RIPARIAN VEGETATION SUSCEPTIBILITY TO WIND AND FLOODING IMPACTS OF HURRICANES

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by

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ABSTRACT

Riparian Vegetation Susceptibility to the Wind and Flooding Impacts of Hurricanes

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Vegetation in riparian zones of southern Texas largely consist of woody trees, shrubs, and vines that grow densely within a short distance from the river. The rich and productive nature of these environments provides critical habitat for aquatic and terrestrial species of commercial and recreational value. This study examines how woody vegetation within the Mission River riparian zone has been impacted by Hurricane Harvey that brought category 3 winds and significant flooding to the areas around the Mission River. To determine the density and the species composition of the vegetation on the riparian zone of the Mission River, vegetation was surveyed in plots that are located along the river. Density and composition of woody riparian species within these plots were determined using measurements of diameter at breast height (DBH) and compared to the findings from previous studies on the Mission River riparian zone. Based on preliminary analyses of ground and aerial images and literature on hurricane impacts to riparian zones, it is expected that Hurricane Harvey caused widespread snapping of trunks/limbs and weakened roots of larger woody vegetation. Structural compromise to woody vegetation can also reduce their ability to stabilize their crowns, resulting in a high volume of downed trees while making way for pioneering species. There are limited studies on disturbance to riparian systems that is induced by hurricanes and this research increases our understanding of how these systems respond to these types of extreme events.

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NOMENCLATURE

MR	Mission River
FR	Fennessey Ranch
CBH	Circumference at Breast Height
DBH	Diameter at Breast Height
LWD	Large Woody Debris

CHAPTER I

INTRODUCTION

Riparian ecosystems continue to face adversity and will need to adapt to the increase in severe weather that is expected from future climate. Studying riparian systems and keeping them healthy is essential because of their interconnected nature and capacity to sustain biodiversity through succession (Hupp and Osterkamp, 1996). In addition, vegetation within riverine landscapes are highly affected by flooding and associated changes to the fluvial geomorphology over space and time (Kamisako et al. 2006); human activities that can modify hydrologic and sediment regimes such as dams (Alldredge and Moore, 2012); land use/land cover change; and flooding events that sustain communities in extended drought. (Moore et al. 2015). In turn, trees and woody vegetation influence the morphodynamics of river channels by affecting bank erosion and sedimentation patterns; they can lead to a decrease in bank erodibility by increasing the resistance of cutbanks to erosion from river flows. Alternatively, they can stabilize sediment depositions such as those on the point bars of meandering rivers and thus change channel geomorphology and deflect streamflows to the outer banks of the channel (Zen et al. 2017). In addition, large wood dislodged by hurricanes and other intense storms has proven to have a destructive effect to both property and streambed morphology (Seo et al. 2015). With this in mind and the integrated evolution between the river and its surround landscape, riverine environments are reflective of multiple stressors and can be used to study the ecological impacts of such stressors; as well as how the changes to riparian communities can impact water resources (Tockner et al. 2010).

Another increasingly important aspect of the study or riverine environments on the coast is the impacts caused by increases in river water salinities as sea levels continue to rise. Rivers near the coast will have higher salinity levels which in turn have shown a mostly negative impact on the health of the vegetation that cannot tolerate a more saline water source (Overton et al. 2006). Moreover, woody vegetation near coastlines can be impacted by tropical cyclones that can cause vegetation to experience an overall browning due to stripping of leaves from wind, flooding, and salt spray carried by hurricanes (Hansen, 2017). Change in species diversity and density reflect historical changes to fluvial processes and depict the long-lasting effects of substantial disturbance (Kamisako et al., 2006). This study aims to develop a better understanding of how riparian vegetation is impacted by intense winds and flooding events.

Tropical cyclones have the ability to cause significant damage to woody vegetation in a variety of ways (Cameron *et al.* 1983). Damage to trees can range from complete uprooting to snapped branches or trunks and defoliation of the tree canopy. The degree and spatial distribution in the vulnerability of trees to hurricane-force winds depend on a number factors. These include meteorological factors (*e.g.*, the size, intensity, path, and duration of the tropical cyclonic storm), site characteristics (*e.g.*, river and floodplain topography and geomorphology, land use and land cover, soil structure and moisture), and tree characteristics (*e.g.*, species type, height, and root morphology) (Cameron *et al.* 1983; Williams and Douglas 1995).

