*	*4*	*5*	*6*
Seedling density	4,943	6,927	13,045	8,968	55,796
% Seedling density	5.5	7.7	14.5	10.0	62.2
Seedling basal area (m^2/ha)	0.7	0.2	0.4	1.8	1.0
% Seedling basal area (m^2/ha)	17.2	5.2	10.0	43.6	24.0
Resprout density	1,172	1,478	3,669	2,038	2,293
% Resprout density	11.0	13.9	34.4	19.1	21.5
Resprout basal area (m^2/ha)	78.1	46.1	29.9	38.2	5.6
% Resprout basal area (m^2/ha)	39.4	23.3	15.1	19.3	2.8

Table 7. Distribution by Pre-Disturbance Vegetation Class

	2	*3*	*4*	*5*	*6*
Seedling density	33,732	4,586	9,376	6,420	35,567
% Seedling density	37.6	5.1	10.5	7.1	39.7
Seedling basal area (m^2/ha)	2.1	0.1	1.4	0.2	0.4
% Seedling basal area (m^2/ha)	49.8	1.7	33.7	4.7	10.1
Resprout density	7,185	0.0	713	510	2,242
% Resprout density	67.5	0.0	6.7	4.8	21.1
Resprout basal area (m^2/ha)	184.8	0.0	2.9	4.7	5.5
% Resprout basal area (m^2/ha)	93.4	0.0	1.5	2.4	2.8

Table 8. Distribution by Soil Type

	1	*2*	*3*	*4*	*5*	*6*	*8*
Seedling density	2,242	24,866	15,847	42,395	1,682	1,172	1,478
% Seedling density	2.5	27.7	17.7	47.3	1.9	1.3	1.6
Seedling basal area (m^2/ha)	0.2	2.4	0.6	0.7	4×10^{-2}	0.1	0.2
% Seedling basal area (m^2/ha)	3.5	57.8	15.5	16.1	1.0	2.4	3.7
Resprout density	102	3,516	2,904	2,650	306	561	611
% Resprout density	1.0	32.9	27.2	24.8	2.9	5.2	5.7
Resprout basal area (m^2/ha)	0.6	88.7	55.9	50.0	0.4	1.7	0.8
% Resprout basal area (m^2/ha)	0.3	44.8	28.2	25.5	0.2	0.8	0.4

6.3 Non-metric Multidimensional Scaling (NMDS)

NMDS resulted in a three-dimensional solution with a final stress of 14.0 (Figures 4, 5, and 6). The three dimensions explained 84% of the variance in the dataset. Axis 1 explained ~ 43% of the variance, axis 2, ~ 25%, and axis 3, ~16%. The only significant correlation on axis 1 was height above the channel (*r* = -0.297; Table 9). Strongest correlations for axis 2 were elevation and height above channel, however a moderate correlation was found between axis 2 and distance from channel. Strongest correlations for axis 3 were soil depth, valley gradient, and channel gradient, and height above the channel was moderately correlated.

Table 9. Pearson Correlations of Environmental Variables with Ordination Axes. *Indicates a moderate correlation. **Indicates a strong correlation.

Variable	*Axis 1*	*Axis 2*	*Axis 3*
Distance from channel	0.188	0.215*	-0.083
Soil depth	-0.154	0.166	-0.503**
Elevation	-0.110	0.308**	0.008
Height above channel	-0.297**	0.495**	-0.235*
Channel gradient	0.183	0.138	0.180
Valley gradient	-0.183	-0.033	0.454**
Channel width	0.26	-0.112	0.390**

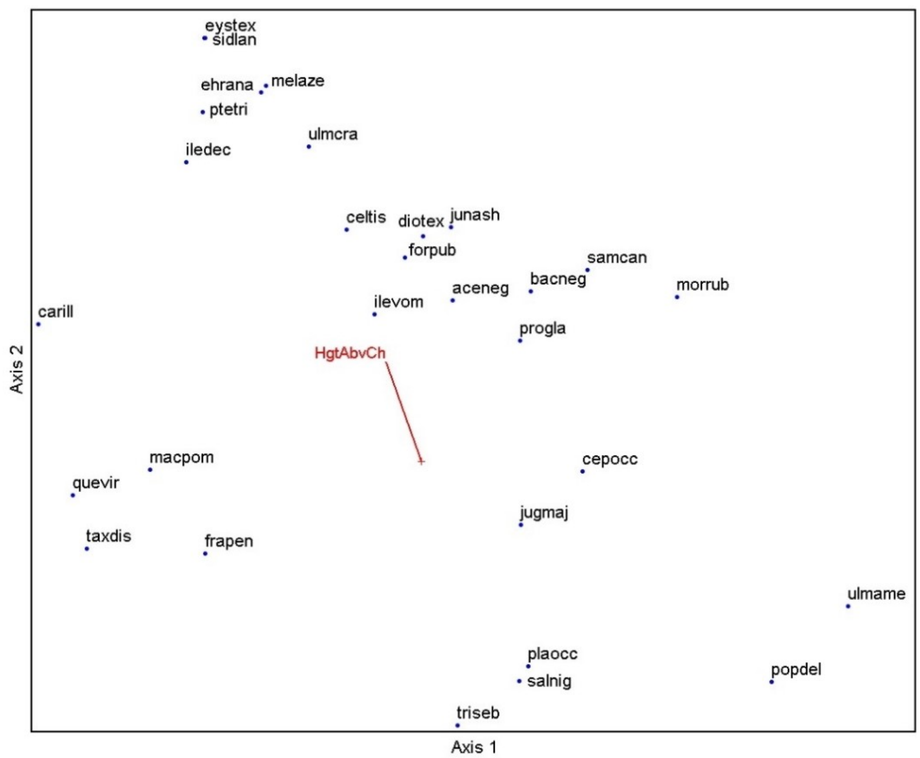

Figure 4. NMDS Ordination Axes 1 and 2. Upland species higher above the channel (top left corner), while riparian species are found lower in the valley.

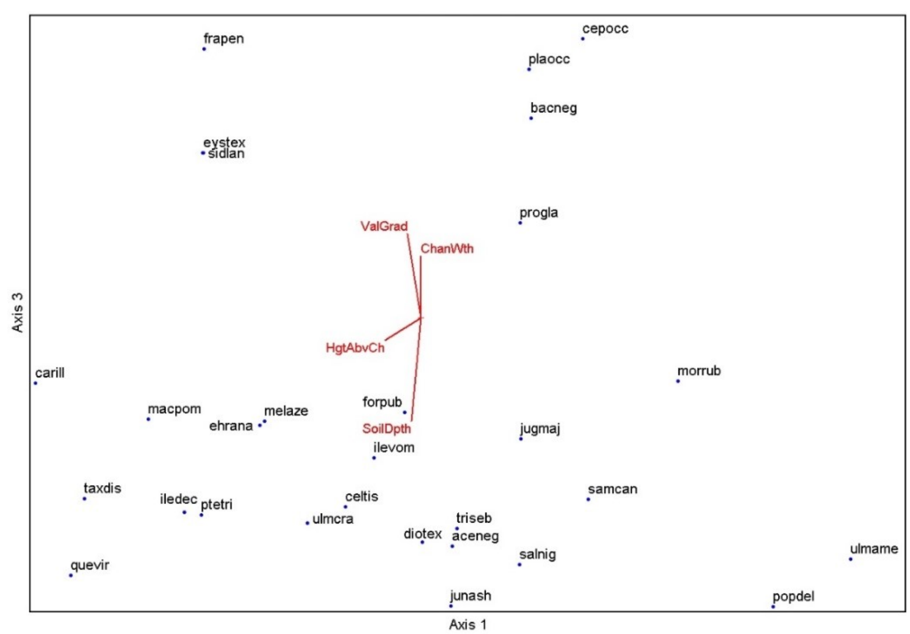

Figure 5. NMDS Ordination Axes 1 and 3. Upland species are found in areas with deep soils, narrow channels, and lower gradients (bottom left), with a few exceptions.

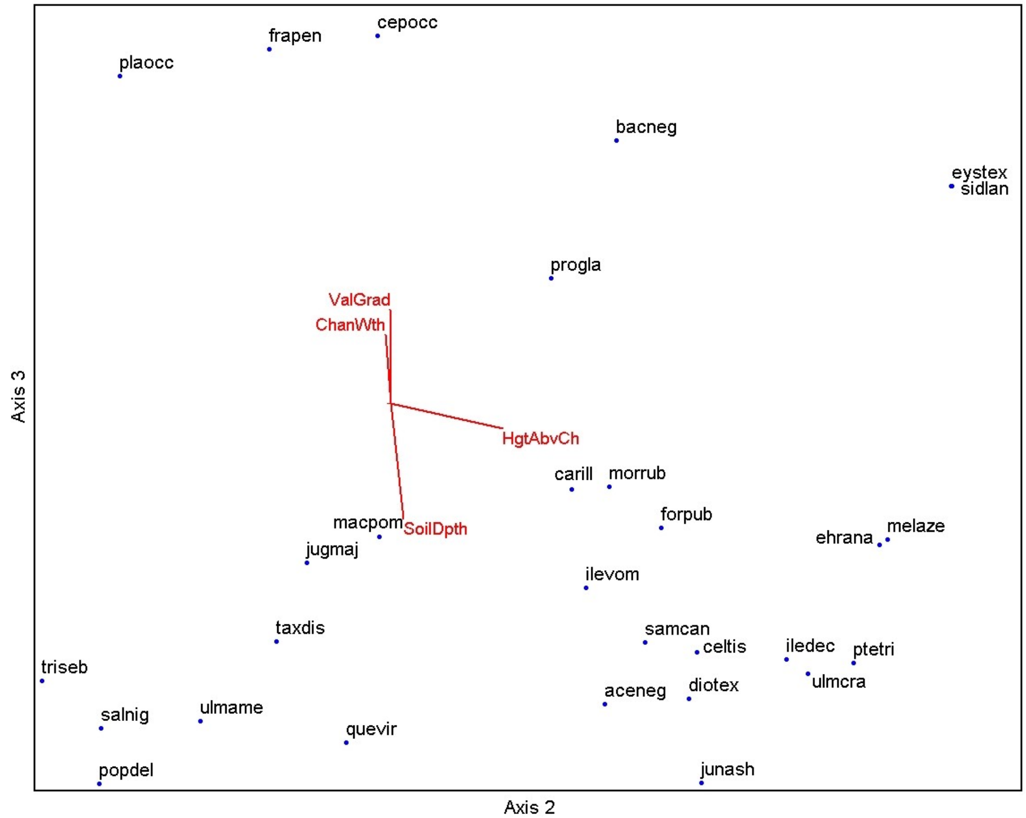

Figure 6. NMDS Ordination Axes 2 and 3. Riparian species are generally found lower in the valley (left side), with differences among species based on soil depth, valley gradient, and channel width.