Hurricane Harvey made its first landfall along the Coast Bend of Texas on 25 Aug. 2017, 47 years after Hurricane Celia, that previously impacted the region on 3 Aug. 1970. The Mission River, whose course passes next to the town of Refugio before reaching the Mission Bay, was, once again, on the path of the destructive core of a hurricane. The area received excessive rainfall, that ranged between 381 and 635 mm; resulted in moderate flooding in the Mission

River. Furthermore, Hurricane Harvey also contained category 3 winds over Refugio; sustained wind speeds reached ~167 km/hr and estimated gusts up to 214 km/hr (NOAA 2017). As a result, a significant number of trees experienced blowdown after the hurricane as indicated by our post-hurricane aerial image of the river and its floodplain.

The type and degree to which particular woody species are impacted by tropical cyclones can be used as a precedent to estimate the vegetation's stage of recovery in the wake of significant disturbance. For example, Bush et al. (2006) tracked the successionary nature of the riparian vegetation along the San Antonio River over two decades and recorded the species found in early-successional, mid-successional, and old-growth stands in a region that has many similar species to those along the Mission River. In addition, Davis and Smith (2013) surveyed transects along the Mission River, Texas in 2009-2010 and found eight of the most important species based on diameter at breast height (DBH) measurements. Of these eight, seven were classified as trees and one was classified as a vine.

This study examines how woody vegetation within the Mission River riparian zone has been impacted by Hurricane Harvey that brought category 3 winds and flooding to the areas around the Mission River. To determine the density and the species composition of the vegetation on the riparian zone of the Mission River, vegetation was surveyed in plots located along the river. Density and composition of woody riparian species within these plots were determined using measurements of DBH and compared to the findings from Davis and Smith (2013) for the Mission River riparian zone. Preliminary analyses of post-hurricane imagery (ground and aerial) and a review of the literature associated with hurricane impacts to riparian zones, suggest that Hurricane Harvey caused widespread snapping of trunks/limbs and weakened roots of larger woody vegetation. This structural compromise to woody vegetation can reduce their ability to stabilize their crowns, resulting in a high volume of downed trees while making way for fast-growing successionary species.

This research contributes to our understanding of the system response of riparian vegetation to hurricane impact. Comprehending the current impacts to the woody riparian system and anticipating future responses can aid effective restoration and preservation of riparian vegetation and riverine landscapes.

CHAPTER II

METHODS

Field methods and data collection

In this study, the vegetation data obtained from Davis and Smith (2013) on the Mission River riparian zone were used as a proxy for the state of pre-hurricane vegetation for comparison. We assume that the conditions obtained from the field surveys conducted by Davis and Smith (2013) in 2009-2010 are representative of the pre-hurricane woody vegetation and thus can be compared to the conditions obtained from the post-hurricane surveys conducted in this study. Although the area experienced severe drought in 2011 that may have significantly contributed to a change in vegetation; we expect that measuring the composition and density of the different types of woody vegetation (tree, shrub, and vine) and densities to be sufficient for comparison. The disturbance of Hurricane Harvey caused widespread disturbance to the study site because it resulted in the site experiencing category 3 winds and significant flooding at the study site. We assume that the wind and flooding that this level of disturbance were significant enough to cause long term successionary impacts to the region. Moreover, I expect that the study meets the criteria that allows for the statistical, field-based (through the establishment of sampling transects), and Geographic Information Systems (GIS)GIS methodologies to be implemented.

The positional coordinates of the vegetation plots used in the surveys conducted by Davis and Smith (2013) were mapped and located in the field. Then, following Davis and Smith (2013), a 3 m x 10 m grid was created at each survey location along the river by placing a flag at every meter along the perimeter, with flags marking the halfway point for visual aid (Figure 1).