Pearson correlations were also calculated for individual species (Table 10). Strongest correlations for axis 1 included *Platanus occidentalis, Morus rubra, Populus deltoides, Ulmus americana, Taxodium distichum, Fraxinus pennsylvanica,* and *Carya illinoiensis*. Strongest correlations for axis 2 included *Platanus occidentalis, Salix nigra, Baccharis neglecta, Acer negundo, Celtis* spp., *Ulmus crassifolia, Eysenhardtia texana,* and *Sideroxylon lanuginosum*. Strongest correlations for axis 3 were *Platanus occidentalis, Salix nigra, Baccharis neglecta, Populus deltoides, Acer negundo, Celtis* spp., *Ulmus crassifolia,* and *Fraxinus pennsylvanica*.

Table 10. Pearson Correlations of Species with Ordination Axes. *Indicates a moderate correlation. **Indicates a strong correlation.

Species	*Axis 1*	*Axis 2*	*Axis 3*
plaocc	0.298**	-0.524**	0.598**
salnig	0.206*	-0.423**	-0.447**
morrub	0.299**	0.177	-0.064
bacneg	0.241*	0.344**	0.381**
popdel	0.446**	-0.258*	-0.318**
aceneg	0.073	0.352**	-0.468**
ulmame	0.446**	-0.139	-0.218*
celtis	-0.150	0.425**	-0.326**
taxdis	-0.442**	-0.105	-0.206*
samcan	0.161	0.171	-0.152
progla	0.103	0.117	0.086
jugmaj	0.078	-0.046	-0.082
ulmcra	-0.188	0.482**	-0.295**
frapen	-0.438**	-0.171	0.472**
carill	-0.403**	0.132	-0.059
triseb	0.031	-0.210*	-0.158
ilevom	-0.051	0.148	-0.133
macpom	-0.198	-0.006	-0.064
ehrana	-0.120	0.254*	-0.069
melaze	-0.114	0.253*	-0.066
forpub	-0.014	.161	-0.070
quevir	-0.255*	-0.023	-0.163
diotex	0.002	0.266*	-0.248*
eystex	-0.159	0.285**	0.105
sidlan	-0.159	0.285**	0.105
cepocc	0.119	-0.007	0.179
ptetri	-0.160	0.235*	-0.125
iledec	-0.189	0.221*	-0.135
junash	0.031	0.225*	-0.260*

6.4 Multi-Response Permutation Procedures (MRPP)

MRPP was run for groups of each of the categorical environmental variables using Sorenson (Bray-Curtis) distance measure (Table 11). Chance-corrected within-group agreement (A) was < 1 for all groups of each environmental variable, indicating some heterogeneity within groups. Though A-values were small, this is not unusual for ecological data, nor is it a sign that community composition is similar among groups.

Table 11. MRPP Results

Variable	***A-value***	***p-value***
Disturbance Class	0.011	0.257
Soil Type	0.042	0.066
Vegetation Class	0.018	0.128

6.5 Indicator Species Analysis (ISA)

ISA was performed for each categorical environmental variable, disturbance class (Table 12), pre-disturbance vegetation class (Table 13), and soil type (Table 14). Significance was tested with 4,999 randomization runs of a Monte Carlo test. A few indicator species were identified, but only for certain classes of each variable. No strong indicators were found for disturbance classes 3, 5, and 6, but *Celtis* spp., *Quercus virginiana,* and *Forestiera pubescens* were associated with class 2, and *Carya ilinoensis* was most strongly related to class 4. The only strong indicators for vegetation class were found in class 5 (*Celtis* spp., *Diospyros texana*, and *Forestiera pubescens*). Strongest indicators for soil type were *Sideroxylon lanuginosum* for type 1 and *Cephalanthus occidentalis* for type 5.

Table 12. Indicator Values by Disturbance Class

Species	***Max***	***Max Group***	***2***	***3***	***4***	***5***	***6***	***p-Value***
plaocc	17	4	0	0	17	10	13	0.841
salnig	18	6	0	1	0	17	18	0.540
morrub	14	6	0	0	0	0	14	0.492
bacneg	18	6	0	3	10	10	18	0.751
popdel	31	5	0	0	0	31	5	0.154
aceneg	27	3	16	27	13	4	2	0.311
ulmame	15	5	0	0	1	15	1	0.456
celtis	45	2	45	27	12	2	2	0.089
taxdis	26	2	26	12	3	0	0	0.291
samcan	14	4	0	0	14	0	1	0.491
progla	9	5	0	0	0	9	1	0.704
jugmaj	9	6	0	0	1	0	9	0.699
ulmcra	38	3	3	38	13	18	0	0.130
frapen	18	6	0	1	5	9	18	0.686
carill	46	4	0	1	46	0	0	0.044
triseb	6	5	0	0	2	6	1	0.810
ilevom	24	3	0	24	6	0	0	0.249
macpom	10	4	0	0	10	0	0	0.537
ehrana	19	2	19	19	1	0	0	0.241
melaze	31	3	0	31	0	0	0	0.118
forpub	37	2	37	22	5	0	1	0.100
quevir	50	2	50	0	0	0	0	0.042
diotex	26	2	26	12	4	1	0	0.230
eystex	5	6	0	0	0	0	5	1.000
sidlan	25	3	0	25	0	0	1	0.178
cepocc	10	6	0	0	6	0	10	0.735
ptetri	10	4	0	0	10	0	0	0.538
iledec	20	3	0	20	4	0	0	0.292
junash	28	2	28	15	0	0	0	0.151

Table 13. Indicator Values by Pre-Disturbance Vegetation Class

Species	*Max*	*Max Group*	*2*	*4*	*5*	*6*	*p-Value*
plaocc	23	6	9	5	5	23	0.445
salnig	10	2	10	10	0	7	0.905
morrub	15	2	15	0	0	0	0.261
bacneg	17	6	4	10	12	17	0.758
popdel	12	2	12	4	0	6	0.745
aceneg	22	5	21	10	22	0	0.473
ulmame	11	2	11	0	6	0	0.520
celtis	44	5	19	4	44	1	0.019
taxdis	26	2	26	0	3	2	0.169
samcan	15	2	15	0	0	0	0.262
progla	9	6	1	0	0	9	0.545
jugmaj	8	4	0	8	0	0	0.672
ulmcra	17	2	17	5	13	2	0.659
frapen	17	6	3	13	0	17	0.593
carill	21	2	21	0	5	0	0.227
triseb	15	2	15	0	0	0	0.209
ilevom	8	2	8	0	0	2	0.608
macpom	5	2	5	0	0	0	1.000
ehrana	15	2	15	0	0	0	0.297
melaze	5	6	3	0	0	5	0.889
forpub	48	5	1	2	48	0	0.008
quevir	5	2	5	0	0	0	1.000
diotex	68	5	0	1	68	0	0.000
eystex	9	4	0	9	0	0	0.572
sidlan	7	4	1	7	0	0	0.695
cepocc	24	6	0	4	0	24	0.098
ptetri	20	5	0	0	20	0	0.110
iledec	18	5	0	0	18	0	0.149
junash	15	5	1	0	15	0	0.196

Table 14. Indicator Values by Soil Type

Species	*Max*	*Max Group*	*1*	*2*	*3*	*4*	*5*	*6*	*8*	*p-Value*
plaocc	20	4	0	0	6	20	7	16	10	0.549
salnig	12	4	0	10	5	12	0	3	0	0.918
morrub	33	4	0	0	0	33	0	0	0	0.203
bacneg	36	8	1	5	3	2	25	2	36	0.178
popdel	12	3	0	6	12	9	0	0	0	0.893
aceneg	31	2	0	31	13	5	0	1	3	0.247
ulmame	16	4	0	0	6	16	0	0	0	0.570
celtis	20	2	13	20	5	9	16	0	0	0.568
taxdis	23	3	0	5	23	0	15	0	0	0.485
samcan	13	4	0	0	5	13	0	0	0	0.557
progla	22	3	0	0	22	0	0	0	0	0.343
jugmaj	11	6	0	0	1	0	0	11	5	0.591
ulmcra	38	2	8	38	4	3	0	0	0	0.153
frapen	27	8	14	1	1	0	14	3	27	0.252
carill	12	4	0	1	6	12	0	0	5	0.817
triseb	17	3	0	2	17	0	0	0	0	0.507
ilevom	22	8	0	1	4	0	0	0	22	0.315
macpom	11	3	0	0	11	0	0	0	0	0.676
ehrana	9	2	0	9	0	3	0	0	0	0.657
melaze	7	6	0	3	0	0	0	7	0	0.809
forpub	14	2	0	14	2	0	10	3	0	0.712
quevir	7	2	0	7	0	0	0	0	0	1.000
diotex	32	1	32	7	2	0	0	0	0	0.074
eystex	50	1	50	0	0	0	0	0	0	0.134
sidlan	46	1	46	0	1	0	0	0	0	0.104
cepocc	52	5	0	0	0	0	52	13	2	0.019
ptetri	7	2	0	7	0	0	0	0	0	1.000
iledec	5	3	0	4	5	0	0	0	0	1.000
junash	13	2	0	13	0	0	0	0	0	0.438

7. DISCUSSION

This chapter discusses the results of the analyses relative to the research question: What are the patterns of succession present in the early recovery stages along the Blanco River following the 2015 floods? To answer this question, the discussion is broken down into three areas: riparian forest composition, recolonization strategies, and the influence of local environmental controls. Possible directions for further research and implications for management are identified at the end of the chapter.

7.1 Riparian Forest Composition

Overall, the most common species, in terms of dominance, were *Platanus occidentalis, Baccharis neglecta, Salix nigra, Acer negundo* and *Fraxinus pennsylvanica*. At least one of these species was found in nearly all plots. All are riparian facultative or obligate species. *P. occidentalis* and *F. pennsylvanica* were more prevalent as resprouts than as seedlings. Both species were dominant at Five Mile Dam and Blanco Riverwalk, where they were often resprouting from damaged trees. Resprout and seedling dominance for *B. neglecta* and *A. negundo* were nearly equal, and seedling dominance was much higher than resprout dominance for *S. nigra*. Very few *S. nigra* trees > 2 cm DBH were observed in this study, but seedlings were plentiful. This is intuitive because willows are pioneer successional species (Friedman, Osterkamp, and Lewis 1996). Most plots where *S. nigra* was observed contained > 20 *S. nigra* seedlings; one plot (BRV3) contained over six hundred. It is highly unlikely that all these seedlings will reach maturity due to the high density, as self-thinning occurs gradually over time as plants become larger (Naiman, Décamps, and McClain 2005). *S. nigra* was common at Blanco River Village, Blanco Shoals, and Blanco Riverwalk, but rare at Five Mile Dam (where the river was dry at the time of data collection) and University Camp (where most plots were shaded by larger trees).