The location of each flag was mapped by marking them using high-precision Global Navigation Satellite Systems (GNSS) equipment (GNSS equipment included an R10 receiver and a TSC3 controller; a WiFi-based real-time kinematic positional correction was also utilized). In the original study by Davis and Smith (2013), each location had multiple plots; however, due to limited time, I only surveyed the plots closest to the river's edge (Figures 2 and 3). We assumed that vegetation closest to the river would experience the greatest impacts from flooding, changes in river salinity, and intense winds (the river channel tends to funnel winds). A decrease in vegetation density closest to the river would also have a more significant impact on the erosion of the banks.

Circumference at breast height (CBH) was recorded for all woody vegetation with CBH values greater than 3 cm within the bounds of my plots (vegetation that crossed into the plot was also measured at the point of entry into the plot). To be measured, the vegetation had to be ≥ 1.3 m in height. Circumference at breast height was then converted to DBH in order for values to be comparable to those from Davis and Smith (2013). The relative location of each measurement within the grid was marked, as well as the type of vegetation (tree, shrub, vine, blown down tree, etc.). The vegetation that appeared to have been disturbed from Hurricane Harvey, either from being blown over or branch breakage, was also specifically noted. Plots were drawn with the river on the topmost edge, with 3 m extending perpendicular to river flow, and 10 m running parallel (Figure 1).

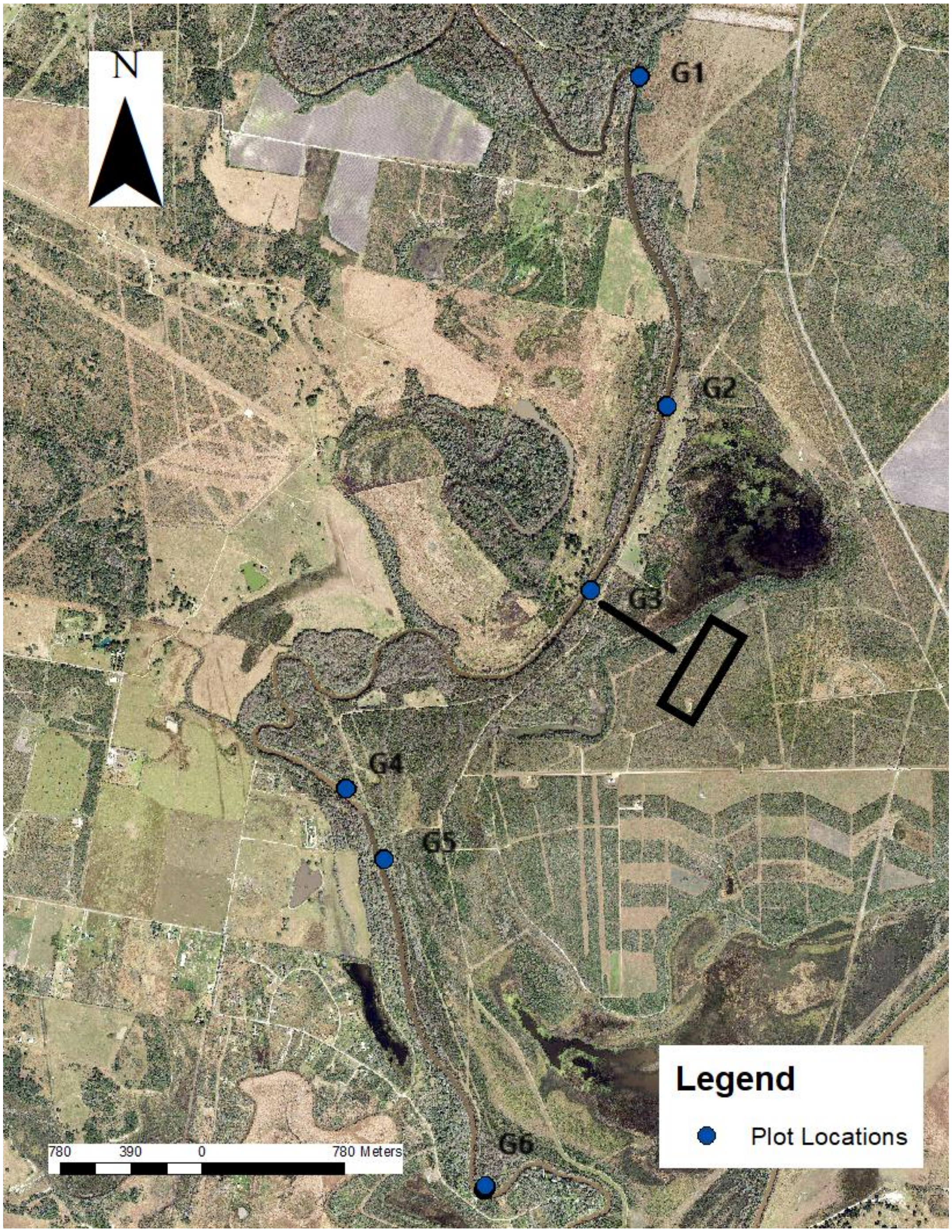

Figure 1. Location of the plots along the Mission River, Texas, and diagram showing magnified orientation relative to the river. Plots were labeled G1 through G6, with G1 being the northernmost point and G6 being the southernmost plot.

Figure 2 (left): Plot G2 (3 m x 10 m) relative to the Mission River.

Figure 3 (right): Plot G6 (10 m x 30 m) with 10 plots along the transect with location of each measurement marked with blue circles.

For G6, the southernmost plot (Figure 3 and 4), 10 plots were simultaneously created by establishing a grid of 10 m x 30 m. Surveying one plot at the location of the previous study's starting point would not have accurately portrayed the composition of the site. Few species were growing within the 3 m closest to the riverbank, but many more individuals were scattered within the 30 m that we recorded. For this plot, we marked the location of each DBH measurement with the GNSS.

Figure 4: Plot G6 was characterized by many more mature tree species that were spaced relatively far apart. In order to get a detailed representation of the area, the plot was extended to 10 m x 30 m, an area equal to 10 plots when compared to the other plots.

Statistical analysis

Total density (individuals per m^2) was calculated for the entire area surveyed (total area = 450 m2) (Table 1). Relative density was calculated as a percentage by dividing the total density of each type of woody vegetation by the total density of all plots (McCune and Grace 2002). The average DBH of each vegetation type for each plot was also calculated (Table 2).

In order to compare these data to those of Davis and Smith (2013), the important species were consolidated into four vegetation types: tree, shrub, vine, and multi trunk trees. Dead trees and windthrow damage were assessed separately. The densities of the same types of woody vegetation were then compiled and compared with the densities recorded post-Harvey. Since dominance and basal area are calculated at a species-specific level, it was deemed inappropriate to directly compare these data to those from Davis and Smith (2013).

CHAPTER III

RESULTS

Plot survey data

Community composition showed a higher relative density of all trees combined across all 6 plots with a 69.51% of all woody vegetation types (Table 1). Among trees, relative density is higher for trees with single trunks than those with multiple trunk (trees multi). Tree composition was then followed by vines, windthrown, dead trees, and shrubs. Trees also showed the highest density (individuals per m^2) with a total of 25.34 (18.67 for single trunks and 6.67 multi trunked trees). Vines also contributed greatly with a density of 7.33.

Table 1: Indicators of community composition using the sums of all plots.

Indicator	Vines	Trees	Shrubs	Multi Trunk	Dead Trees	Windthrow	All
n	33	84	5	30	5	7	164
Density	7.33	18.67	1.11	6.67	1.11	1.56	36.45
Relative Density	20.12	51.22	3.05	18.29	3.05	4.27	100

Density (number of individuals per square meter) and Relative Density (percentage) from March 2018.

In order to analyze patterns across all of the plots and the differences between the locations, the average DBH of each vegetation type was compiled (Table 2). Plots G1, G2, and G4 all had a high average DBH for dead trees. The tree averages ranged from 3.78 cm to 9.88

cm. All multi trunked tree (multi trunk) averages were similar, centering around 3.17 cm. The vines in G1, G2, and G3 were also similar with measurements of 3.60 cm, 2.59 cm, and 2.72 cm respectively, however G6 had a much higher average of 7.23 cm. Spatially, DBH values decreased from the first most upstream location (G1) to G4, and then increased again starting from G5 to the most downstream location.

Table 2 – Average DBH (cm) of each vegetation type across all plots.