For the most part, upland species such as *Juniperus ashei, Diospyros texana,* and *Ilex* spp. were found higher above the channel and farther from the channel than obligate riparian species such as *Cephalanthus occidentalis* or *Salix nigra* (Figures 4, 5, and 6). This pattern is most likely related to soil moisture (Hosner and Minckler 1963). Upland species were more common at plots with low to moderate disturbance classes (Table 12), particularly at University Camp, where much of the riparian forest remains in certain locations.

One exception was *Quercus virginiana*, which is an upland species that, for this study, was found at a low height above and a short distance from the channel. *Q. virginiana* was only found on one plot in this study, BS8. BS8 was on a steep bank very near the channel, but much of it is protected by a very large *Taxodium distichum*. This plot was shady and heavily vegetated (Figure 7), which could explain why more upland than riparian species were found there. Shade is associated with late-seral species (Egger et al. 2015), and *Q. virginiana* is a late-successional riparian species in southern Texas (Davis and Smith 2013). Because that particular *T. distichum* was the largest in this study, *T. distichum* and *Q. virginiana* appear to respond similarly to environmental variables (Figures 4, 5, and 6), but *Q. virginiana* may actually be responding to the presence of *T. distichum*.

Figure 7. Plot BS8. This plot is shaded and heavily vegetated, allowing upland species such as *Quercus virginiana* to establish relatively close to the channel.

Most of the tree species in this study were associated with deeper soils, lower valley gradients, and narrower channels. The exceptions to this include obligate and facultative riparian species such as *Platanus occidentalis, C. occidentalis, Fraxinus pennsylvanica,* and *Baccharis neglecta*, along with upland species *Prosopis glandulosa, Eysenhardtia texana,* and *Sideroxylon lanuginosum*. *E. texana* and *S. lauginosum* were found only on plots where the substrate consisted of only bedrock, where they established in cracks in the limestone (Figure 8). *P. glandulosa* is a drought-resistant species, which may explain its establishment on the shallower soils, but it should be noted that all *P. glandulosa* trees observed in this study were seedlings or small resprouts. *P. glandulosa* has a long taproot, which allows it to access deep groundwater, but Eggemeyer and Schwinning (2009) reason that thin soils negatively affect mature *P. glandulosa*, limiting its range on the Edwards Plateau.

Figure 8. *Eysenhardtia texana* at Five Mile Dam. *Eysenhardtia* and other drought-tolerant plants, including grasses, have established in cracks and holes in the limestone bedrock at five Mile Dam.

P. occidentalis, C. occidentalis, F. pennsylvanica, and *B. neglecta* are sun-tolerant species which may preferentially establish on flood-scoured areas. Higher gradients and wider channels increase flood discharges, and higher discharges are associated with scouring. Riparian trees frequently take advantage of the lack of competition on flood-scoured surfaces (Naiman and Décamps 1997) and are often associated with post-flood channel narrowing (Friedman, Osterkamp, and Lewis 1996). At Five Mile Dam, these species were common in plots with coarse soils and little other vegetation (Figure 9). *P. occidentalis, F. pennsylvanica,* and *B. neglecta* were also found on the islands at University Camp and Blanco Riverwalk. The islands had evidence of significant disturbance (Figure 9), and most of the trees were fairly young (Figure 10). All four species were primarily found on plots with little shade from established trees.

Figure 9. Island at University Camp. *Platanus occidentalis* and *Baccharis neglecta* seedlings are establishing among flood debris, boulders, and snags.

Two exotic species were found in this study, *Triadica sebifera* and *Melia azedarach*. Both species favored moderately-disturbed plots. *T. sebifera* was found in three plots, all ≤ 20 m from the channel. Two of the plots were at Blanco Shoals, and the other was on an island at Blanco Riverwalk. *M. azedarach* was quite abundant (10 individuals) at plot BS7, which is located on a ridge ~5 m above the channel. A large tree downed by the flood lies parallel to the channel between the channel and the plot. The edge of the plot farthest from the channel is sloped into a swale. Davis and Smith (2013) observed that microtopographic variation drives some of the landscape patchiness on the Mission River in South Texas because it provides some protection from inundation. In this case, the topography and the downed tree may provide some protection for *M. azedarach* from further disturbance.

Figure 10. Island at Blanco Riverwalk. Young *Platanus occidentalis* dominate a low island.

T. distichum is often regarded as the dominant species along the Blanco River, and has historically been observed growing along the banks closest to the river channel. In many reaches of the Blanco River, centuries-old *T. distichum* trees were completely removed by the 2015 floods (Gaskill 2015). At the present time, *T. distichum* is not recovering as quickly as some other riparian species, such as *P. occidentalis* and *S. nigra*. It is possible that moisture conditions have not been favorable for recruitment in the time between the 2015 floods and the data collection for the present study. Regeneration of *T. distichum* is highly dependent on hydrologic regime and light availability (Souther and Shaffer 2000; Keeland et al. 2011). Changes in hydrologic regime and shading have prevented *T. distichum* regeneration following intense logging on the Gulf Coast (Souther and Shaffer 2000). Herbivory may also be affecting *T. distichum* regeneration. Herbivory by beavers (*Castor canadensis*) and nutria (*Myocastor coypus*) caused *T. distichum* damage and mortality in an East Texas reforestation project (Keeland et al. 2011) and both species are present in Central Texas. Herbivory by white-tailed deer (*Odocoileus virginicus*) has contributed to changes in savanna vegetation on the Edwards Plateau (Fowler and Simmons 2008), and it is reasonable to assume that the same species could be affecting riparian vegetation as well. These variables were beyond the scope of this study, and their effects on *T. distichum* regeneration on the Blanco River are unknown. Several large *T. distichum* remain, but in many reaches of the Blanco, this iconic tree may not recover for some time.

7.2 Recolonization Strategies

The second objective of this study was to quantify the percentage of the recovering population that is recolonizing from the seed bank or resprouting from damaged trees. Seedlings had much higher density than resprouts, but resprouts had a significantly higher basal area than seedlings. High resprout biomass is mostly due to the fact that surviving trees, which can be quite large, were grouped in with resprouts. High seedling density is expected, as stem density is high at the seedling stage and declines with stand age (Friedman and Lee 2002).

Seedlings dominated the more heavily disturbed plots; both density and basal area were highest in classes 5 and 6, where at least some floodplain stripping occurred. Seedlings require adequate soil moisture, which is usually found closest to the channel (Friedman, Osterkamp, and Lewis 1996). Sites close to the channel were more severely disturbed by the 2015 floods (Meitzen et al. 2018), and the floodplain stripping that occurred created bare patches of soil for seedlings to establish.

On the other hand, resprouts were dominant in the less-disturbed plots. High resprout density was associated with class 4, while highest resprout basal area values were found in class 2. This is not unexpected, as the plots where stripping occurred tended to have few or no standing surviving trees. Resprouts from class 4 plots were predominantly sprouting from laid-over trees or from stumps left behind after post-flood debris removal (Figure 11). Class 2 and 3 plots had both surviving trees and resprouts from damaged trees (Figure 12). Some of the surviving trees were quite large, with the largest measuring 137 cm across.

Trees were most abundant in pre-disturbance vegetation class 2 plots (floodplain hardwood forest), regardless of recovery method or how abundance was calculated. Class 2 was the most common class among all plots and was associated with some of the deepest and finest soils. Class 2 is the only forest class found in the study area, so class 2 plots would be expected to have denser woody vegetation than other plots.

Figure 11. Tree Resprouting from Stump. This *Platanus occidentalis* was cut down during the debris removal process following the flood at Five Mile Dam. Several stems have begun to resprout from the stump.

Figure 12. Surviving Trees. These *Taxodium distichum* at University Camp were not removed by the floods. The tree in front is most likely dead, as the bark and cambium are removed, but the trees in the background are still alive.

The quantitative variables (soil depth, distance to channel, channel and valley gradients, height above channel, elevation, and channel width) have been used in previous studies on succession and riparian forest development (e.g., Baker and Walford

1995). These variables are all related to geomorphology and disturbance patterns, which govern riparian plant establishment and survival (Naiman and Décamps 1997).

Finer soils (classes 2, 3, and 4) were associated with higher abundance of all trees regardless of how abundance was calculated. Finer soils are associated with higher soil moisture and nutrient content (Friedman, Osterkamp, and Lewis 1996), which may explain the higher diversity and abundance on finer soils. That said, some patterns were observed on coarser soils and bedrock. Bedrock plot FMD1 had a resprouting *Fraxinus pennsylvanica* stump, but the only other woody plants in that plot were two seedlings sprouting from accumulated sediment near its base. Plot FMD2, also a bedrock plot, had denser vegetation, mostly *Eysenhardtia texana*, which was not found on any other plots in the study, but is a drought-tolerant upland obligate species (Vines 1984). Most of the plots with the coarsest substrate (gravel, cobbles, and/or boulders with little to no fine material) were found on islands at University Camp and the high-water channel at Five Mile Dam. At several coarse-soil plots at Five Mile Dam, annuals such as *Xanthium* sp. and *Ricinus communis* dominated, while most of the woody vegetation was resprouting from damaged stumps (Figure 13). Seedlings were found at many of these sites, but densities were generally lower than at plots with finer soils.

Seedling abundance was most responsive to soil depth, height above channel, and distance from channel. Resprout abundance was weakly related to distance from channel and channel width but was not affected by soil depth. One possible explanation for the lack of a relationship between resprout abundance and soil depth could be that soil depth has changed significantly at some plots since the trees were established. In some plots, branches were observed resprouting from trees that were partially buried by sediment. In other plots, the only soil was found around the roots of a damaged tree. Channel width is a control of stream discharge, and small differences in discharge could determine whether the trees or parts of trees in a given plot remain in place. Distance from channel was associated with disturbance class, so it affects both the presence of resprouting or surviving trees, and the availability of bare ground where seedlings can establish.

Figure 13. Coarse Soils at Five Mile Dam. Vegetation at this plot is dominated by annuals such as *Xanthium* sp. and *Platanus occidentalis*, which is resprouting from damaged stumps. Soils are quite coarse, with clasts ranging from gravel- to cobble-size.

7.3 Environmental Controls on Recovery

The environmental variables had varying control on the recovery of the riparian community. This is expected, as riparian vegetation may respond more strongly to variables beyond the scope of this study (Baker and Walford 1995).

Community composition was least correlated to disturbance class (Table 11), although ISA revealed patterns there. In general, riparian species, such as *P. occidentalis, S. nigra, Populus deltoides* and *F. pennsylvanica* were found more often on highly disturbed sites with at least some floodplain stripping (classes 5 and 6; Table 12). This is unsurprising, since many riparian species rely on floodplain stripping for recruitment, and changes to the hydrologic regime that result in less frequent flooding has caused a decline in riparian species in some locations (Lytle and Merritt 2004; Holloway, Rillig, and Gurnell 2017). Upland species such as *Q. virginiana, D. texana,* and *J. ashei* were found on less disturbed sites (classes 2 and 3). Upland species may not be adapted to survive inundation as well as riparian species. For example, *J. ashei* has a shallow root system (Eggemeyer and Schwinning 2009), which would limit its ability to resist uprooting during a severe flood.

Surprisingly, obligate riparian species *T. distichum*, and facultative wetland species *Celtis* spp. were more frequent in less disturbed sites. *Celtis* was found more often on shadier plots, and is a mid- to late-successional tree in Texas (Davis and Smith 2013); so perhaps it preferentially establishes on less disturbed plots because they offer more shade. Because many of the highly disturbed plots were completely stripped of their vegetation, other species may need to establish there before *Celtis* is able to. The size variance of *T. distichum* individuals surveyed may be distorting the results. Some of the largest trees in this study were *T. distichum*, but seedlings were fairly rare (section 6.1). Only 27 seedlings were found among all plots. Six surviving trees were identified, ranging from 10.5 cm to 137 cm DBH. All of the seedlings were found in moderately to highly disturbed plots (classes 4 – 6). The surviving trees were all found in minimally to moderately disturbed plots (classes 2 – 4). *T. distichum* is most indicative of class 2 disturbance, but that result is skewed by one very large tree.

The only strong indicators for pre-disturbance vegetation class were for deciduous woodland (class 5; Table 13). *Forestiera pubescens* and *D. texana* were fairly uncommon throughout the study, but were found in over half of the plots in University Camp. This may be more of a reflection of University Camp's location on the Edwards Plateau than of this particular vegetation type. Both the Blackland Prairie and the Edwards Plateau are subject to woody plant encroachment, but dominance of invading trees is different between the two regions because of differences in soil depth (Eggemeyer and Schwinning 2009). Though soils at University Camp were fairly deep, upland forest composition may be influencing riparian forest recovery to some degree. *Celtis* spp. was also found to indicate deciduous woodland. *Celtis* was very common in this study; various sizes were found and it occurred in at least one plot at every site.

Soil type was a more significant influence on community makeup than the other categorical variables. Soil particle size was also a significant variable in Baker and Walford's (1995) study on the Animas River in Colorado. Size and makeup of sediments strongly influence root structure (Holloway, Rillig, and Gurnell 2017), which, in part, governs moisture uptake (Tron et al. 2015). The strongest indicator of soil type was *C. occidentalis*, which was found in cobble-dominant soils at Five Mile Dam. The next strongest indicators were for bedrock (type 1) – *E. texana* and *S. lanuginosum* (Section 6.2; Figure 11). *E. texana, S. lanuginosum,* and *C. occidentalis* were all fairly rare in this study, which may explain why they were found on so few soil types.

Of the quantitative variables, height above channel had the most influence on community composition, while distance to channel had the least (Table 9). This result is consistent with Friedman, Osterkamp, and Lewis (1996) and Hefley (1937), who found that elevation relative to channel elevation was analogous to geomorphic surface age, and had a significant influence on forest composition because it determined substrate material and texture. Surfaces nearest the channel are more affected by floods (Meitzen et al. 2018), so subsequent minor floods could have an effect here as well. The strength of the response of riparian forest composition to these types of variables may vary, however. Baker and Walford (1995) found that geomorphic variables such as height above the channel and distance to the channel were only weakly correlated to riparian forest composition on the Animas River. Values for geomorphic variables in that study were fairly similar, however. In the present study, there is quite a bit of variance in the landscape. The highest plots were found at University Camp (UC1, UC2, UC4, UC5, and UC6) and Blanco Shoals (BS6, BS7 and BS8), where banks were quite steep. Upland and facultative species such as *D. texana, Ilex* spp., *F. pubescens,* and *J. ashei* were abundant at these sites. Soils were fine-grained, and disturbance levels were minor to moderate, though UC1 had a higher disturbance level and coarser soils than the other plots.

Valley gradient and elevation were somewhat related to each other, with lower elevations having lower gradients. University Camp was the highest elevation site, approximately 50 m higher than Five Mile Dam, the next highest site. The elevation difference between Five Mile Dam and the lowest site, Blanco River Village, is < 15 m. As University Camp is on the Edwards Plateau and all other sites are mostly on the Blackland Prairie, some of the vegetation at University Camp is distinctive from the other sites. *J. ashei, Ptelea trifoliata,* and *Ilex decidua* were only found at University Camp. *D. texana* and *F. pubescens* were more abundant there than at the other sites. It should be noted that these are facultative and upland species, and the plots on which they occurred were some of the highest in the study relative to channel elevation.

Valley gradient was highest at Five Mile Dam, followed by University Camp. Gradients at Five Mile Dam are probably slightly steeper than at other sites due to its position on Balcones Escarpment. Nearly all sites at Five Mile Dam were exposed to full sunlight due to a lack of overstory vegetation. Soils consisted of either bedrock or coarse material, with few exceptions. These characteristics may be related to increased flood velocities due to the gradient, but could also be attributed to the presence of the dam. The dam retains sediment, reducing sediment delivery to the reach just below. All the plots at this site are below the dam, and ground coverage by vegetation upstream of the dam is denser than downstream of the dam.

7.4 Further Research Directions

Future study could examine the effects of microtopography, large woody debris, canopy cover, and herbivory on the recovery of the riparian forest along the Blanco River. Some of these effects were observed in this study, but the variables were not analyzed. Topographic features such as ridges, swales, islands, and point bars seemed to have an effect on seedling establishment. These features can determine height above the channel, channel width, soil depth, and other variables which were found to significantly influence vegetation establishment. Simmons, Wu, and Whisenant (2012) observed that microtopography was important to the survival of certain riparian species, especially late-seral species. Davis and Smith (2013) noted that microtopographic features allow upland species, such as *Ehretia anacua*, to survive much closer to the channel than they normally would. In the present study, *M. azeradach* and *E. anacua* were found on higher plots, such as ridges and cut banks. *S. nigra, P. deltoides,* and *B. neglecta* were more frequent on low, flat areas, i.e., point bars. Further research could identify microtopographic features and analyze their effects on forest regeneration.

Large wood has been recognized as an essential component of instream processes such as creation of pools (Marston 1982), sediment storage (Wohl and Scott 2017), and aquatic habitat (Mitchell, Entrekin, and Adams 2012). Large woody debris can also affect floodplain processes, such as sedimentation and bank erosion (Wohl and Scott 2017). In most of the sites surveyed in this study, large woody debris was cleared and mulched following the 2015 floods. Cleanup was executed by several groups of contractors, each using slightly different methods. Because of inconsistencies in how this cleanup was done, and because exact locations of cleanup at each site could not be accurately determined, the effects of this cleanup could not be quantified for this study. Parts of Five Mile Dam, Blanco Shoals, and University Camp were all cleared of flood debris. At Blanco Riverwalk, Blanco River Village, and a small section of University Camp, some of the woody debris was left behind. Even in parks that were cleared, some woody debris remains, especially in areas that experienced only minor or moderate disturbance. Debris was not cleared from the islands, or from some of the private land adjacent to the parks. This large wood may affect forest recovery by protecting seedlings during small floods. Further study on the Blanco River could investigate the effects of large woody debris, or debris clean-up, in the floodplain.

Canopy cover was not considered in this study because the overall goal was to examine the effects of geomorphic variables on forest regeneration, but light is a well-known control on forest composition (Egger et al. 2015; Lindsey et al. 1961) and channel processes (Julian et al. 2011). Canopy cover along the Blanco River is mostly provided by large surviving trees, such as *T. distichum* and *Carya illinoensis*. In plots shaded by large trees, pioneer species such as *S. nigra, P. occidentalis,* and *P. deltoides* were relatively rare, while slower-growing species such as *D. texana* and *Ulmus crassifolia* were more common. Turnover from fast-growing, sun-loving trees to longer-living, shade-tolerant trees is an important characteristic of secondary succession (Egger et al. 2015). Shading by herbaceous vegetation has played a part in preventing *T. distichum* regeneration in Louisiana (Souther and Shaffer 2000), and tall herbaceous species such as *Ricinus communisis, Sorghum halepense,* and *Ambrosia trifida* were found in most plots. Additional research on the recovery of the Blanco River floodplain could examine the effects of light availability on forest composition and relevant channel processes.

Herbivory has played a significant role in vegetation dynamics in East Texas (Keeland et al. 2011) and in savannas in Central Texas (Fowler and Simmons 2008). Browsing has affected recruitment of bigtooth maple (*Acer gradidentatum*) at a relict site in Central Texas (Dickinson and Van Auken 2016), and influenced riparian forest recovery following a wildfire in Rocky Mountain National Park (Kaczynski and Cooper 2015). In addition to the white-tailed deer which are causing vegetation change in savannas (Fowler and Simmons 2008), feral hogs (*Sus scrofa*) are common in Central Texas. Packs of *S. scrofa* were observed at Blanco Shoals Natural Area and Blanco Riverwalk Park during the data collection portion of this study. Evidence of recent rooting by *S. scrofa* was observed at University Camp and Blanco River Village Park. *S. scrofa* has affected the forest composition in Florida (Arrington, Toth, and Koebel 1999) and East Texas (Siemann et al. 2009) by uprooting plants and consuming some seeds. The effects of browsing by herbivorous animals on riparian forest regeneration along the Blanco River could be considerable.

7.5 Implications for Management

The results of this study could inform management and restoration decisions for the Blanco River riparian corridor. Post-flood reforestation along the Blanco River is ongoing, but had not occurred in these areas at the time of data collection. This reforestation project is administered by TreeFolks, an Austin, TX-based non-profit. TreeFolks uses contract and volunteer labor to plant seedlings in the Blanco River riparian zone in Hays County. As of early 2018, over 100,000 trees have been planted on public and private lands, including parts of Five Mile Dam, University Camp, and Blanco Shoals (Leos 2018). TreeFolks uses around 20 species of trees native to the Blanco River for reforestation (Meitzen et al. 2018). Successful reforestation projects should consider not only species, but also the diversity, density, and structure found at reference sites (Guillozet, Smith, and Guillozet 2014). Further, species composition for reforestation should be appropriate for the geomorphic, biologic, and hydrologic setting (Palmer et al. 2005). The results of this study could guide TreeFolks in selecting trees that are likely to become established in a variety of geomorphic contexts.