Plot	Vines	Trees	Shrubs	Trees Multi	Dead Trees	Windthrow
G1	3.60	8.45	--	4.43	37.88	--
G2	2.59	8.20	--	--	15.92	--
G3	2.72	5.29	--	3.17	--	--
G4	--	3.78	--	--	19.41	--
G5	--	4.35	--	4.22	--	--
G6	7.23	9.88	2.27	2.85	--	5.87

Note: -- indicates no individuals of this woody vegetation type were present

Visual analysis

Through on-site visual analysis, we were able to gather general information on the widespread disturbance of riparian vegetation at the study site. Many trees along the riverbank had snapped or subsided into the river (Figure 5). There were also several mature trees that showed signs of root destabilization and resulting windthrow damage (Figure 6). The species most frequently observed blown down with root destabilization were mature individuals of species such as *Quercus virginiana* that have extensive crowns. In addition, a majority of the vegetation showed signs of wind stripping leaves and browning. Younger trees and mature trees that were not blown down exhibited widespread snapping of hefty branches (Figure 7) and one exceptionally impressive *Quercus virginiana* had also snapped across the girth of its trunk

(Figure 8). Although larger trees were more susceptible to breakage, there were some signs of damage to smaller shrubs as well (Figure 9). The roots of these individuals also appeared to have been weakened, causing higher susceptibility to wind and a bending of the trunks. One particular species of tree found in several stands across the site seemed especially affected by the wind and flooding disturbance (Figure 10). The species was found in stands with few other types of vegetation and was characterized by an extensive amount of snapping and leaf stripping.

Figure 5 (left): Large tree that had fallen into the Mission River, Texas.

Figure 6 (right): Tree showing root destabilization and snapping.

Figure 7 (left): Small to medium size tree showing significant snapping.

Figure 8 (right): Massive *Quercus virginiana* with snapped trunk.

Figure 9 (left): Shrubs displaying wind damage and tilting of their trunks.

Figure 10 (right): One species of tree appeared in strands across the site and had wide spread snapping.

CHAPTER IV

DISCUSSION AND CONCLUSIONS

The data collected in the vegetation survey showed a high average DBH for woody vegetation in plots G1, G2, and G4. This is likely due to singular fallen trees with large biomasses that took up an extensive portion of these grids. The fallen trees from these plots showed signs of decomposition at stages too far along for the damage to be a result of Hurricane Harvey. However, the high average DBH shows the increased susceptibility to disturbance of the more mature trees. The large biomass of the trees results in their subsequent tendency to remain in the plot because they are not easily displaced. Large wood debris (LWD) can positively impact the environment through addition of nutrients into the soil, and by providing shelter for pioneering species (Mangan *et al.* 2010). This effect was seen in at least 4 out of the 6 plots surveyed.

From G1 (the northernmost plot) to G4, the average DBH values per vegetation type decreased. From G5 to the southernmost plot, average DBH began increasing again. The observed spatial pattern of DBH may be related to the wind structure and how it dissipates along the stream channel and thus requires further investigation.

Visual analysis of the site allowed more comprehensive information to be gathered. Since trees are by far the most dominant and important type of woody vegetation (Davis and Smith 2013), many of the biggest impacts were from windthrow and snapping. Determining whether the destruction has shocked the riparian system or created opportunity for an increase in biodiversity will require more extensive study and continual monitoring.

Since the available observation period was quite short and occurred during the winter months, it was not possible to survey a comprehensive number of plots with species identification. The bulk of the woody vegetation was in a “leaf-off” state, making species identification even more difficult. For future studies, it is recommended that surveys be done during the summer, and for more plots to be surveyed on both banks and extending away from the river. A review of aerial imagery will also aid in estimating the total change in biomass due to damage of the canopy, and when paired with species identification this type of data can provide a means for validating estimates produced using remote sensing. Although there was no conclusive data on the importance of salinity in creating a browning effect, further analysis of aerial imagery paired with temperature and salinity logs will help create insight into this phenomenon.

Riparian vegetation is important to study because of its crucial role in creating biodiversity, influencing sediment deposition, and the potential for human impact through downed trees causing property damage. The root systems of riparian vegetation have a high influence on the erodibility of river banks and the location of sediment deposits. By gathering information on this subject, we are able to more accurately produce climate models and to prepare for the effects of extreme weather on riparian corridors as we move into the future.

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