Employees of the City of San Marcos were interested in how flood cleanup efforts affected tree establishment, especially in Blanco Shoals Natural Area. While this could not be accurately quantified (see section 7.4), some observations were made with regards to density and diversity at the plots affected by the cleanup. Overall, tree density and diversity were lower at cleared plots than at nearby, uncleared plots. Herbaceous cover was lower as well. At plots that were cleared of flood debris, vegetation was sparse and dominated by annuals, including *Xanthium* sp., *R. communis,* and *A. trifida*, as well as the non-native perennial *S. halepense*. While these plants also appeared at plots that were not cleared of debris, they were less dominant at those plots in general. Plots that were not cleared contained other grasses such as *Panicum virgatum* and *Chasmanthium latifolium*, vines such as *Toxicodendron radicans, Vitis* spp., *Smilax* spp., and *Rubus trivialis*, and forbs such as *Gaillardia* spp. At Blanco Shoals, part of the cleared area was mulched, while another part was not. Herbaceous cover was higher in the mulched area, except on established trails. It is unclear whether these patterns are related to the cleanup or to the geomorphic disturbance that has occurred in these areas. Most of the cleanup took place on a point bar, so frequent disturbance is likely to occur in this area. Areas that were not cleared experienced less significant flood disturbance.

Legacy effects of past floods and/or clearing can be observed at Blanco Riverwalk and Blanco River Village. Blanco Riverwalk was cleared of vegetation in 2005. It is unclear whether this is related to a post-flood cleanup, or to the installation of roads for a future subdivision. Trees at Blanco Riverwalk exist immediately adjacent to the channel, and are sparse on the floodplain. Density and diversity at this site are fairly low. Even after 13 years, annuals continue to dominate. Low species density and diversity could be an effect of the riparian clearing, as land use changes can have lasting effects on soil seed banks (Richter and Stromberg 2005). In fact, clearing of riparian vegetation can cause changes in riparian communities that last decades or longer. The clearing of riparian forests for log transport in mountain environments has affected riparian and instream communities for ~100 years (Wohl and Merritts 2007).

The riparian buffer at Blanco River Village appears to have been severely damaged in a flood between 2011 and 2014, most likely the flood of October 30, 2013, but it does not appear to have been cleared of debris or vegetation. Vegetation cover by perennial herbaceous and woody species is high, but very little overstory exists in the riparian zone at this time. Diversity and density at Blanco River Village are high, and most trees adjacent to the channel are seedlings. High seedling density indicates that this area is recovering better than Blanco Riverwalk, where seedling density remains low. Conditions at Blanco Riverwalk could predict future conditions at Blanco Shoals in areas that were cleared of flood debris.

8. CONCLUSIONS

The aim of this research was to evaluate the riparian forest recovery following the floods of 2015. A few weak patterns of community composition were identified. Overall, upland obligate and facultative species were observed in plots that were higher above the channel with deeper soils, shallow gradients, and a narrower channel. Riparian obligate and facultative species were generally more tolerant of lower plots with shallower soils and steeper gradients.

The floods of 2015 had a significant effect on the riparian forest composition along the Blanco River. All of the plots surveyed had at least some changes to the riparian buffer as a result of the floods. Though the damage to the riparian buffer was significant, the riparian forest is beginning to recover through regeneration from the seed bank and resprouting of damaged trees. As succession processes continue to take place over the next years to decades, the composition of the riparian forest will continue to evolve.

APPENDIX SECTION

APPENDIX A: UNIVERSITY CAMP DATA

UC1	UTM	0592691	3317697				
Diversity	3						
Species	**Freq.**	**Density (Freq. / Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA sum/Ha**	**Relative Dominance (BA / plot BA)**	**Importance ((Dominance + Density)/2)**
bacneg	11	560.51	0.73	1.6E-03	0.08	0.99	0.86
diotex	3	152.87	0.2	1.5E-05	7.5E-04	9.4E-03	0.1
celtis	1	50.96	0.07	4.9E-06	2.5E-04	3.1E-03	0.03
Totals	**15**	**764.33**	**1**	**1.6E-03**	**0.08**	**1**	**1**

UC2	UTM	0592680	3317692				
Diversity	7						
Species	**Freq.**	**Density (Freq. / Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA sum/Ha**	**Relative Dominance (BA / plot BA)**	**Importance ((Dominance + Density)/2)**
diotex	8	407.64	0.3	1.5E-03	0.08	0.02	0.16
celtis	4	203.82	0.15	0.04	2.12	0.46	0.3
forpub	1	50.96	0.04	4.9E-06	2.5E-04	5.4E-05	0.02
ptetri	9	458.6	0.33	4.4E-05	2.3E-03	4.8E-04	0.17
ulmcra	3	152.87	0.11	0.05	2.45	0.53	0.32
iledec	1	50.96	0.04	4.9E-06	2.5E-04	5.4E-05	0.02
aceneg	1	50.96	0.04	4.9E-06	2.5E-04	5.4E-05	0.02
Totals	**27**	**1375.8**	**1**	**0.09**	**4.65**	**1**	**1**

UC3	UTM	0592734	3317754				
Diversity	10						
Species	**Freq.**	**Density (Freq. / Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA sum/Ha**	**Relative Dominance (BA / plot BA)**	**Importance ((Dominance + Density)/2)**
taxdis	4	203.82	0.06	0.88	44.92	0.99	0.53
plaocc	1	50.96	0.016	2.6E-03	0.13	3.0E-03	9.6E-04
celtis	1	50.96	0.016	4.9E-06	2.5E-04	5.5E-06	8.1E-03
forpub	7	356.69	0.11	1.1E-04	5.5E-03	1.2E-04	0.06
ulmcra	3	152.87	0.05	1.5E-05	7.5E-04	1.7E-05	0.02
aceneg	35	1783.44	0.56	2.5E-04	0.01	2.8E-04	0.28
diotex	2	101.91	0.03	6.3E-04	0.03	7.1E-04	0.02
sidlan	4	203.82	0.06	3.4E-05	1.8E-03	3.9E-05	0.03
iledec	1	50.956	0.02	4.9E-06	2.5E-04	5.5E-06	8.1E-03
salnig	4	203.82	0.06	3.4E-05	1.8E-03	3.9E-05	0.03
Totals	**62**	**3159.24**	**1**	**0.89**	**45.1**	**1**	**1**

UC4	UTM	0592782	3317822				
Diversity	8						
Species	**Freq.**	**Density (Freq. / Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA sum/Ha**	**Relative Dominance (BA / plot BA)**	**Importance ((Dominance + Density)/2)**
taxdis	7	356.69	0.1	3.4E-05	1.8E-03	0.01	0.06
ulmcra	1	50.96	0.01	7.9E-05	4.0E-03	0.03	0.02
diotex	4	203.82	0.06	4.0E-04	0.02	0.16	0.11
celtis	20	1019.11	0.29	3.8E-04	0.02	0.15	0.22
aceneg	8	407.64	0.12	7.1E-04	0.04	0.29	0.2
forpub	21	1070.06	0.3	1.0E-04	5.3E-03	0.04	0.17
bacneg	7	356.69	0.1	4.1E-04	0.02	0.17	0.14
carill	1	50.96	0.01	3.1E-04	0.02	0.13	0.07
Totals	**69**	**3515.92**	**1**	**2.4E-03**	**0.12**	**1**	**1**

UC5	UTM	0592824	3317864				
Diversity	9						
Species	**Freq.**	**Density (Freq. / Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA sum/Ha**	**Relative Dominance (BA / plot BA)**	**Importance ((Dominance + Density)/2)**
ulmcra	9	458.6	0.24	4.4E-05	2.3E-03	0.01	0.12
bacneg	2	101.91	0.05	2.0E-05	1.0E-03	5.6E-03	0.03
ilevom	4	203.82	0.11	3.1E-04	0.02	0.09	0.1
celtis	15	764.33	0.39	8.8E-05	4.5E-03	0.03	0.21
diotex	2	101.91	0.05	2.6E-04	0.01	0.07	0.06
junash	2	101.91	0.05	9.8E-04	0.05	0.28	0.17
aceneg	1	50.96	0.03	1.8E-03	0.09	0.51	0.27
frapen	2	101.91	0.05	9.8E-06	5.0E-04	2.8E-03	0.03
forpub	1	50.96	0.03	4.9E-06	2.5E-04	1.4E-03	0.01
Totals	**38**	**1936.31**	**1**	**3.5E-03**	**0.18**	**1**	**1**

UC6	UTM	0592805	3317861				
Diversity	5						
Species	**Freq.**	**Density (Freq. / Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA sum/Ha**	**Relative Dominance (BA / plot BA)**	**Importance ((Dominance + Density)/2)**
aceneg	13	662.42	0.52	1.0E-03	0.05	0.48	0.5
celtis	7	356.69	0.28	1.2E-04	6.3E-03	0.06	0.17
forpub	2	101.91	0.08	9.8E-06	5.0E-04	4.6E-03	0.04
diotex	2	101.91	0.08	4.9E-04	0.03	0.23	0.15
junash	1	50.96	0.04	4.9E-04	0.03	0.23	0.13
Totals	**25**	**1273.89**	**1**	**2.1E-03**	**0.11**	**1**	**1**

UC7	UTM	0592687	3317648				
Diversity	5						
Species	**Freq.**	**Density (Freq. / Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA sum/Ha**	**Relative Dominance (BA / plot BA)**	**Importance ((Dominance + Density)/2)**
bacneg	5	254.78	0.5	2.4E-03	0.12	0.32	0.41
plaocc	1	50.96	0.1	3.3E-03	0.17	0.445	0.27
cepocc	1	50.96	0.1	1.8E-03	0.09	0.24	0.17
celtis	1	50.96	0.1	4.9E-06	2.5E-04	6.5E-04	0.05
taxdis	2	101.91	0.2	9.8E-06	5.0E-04	1.3E-03	0.1
Totals	**10**	**509.55**	**1**	**0.007559**	**0.39**	**1**	**1**

UC8	UTM	0592649	3317556				
Diversity	8						
Species	**Freq.**	**Density (Freq. / Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA sum/Ha**	**Relative Dominance (BA / plot BA)**	**Importance ((Dominance + Density)/2)**
aceneg	2	101.91	0.08	1.4E-04	0.01	0.01	0.04
frapen	1	50.96	0.04	6.0E-04	0.03	0.05	0.05
plaocc	9	458.6	0.35	0.01	0.28	0.48	0.41
bacneg	10	509.56	0.38	4.8E-03	0.25	0.43	0.41
ilevom	1	50.96	0.04	1.8E-04	0.01	0.02	0.03
cepocc	1	50.96	0.04	4.9E-06	2.5E-04	4.3E-04	0.02
jugmaj	1	50.96	0.04	1.8E-04	0.01	0.02	0.03
carill	1	50.96	0.04	4.9E-06	2.5E-04	4.3E-04	0.02
Totals	**26**	**1324.84**	**1**	**0.01**	**0.58**	**1**	**1**

APPENDIX B: FIVE MILE DAM DATA

FMD1	UTM	0606049	3312675				
Diversity	3						
Species	**Freq.**	**Density (Freq. / Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA sum/Ha**	**Relative Dominance (BA / plot BA)**	**Importance ((Dominance + Density)/2)**
frapen	1	50.96	0.33	0.01	0.31	0.99	0.67
diotex	1	50.96	0.33	4.9E-06	2.5E-04	8.2E-04	0.17
celtis	1	50.96	0.33	4.9E-06	2.5E-04	8.2E-04	0.17
Totals	**3**	**152.87**	**1**	**0.01**	**0.31**	**1**	**1**

FMD2	UTM	0606093	3312643				
Diversity	4						
Species	**Freq.**	**Density (Freq. / Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA sum/Ha**	**Relative Dominance (BA / plot BA)**	**Importance ((Dominance + Density)/2)**
eystex	33	1681.53	0.77	2.5E-03	0.13	0.84	0.8
sidlan	4	203.82	0.09	1.6E-04	0.01	0.05	0.07
bacneg	3	152.87	0.07	4.4E-05	2.3E-03	0.01	0.04
ulmcra	3	152.87	0.07	2.8E-04	0.01	0.09	0.08
Totals	**43**	**2191.08**	**1**	**3.0E-03**	**0.15**	**1**	**1**

FMD3	UTM	0606086	3312657				
Diversity	5						
Species	**Freq.**	**Density (Freq. / Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA sum/Ha**	**Relative Dominance (BA / plot BA)**	**Importance ((Dominance + Density)/2)**
frapen	11	560.51	0.37	0.04	1.94	0.97	0.67
cepocc	7	356.69	0.23	3.4E-05	1.8E-03	8.7E-04	0.12
bacneg	8	407.64	0.27	1.2E-03	0.06	0.03	0.15
forpub	1	50.96	0.03	4.9E-06	2.5E-04	1.3E-04	0.02
celtis	3	152.87	0.1	1.5E-05	7.5E-04	3.7E-04	0.05
Totals	**30**	**1528.66**	**1**	**0.039319**	**2**	**1**	**1**

FMD4	UTM	0606116	3312608				
Diversity	1						
Species	**Freq.**	**Density (Freq. / Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA sum/Ha**	**Relative Dominance (BA / plot BA)**	**Importance ((Dominance + Density)/2)**
bacneg	15	764.33	1	0.01	0.56	1	1
Total	**15**	**764.33**	**1**	**0.01**	**0.56**	**1**	**1**

FMD5	UTM	0606159	33125434				
Diversity	1						
Species	**Freq.**	**Density (Freq. / Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA sum/Ha**	**Relative Dominance (BA / plot BA)**	**Importance ((Dominance + Density)/2)**
cepocc	1	50.96	1	4.9E-06	2.5E-04	1	1
Total	**1**	**50.96**	**1**	**4.9E-06**	**2.5E-04**	**1**	**1**

FMD6	UTM	0606176	3312561				
Diversity	2						
Species	**Freq.**	**Density (Freq. / Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA sum/Ha**	**Relative Dominance (BA / plot BA)**	**Importance ((Dominance + Density)/2)**
aceneg	1	50.96	0.25	4.9E-06	2.5E-04	0.14	0.2
salnig	3	152.87	0.75	2.9E-05	1.5E-03	0.86	0.8
Totals	**4**	**203.82**	**1**	**3.43E-05**	**1.8E-03**	**1**	**1**

FMD7	UTM	0606207	3312502				
Diversity	2						
Species	**Freq.**	**Density (Freq. / Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA sum/Ha**	**Relative Dominance (BA / plot BA)**	**Importance ((Dominance + Density)/2)**
plaocc	3	152.87	0.75	0.01	0.28	0.99	0.87
cepocc	1	50.96	0.25	4.9E-06	2.5E-04	8.9E-04	0.13
Totals	**4**	**203.82**	**1**	**0.01**	**0.28**	**1**	**1**

FMD8	UTM	0606229	3312528				
Diversity	4						
Species	**Freq.**	**Density (Freq. / Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA sum/Ha**	**Relative Dominance (BA / plot BA)**	**Importance ((Dominance + Density)/2)**
aceneg	7	356.69	0.39	3.5E-04	0.02	0.08	0.23
plaocc	1	50.96	0.06	4.9E-06	2.5E-04	1.1E-03	0.03
bacneg	9	458.6	0.5	4.1E-03	0.21	0.92	0.71
celtis	1	50.96	0.06	2.0E-05	1.0E-03	4.4E-03	0.03
Totals	**18**	**917.2**	**1**	**4.5E-03**	**0.23**	**1**	**1**

FMD9	UTM	0606253	3312460				
Diversity	2						
Species	**Freq.**	**Density (Freq. / Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA sum/Ha**	**Relative Dominance (BA / plot BA)**	**Importance ((Dominance + Density)/2)**
plaocc	1	50.96	0.5	3.3E-03	0.17	0.58	0.54
frapen	1	50.96	0.5	2.4E-03	0.12	0.42	0.46
Totals	**2**	**101.91**	**1**	**0.01**	**0.29**	**1**	**1**

FMD10	UTM	0606285	3312480				
Diversity	2						
Species	**Freq.**	**Density (Freq. / Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA sum/Ha**	**Relative Dominance (BA / plot BA)**	**Importance ((Dominance + Density)/2)**
frapen	4	203.82	0.29	4.4E-03	0.22	0.88	0.58
bacneg	10	509.56	0.71	5.9E-04	0.03	0.12	0.42
Totals	**14**	**713.38**	**1**	**5.0E-03**	**0.25415**	**1**	**1**

FMD11	UTM	0606324	3312451				
Diversity	4						
Species	**Freq.**	**Density (Freq. / Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA sum/Ha**	**Relative Dominance (BA / plot BA)**	**Importance ((Dominance + Density)/2)**
frapen	2	101.91	0.33	4.5E-03	0.23	0.47	0.4
plaocc	1	50.96	0.17	5.0E-03	0.25	0.52	0.34
bacneg	2	101.91	0.33	9.8E-05	0.01	0.01	0.17
melaze	1	50.96	0.17	4.9E-06	2.5E-04	5.1E-04	0.08
Totals	**6**	**305.73**	**1**	**0.01**	**0.49**	**1**	**1**

FMD12	UTM	0606386	3312439				
Diversity	3						
Species	**Freq.**	**Density (Freq. / Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA sum/Ha**	**Relative Dominance (BA / plot BA)**	**Importance ((Dominance + Density)/2)**
plaocc	1	50.96	0.07	0.01	0.34	0.81	0.44
bacneg	12	611.47	0.8	1.8E-03	0.09	0.19	0.5
forpub	2	101.91	0.13	9.8E-06	5.0E-04	1.0E-03	0.07
Totals	**15**	**764.33**	**1**	**0.01**	**0.48**	**1**	**1**

FMD13	UTM	0606337	3312473				
Diversity	1						
Species	**Freq.**	**Density (Freq. / Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA sum/Ha**	**Relative Dominance (BA / plot BA)**	**Importance ((Dominance + Density)/2)**
jugmaj	1	50.96	1	0.01	0.37	1	1
Total	**1**	**50.96**	**1**	**0.01**	**0.37**	**1**	**1**

APPENDIX C: BLANCO RIVERWALK DATA

BRW1	UTM	0606085	3310994				
Diversity	4						
Species	**Freq.**	**Density (Freq. / Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA sum/Ha**	**Relative Dominance (BA / plot BA)**	**Importance ((Dominance + Density)/2)**
salnig	47	2394.9	0.85	6.3E-04	0.03	0.7	0.78
popdel	5	254.78	0.09	1.7E-04	0.001	0.19	0.14
ulmcra	2	101.91	0.04	8.3E-05	4.3E-03	0.09	0.06
celtis	1	50.96	0.02	2.0E-05	1.0E-03	0.02	0.02
Total	**55**	**2802.55**	**1**	**9.1E-04**	**0.05**	**1**	**1**

BRW2	UTM	0606089	3310990				
Diversity	3						
Species	**Freq.**	**Density (Freq. / Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA sum/Ha**	**Relative Dominance (BA / plot BA)**	**Importance ((Dominance + Density)/2)**
salnig	9	458.6	0.45	5.7E-04	0.03	1.2E-05	0.23
aceneg	8	407.64	0.4	3.3E-03	0.17	6.9E-05	0.2
frapen	3	152.87	0.15	47.63	0.02	0.99	0.57
Total	**20**	**1019.11**	**1**	**47.63**	**0.22**	**1**	**1**

BRW3	UTM	0606021	3310859				
Diversity	2						
Species	**Freq.**	**Density (Freq. / Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA sum/Ha**	**Relative Dominance (BA / plot BA)**	**Importance ((Dominance + Density)/2)**
popdel	3	152.87	0.75	5.5E-04	0.28	0.88	0.81
ulmame	1	50.96	0.25	7.9E-05	0.04	0.12	0.19
Total	**4**	**203.82**	**1**	**6.3E-04**	**0.32**	**1**	**1**

BRW4	UTM	0605998	3310878				
Diversity	6						
Species	**Freq.**	**Density (Freq./ Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA sum/Ha**	**Relative Dominance (BA / plot BA)**	**Importance ((Dominance + Density)/2)**
plaocc	7	356.69	0.44	0.06	3.12	0.95	0.69
ulmame	1	50.96	0.06	1.8E-04	0.01	2.7E-03	0.03
carill	1	50.96	0.06	2.0 E-05	1.0E-03	3.1E-04	0.03
frapen	3	152.87	0.19	2.2E-03	0.11	0.03	0.11
celtis	2	101.91	0.13	7.1E-04	0.04	0.01	0.07
ulmcra	2	101.91	0.13	9.8E-06	5.0E-04	1.5E-04	0.06
Total	**16**	**815.29**	**1**	**0.06**	**3.28**	**1**	**1**

BRW5	UTM	0606034	3310952				
Diversity	3						
Species	**Freq.**	**Density (Freq./Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA sum/Ha**	**Relative Dominance (BA / plot BA)**	**Importance ((Dominance + Density)/2)**
plaocc	28	1426.75	0.88	0.17	8.5	0.94	0.91
frapen	3	152.87	0.09	0.01	0.53	0.06	0.08
celtis	1	50.96	0.03	4.9E-06	2.5E-04	2.8E-05	0.02
Totals	**32**	**1630.57**	**1**	**0.18**	**9.04**	**1**	**1**

BRW6	UTM	0606055	3310998				
Diversity	7						
Species	**Freq.**	**Density (Freq./Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA sum/Ha**	**Relative Dominance (BA / plot BA)**	**Importance ((Dominance + Density)/2)**
salnig	51	2598.73	0.82	1.0E-03	0.05	0.05	0.44
frapen	2	101.91	0.03	2.3E-03	0.12	0.12	0.08
plaocc	2	101.91	0.03	0.02	0.8	0.82	0.43
triseb	3	152.87	0.05	2.9E-05	1.5E-03	1.5E-04	0.02
popdel	3	152.87	0.05	1.5E-05	7.5E-04	7.7E-04	0.02
taxdis	1	50.96	0.02	4.9E-06	2.5E-04	2.6E-04	0.01
Totals	**62**	**3159.24**	**1**	**0.02**	**0.97**	**1**	**1**

BRW7	UTM	0606148	3311095				
Diversity	4						
Species	**Freq.**	**Density (Freq./Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA sum/Ha**	**Relative Dominance (BA / plot BA)**	**Importance ((Dominance + Density)/2**
aceneg	1	50.96	0.17	4.1E-04	0.021	0.884211	0.525439
bacneg	1	50.96	0.17	2.0E-05	0.001	0.042105	0.104386
popdel	1	50.96	0.17	2.0E-05	0.001	0.042105	0.104386
ulmcra	3	152.87	0.5	1.5E-05	0.00075	0.031579	0.265789
Totals	**6**	**305.73**	**1**	**4.7E-04**	**0.02375**	**1**	**1**

BRW8	UTM	0606134	3311103				
Diversity	4						
Species	**Freq.**	**Density (Freq./Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA / Ha**	**Relative Dominance (BA/ plot BA)**	**Importance ((Dominance + Density)/2)**
aceneg	1	50.96	0.14	8.0E-04	0.04	0.35	0.25
celtis	2	101.91	0.29	2.6E-04	0.01	0.11	0.2
salnig	1	50.96	0.14	7.9E-05	4.0E-03	0.03	0.09
ulmcra	3	152.87	0.43	1.1E-03	0.06	0.5	0.46
Totals	**7**	**356.69**	**1**	**2.3E-03**	**0.12**	**1**	**1**

BRW9	UTM	0606172	3311219				
Diversity	2						
Species	**Freq.**	**Density (Freq./Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA / Ha**	**Relative Dominance (BA/ plot BA)**	**Importance ((Dominance + Density)/2)**
plaocc	25	1273.89	0.89	0.07	3.48	0.99	0.95
ulmcra	3	152.87	0.11	1.5E-05	7.5E-04	2.2E-04	0.05
Total	**28**	**1426.75**	**1**	**0.07**	**3.49**	**1**	**1**

BRW10	UTM	0606193	3311208				
Diversity	3						
Species	**Freq.**	**Density (Freq./Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA / Ha**	**Relative Dominance (BA/ plot BA)**	**Importance ((Dominance + Density)/2)**
progla	1	50.96	0.33	3.5E-04	0.02	0.15	0.24
bacneg	1	50.96	0.33	2.0E-03	0.1	0.85	0.59
ulmcra	1	50.96	0.33	4.9E-06	2.5E-04	2.1E-03	0.17
Totals	**3**	**152.87**	**1**	**2.3E-03**	**0.12**	**1**	**1**

APPENDIX D: BLANCO SHOALS DATA

BS1	UTM	0606732	3309433				
Diversity	3						
Species	**Freq.**	**Density (Freq./Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA / Ha**	**Relative Dominance (BA/ plot BA)**	**Importance ((Dominance + Density)/2)**
popdel	14	713.38	0.36	1.1E-04	0.01	0.29	0.33
celtis	1	50.96	0.03	4.9E-06	2.5E-04	0.01	0.02
salnig	24	1222.93	0.62	2.7E-04	0.01	0.69	0.65
Totals	**39**	**1987.26**	**1**	**3.8E-04**	**0.02**	**1**	**1**

BS2	UTM	0606803	3309401				
Diversity	2						
Species	**Freq.**	**Density (Freq./Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA / Ha**	**Relative Dominance (BA/ plot BA)**	**Importance ((Dominance + Density)/2)**
aceneg	4	203.82	0.8	1.8E-03	0.09	0.07	0.43
ulmcra	1	50.96	0.2	0.03	1.3	0.93	0.57
Totals	**5**	**254.78**	**1**	**0.03**	**1.39**	**1**	**1**

BS3	UTM	0606779	3309389				
Diversity	2						
Species	**Freq.**	**Density (Freq./Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA / Ha**	**Relative Dominance (BA/ plot BA)**	**Importance ((Dominance + Density)/2)**
plaocc	86	4382.17	0.96	1.4E03	0.07	0.99	0.97
ulmame	4	203.82	0.04	2.0E-05	1.0E-03	0.01	0.03
Totals	**90**	**4585.99**	**1**	**1.4E-03**	**0.07**	**1**	**1**

BS4	UTM	0606808	3309307				
Diversity	9						
Species	**Freq.**	**Density (Freq./Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA / Ha**	**Relative Dominance (BA/ plot BA)**	**Importance ((Dominance + Density)/2)**
celtis	8	407.64	0.17	1.4E-03	0.07	0.1	0.13
taxdis	1	50.96	0.02	0.01	0.44	0.61	0.32
ilevom	8	407.64	0.17	5.8E-04	0.03	0.04	0.1
carill	3	152.87	0.06	1.5E-03	0.08	0.11	0.09
macpom	16	815.29	0.33	9.1E-04	0.05	0.06	0.2
frapen	6	305.73	0.13	4.4E-04	0.02	0.03	0.08
aceneg	3	152.87	0.06	2.4E-04	0.01	0.02	0.04
ulmcra	2	101.91	0.04	3.2E-04	0.02	0.02	0.03
triseb	1	50.96	0.02	4.9E-06	2.5E-04	3.5E-04	0.01
Totals	**48**	**2445.86**	**1**	**0.01**	**0.72**	**1**	**1**

BS5	UTM	0606789	3309323				
Diversity	5						
Species	**Freq.**	**Density (Freq./Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA / Ha**	**Relative Dominance (BA/ plot BA)**	**Importance ((Dominance + Density)/2)**
aceneg	2	101.91	0.2	1.7E-03	0.09	0.8	0.5
carill	2	101.91	0.2	1.9E-04	0.01	0.09	0.15
celtis	1	50.96	0.1	7.9E-05	4.0E-03	0.04	0.07
frapen	1	50.96	0.1	4.9E-06	2.5E-04	2.3E-03	0.05
samcan	4	203.82	0.4	1.4E-04	0.01	0.07	0.23
Totals	**10**	**509.55**	**1**	**2.1E-03**	**0.11**	**1**	**1**

BS6	UTM	0606742	3309178				
Diversity	7						
Species	**Freq.**	**Density (Freq./Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA / Ha**	**Relative Dominance (BA/ plot BA)**	**Importance ((Dominance + Density)/2)**
carill	1	50.96	0.09	0.26	13.27	0.99	0.54
celtis	2	101.91	0.18	9.8E-06	5.0-E04	3.8E-05	0.09
samcan	1	50.96	0.09	4.9E-06	2.5E-04	1.9E-05	0.05
bacneg	1	50.96	0.09	2.0E-05	1.0E-03	7.5E-05	0.05
aceneg	3	152.87	0.27	1.6E-04	0.01	6.2E-04	0.14
ehrana	2	101.91	0.18	9.8E-05	0.01	3.7E-04	0.09
ulmcra	1	50.96	0.09	4.9E-06	2.4E-04	1.9E-05	0.05
Totals	**11**	**560.51**	**1**	**0.26**	**13.29**	**1**	**1**

BS7	UTM	0606724	3309204				
Diversity	7						
Species	**Freq.**	**Density (Freq./Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA / Ha**	**Relative Dominance (BA/ plot BA)**	**Importance ((Dominance + Density)/2)**
ulmcra	10	509.55	0.15	0.01	0.36	0.36	0.26
bacneg	2	101.91	0.03	2.6E-04	0.01	0.01	0.02
ehrana	28	1426.75	0.43	2.4E-03	0.12	0.12	0.28
melaze	10	509.55	0.15	4.3E-03	0.22	0.22	0.18
celtis	10	509.55	0.15	0.01	0.3	0.29	0.22
carill	1	50.96	0.02	4.9E-06	2.5E-04	2.5E-04	0.01
aceneg	4	203.82	0.06	2.0E-05	1.0E-03	9.9E-04	0.03
Totals	**65**	**3312.1**	**1**	**0.02**	**1.01348**	**1**	**1**

BS8	UTM	0606463	3308501				
Diversity	6						
Species	**Freq.**	**Density (Freq./Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA / Ha**	**Relative Dominance (BA/ plot BA)**	**Importance ((Dominance + Density)/2)**
taxdis	1	50.96	0.01	1.47	75.08	0.95	0.48
celtis	57	2904.46	0.6	0.07	3.38	0.04	0.32
quevir	5	254.78	0.05	9.8E-05	0.01	6.4E-05	0.03
ehrana	22	1121.02	0.23	3.1E-03	0.16	2.0E-03	0.12
forpub	2	101.91	0.02	9.8E-06	5.0E-04	6.4E-06	0.01
ulmcra	8	407.64	0.08	5.5E-04	0.03	3.6E-04	0.04
Totals	**95**	**4840.76**	**1**	**1.54**	**78.65**	**1**	**1**

BS9	UTM	0606408	3308361				
Diversity	6						
Species	**Freq.**	**Density (Freq./Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA / Ha**	**Relative Dominance (BA/ plot BA)**	**Importance ((Dominance + Density)/2)**
popdel	8	407.64	0.19	3.9E-05	2.0E-03	0.06	0.12
plaocc	2	101.91	0.05	9.8E-06	5.0E-04	0.01	0.03
salnig	26	1324.84	0.6	5.5E-04	0.03	0.83	0.72
bacneg	4	203.82	0.09	4.9E-05	2.5E-03	0.07	0.08
frapen	2	101.91	0.05	9.8E-06	5.0E-04	0.01	0.03
taxdis	1	50.96	0.02	4.9E-06	2.5E-04	0.01	0.02
Totals	**43**	**2191.08**	**1**	**6.7E-04**	**0.034**	**1**	**1**

BS10	UTM	0606393	3308365				
Diversity	8						
Species	**Freq.**	**Density (Freq./Ha)**	**Relative Density (species density / plot density)**	**BA sum**	**BA / Ha**	**Relative Dominance (basal area/ plot BA)**	**Importance ((Dominance + Density)/2)**
salnig	41	2089.17	0.59	3.7E-03	0.19	0.92	0.75
triseb	2	101.91	0.03	3.9E-05	2.0E-03	0.01	0.02
popdel	10	509.55	0.14	1.5E-04	0.01	0.04	0.09
aceneg	9	458.6	0.13	4.4E-05	2.3E-03	0.01	0.07
frapen	3	152.87	0.04	2.9E-05	1.5E-03	0.01	0.03
taxdis	1	50.96	0.01	4.9E-06	2.5E-04	1.2E-03	0.01
plaocc	1	50.96	0.01	4.9E-06	2.5E-04	1.2E-03	0.01
carill	3	152.87	0.04	4.4E-05	2.3E-03	0.01	0.03
Totals	**70**	**3566.88**	**1**	**4.0E-03**	**0.21**	**1**	**1**

APPENDIX E: BLANCO RIVER VILLAGE DATA

BRV1	UTM	0605514	3306351				
Diversity	5						
Species	**Freq.**	**Density (Freq./Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA / Ha**	**Relative Dominance (BA/ plot BA)**	**Importance ((Dominance + Density)/2)**
plaocc	13	662.42	0.19	7.9E-05	4.0E-03	0.02	0.11
salnig	25	1273.89	0.36	2.7E-04	0.01	0.08	0.22
morrub	9	458.6	0.13	1.5E-03	0.08	0.43	0.28
bacneg	19	968.15	0.28	1.6E-03	0.08	0.46	0.37
popdel	3	152.87	0.04	1.5E-05	7.5E-04	4.3E-03	0.02
Totals	**69**	**3515.92**	**1**	**3.5E-03**	**0.18**	**1**	**1**

BRV2	UTM	0605533	3306340				
Diversity	5						
Species	**Freq.**	**Density (Freq./Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA / Ha**	**Relative Dominance (BA/ plot BA)**	**Importance ((Dominance + Density)/2)**
aceneg	3	152.87	0.43	2.9E-03	0.15	0.37	0.4
plaocc	1	50.96	0.14	4.9E-06	2.5E-04	6.3E-04	0.07
ulmame	1	50.96	0.14	3.5E-04	0.02	0.04	0.09
celtis	1	50.96	0.14	3.2E-03	0.16	0.41	0.28
morrub	1	50.96	0.14	1,4E-03	0.07	0.18	0.16
Totals	**7**	**356.69**	**1**	**0.01**	**0.4**	**1**	**1**

BRV3	UTM	0605517	3306380				
Diversity	4						
Species	**Freq.**	**Density (Freq./Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA / Ha**	**Relative Dominance (BA/ plot BA)**	**Importance ((Dominance + Density)/2)**
salnig	605	30828.03	0.99	3.0E-03	0.15	0.99	0.99
plaocc	3	152.87	4.9E-03	1.4E-05	7.5E-04	4.9E-03	4.9E-03
popdel	1	50.96	1.6E-03	4.9E-06	2.5E-04	1.6E-03	1.6E-03
taxdis	1	50.96	1.6E-03	4.9E-06	2.5E-04	1.6E-03	1.6E-03
Totals	**610**	**31082.8**	**1**	**3.0E-03**	**0.15**	**1**	**1**

BRV4	UTM	0605535	3306366				
Diversity	6						
Species	**Freq.**	**Density (Freq./Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA / Ha**	**Relative Dominance (BA/ plot BA)**	**Importance ((Dominance + Density)/2)**
aceneg	1	50.96	0.07	1.1E-04	0.01	0.03	0.05
samcan	5	254.78	0.36	6.7E-04	0.03	0.16	0.26
morrub	5	254.78	0.36	3.4E-03	0.17	0.79	0.58
bacneg	1	50.96	0.07	2.0E-05	1.0E-03	4.6E-03	0.04
celtis	1	50.96	0.07	7.9E-05	4.0E-03	0.02	0.04
plaocc	1	50.96	0.07	4.0E-06	2.0E-04	9.3E-04	0.04
Totals	**14**	**713.38**	**1**	**4.3E-03**	**0.22**	**1**	**1**

BRV5	UTM	0605582	3306440				
Diversity	6						
Species	**Freq.**	**Density (Freq./Ha)**	**Relative Density (sp. density / plot density)**	**BA sum**	**BA / Ha**	**Relative Dominance (BA/ plot BA)**	**Importance ((Dominance + Density)/2)**
salnig	50	2547.77	0.38	2.6E-04	0.01	0.22	0.3
taxdis	6	305.73	0.05	2.9E-05	1.5E-03	0.02	0.04
progla	2	101.91	0.02	1.6E-04	0.01	0.13	0.07
aceneg	41	2089.17	0.31	3.5E-04	0.02	0.29	0.3
jugmaj	4	203.82	0.03	2.6E-04	0.01	0.21	0.12
plaocc	29	1477.71	0.22	1.4E-04	0.01	0.12	0.17
Totals	**132**	**6726.12**	**1**	**1.2E-03**	**0.06**	**1**	**1**

APPENDIX F: ENVIRONMENTAL VARIABLES BY PLOT

Plot Name	Distance	Soil Depth	Soil Type	Plot Elevation	Height Above Channel	Channel Gradient	Valley Gradient	Channel Width	Disturb. Class	Veg. Class
FMD1	12.95	0.00	1	183.06	0.82	0.0028	0.0068	81.65	6	4
FMD10	40.46	12.00	8	182.54	2.01	0.0028	0.0068	70.83	6	6
FMD11	10.69	10.00	6	182.37	1.89	0.0028	0.0068	96.80	6	6
FMD12	12.33	12.00	6	181.67	1.17	0.0028	0.0068	87.47	6	4
FMD13	48.48	38.00	6	183.27	2.83	0.0028	0.0068	81.07	6	4
FMD2	8.31	0.00	1	183.21	2.39	0.0028	0.0068	76.51	6	4
FMD3	24.33	31.00	5	182.96	2.14	0.0028	0.0068	76.51	6	4
FMD4	13.24	24.00	2	182.74	1.90	0.0028	0.0068	32.81	6	2
FMD5	10.67	13.00	6	181.23	0.05	0.0028	0.0068	39.27	6	6
FMD6	34.65	28.00	6	182.69	1.51	0.0028	0.0068	35.52	6	4
FMD7	6.90	28.00	6	181.89	1.23	0.0028	0.0068	57.72	6	4
FMD8	42.37	42.00	2	182.29	1.56	0.0028	0.0068	50.65	6	4
FMD9	5.36	32.00	6	182.83	2.30	0.0028	0.0068	72.80	6	6
BRV1	6.01	36.00	4	170.52	1.45	0.0038	0.0006	56.04	6	2
BRV2	32.26	61.00	4	170.65	1.63	0.0038	0.0006	56.04	6	2
BRV3	3.46	22.00	4	170.46	1.46	0.0038	0.0006	62.12	6	6
BRV4	25.36	17.00	4	170.11	1.11	0.0038	0.0006	60.55	6	2
BRV5	4.65	42.00	3	171.30	2.08	0.0038	0.0006	58.12	6	2
BRW1	4.50	88.00	2	178.62	1.17	0.0014	0.0012	44.03	5	4
BRW10	25.28	20.00	3	179.27	1.52	0.0014	0.0012	28.65	5	6
BRW2	11.62	36.00	2	178.70	1.21	0.0014	0.0012	44.20	5	4
BRW3	30.00	20.00	3	178.42	1.87	0.0014	0.0012	19.34	5	2
BRW4	6.77	26.00	4	178.16	1.58	0.0014	0.0012	11.88	5	2
BRW5	0.00	16.00	3	178.15	1.19	0.0014	0.0012	42.06	4	2
BRW6	0.00	53.00	3	177.50	0.43	0.0014	0.0012	46.59	5	2
BRW7	21.64	75.00	2	179.02	1.54	0.0014	0.0012	24.74	5	4
BRW8	6.81	82.00	2	178.15	0.66	0.0014	0.0012	25.20	5	2
BRW9	18.40	24.00	4	178.99	1.24	0.0014	0.0012	27.37	5	6
BS1	13.94	97.00	4	175.96	2.31	0.0004	0.0014	84.55	6	6
BS10	20.92	66.00	2	173.57	1.37	0.0004	0.0014	34.92	6	2
BS2	5.04	77.00	2	176.09	2.68	0.0004	0.0014	54.75	4	2
BS3	31.66	66.00	4	174.04	0.61	0.0004	0.0014	43.24	4	3
BS4	3.20	102.00	3	175.04	1.71	0.0004	0.0014	16.90	4	2
BS5	24.86	14.00	3	175.45	2.12	0.0004	0.0014	15.72	4	2
BS6	5.93	82.00	4	177.77	4.16	0.0004	0.0014	18.20	4	2
BS7	31.61	92.00	2	178.40	5.13	0.0004	0.0014	29.53	3	2
BS8	6.18	100.00	2	176.83	4.53	0.0004	0.0014	36.10	2	2
BS9	8.92	50.00	2	173.87	1.58	0.0004	0.0014	34.56	6	2
UC1	8.23	29.00	3	235.93	6.05	0.0032	0.0019	38.05	5	5
UC2	16.45	58.00	2	238.46	8.36	0.0032	0.0019	42.60	4	5
UC3	4.88	7.00	3	231.72	2.18	0.0032	0.0019	20.42	3	2

Plot Name	Distance	Soil Depth	Soil Type	Plot Elevation	Height Above Channel	Channel Gradient	Valley Gradient	Channel Width	Disturb. Class	Veg. Class
UC4	4.93	92.00	2	238.43	9.33	0.0032	0.0019	38.89	4	5
UC5	4.77	37.00	2	232.34	3.22	0.0032	0.0019	32.01	3	2
UC6	21.69	56.00	2	233.35	4.28	0.0032	0.0019	31.55	2	5
UC7	0.00	18.00	5	231.05	0.72	0.0032	0.0019	54.67	4	6
UC8	0.00	10.00	8	231.43	0.37	0.0032	0.0019	55.74	4	6

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