# Riparian Productivity in Relation to Stream Dynamics Along Two Rivers: San Antonio and Brazos, in Central/South Texas

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CONTRACT ADMINISTRATION
2011 OCT 12 PM 3:45

Prepared for the Texas Water Development Board
In fulfillment of Contract # 1000011020

FINAL REPORT
SEPTEMBER 2011

## SUMMARY

In order to determine whether a riparian forest and its associated stream are functioning in a sustainable manner it is necessary to characterize both the vigor of the existing community as well as its ability to provide for continued maintenance and/or recovery of desirable traits. This study characterized historic river flow along two central Texas rivers (San Antonio and Brazos River), and riparian vigor (measured as tree productivity) as a response to that flow. Black willow, green ash and box elder emerged as key indicator species for describing healthy riparian zones, while hackberry emerged as an indicator of degrading riparian zones. Results indicated that because channel slopes were between 5 and 13m below surrounding landscape on these two rivers, loss of connectivity to saturated soils occurred rapidly with distance to stream.

Key species examination showed that while excessively high flows on each river suppress basal increment (BI) for green ash, box elder and black willow thrive at those same flows. Analysis of select floods indicate several events whose flows were large enough to be seen at the monthly as well as the yearly scale and even in tree records, indicating that changes in timing of flood pulses have the potential to influence annual BI for that year's growth so strongly tree rings reflect that event.

Currently along the San Antonio River seed dispersal appears to be adequately maintained. Total tree counts, biodiversity and seed dispersal along the Brazos River are lower than the San Antonio, but generally productivity is higher. Flow regimes necessary to maintain vigor in the riparian zones of both these rivers need to include measures to ensure that early life stages of the key indicators are met by ensuring a flooding frequency that a) encompasses their spatial locations, b) provides proper soil saturation to both disperse seedlings and maintain saplings, c) recharges groundwater in the near-bank regions to support a healthy root mass, and d)allows for optimal productivity of mature trees so that resiliency of episodic events allows for rapid recovery. Species of interest for future monitoring include hackberry, as it is seen to be expanding along both rivers, though more-so along the Brazos, and cottonwood and green ash because of their low prevalence along the San Antonio River and low recruitment along the Brazos River. Plant invasions into the active channel do not appear to be an issue for either river.

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# Chapter 1
# Overview, Background, Study Area and Methods

## OVERVIEW OF STUDY PLAN

The purpose of this study is to characterize the riparian zone along two central Texas Rivers (San Antonio River and Brazos River) to determine their connectivity to stream dynamics. It will also examine tree basal growth in response to river flow in the riparian forest along each of the rivers.

Six specific objectives were posed (listed below). Each of these objectives will be specifically addressed in the Conclusions Section (for each river individually), following presentation of the Results/Discussion Section of the data collected for that river.

1.) Map vegetation patterns along a 50 ft. transect line perpendicular to the stream in the study site stream corridor, noting breaks in slope.
2.) Identification of riparian zone using test plots perpendicular to the river to determine depth to soil water table.
3) Tie riparian definitions across other disciplines to a consistent jargon for the riparian area.
4) Relate different flow regime patterns to productivity in the riparian zone, based on a representative tree species, with an emphasis on determining an estimated flow regime necessary to protect riparian zones along Texas rivers.
5) Discuss flow regime (frequency, timing and water flow level) necessary to maintain seed dispersal into the riparian zone.
6) Define possible flow levels that must be maintained to prevent riparian plant invasions on active channel, thereby reducing the size of the channel.

Selected sites along each river were examined for biodiversity and stand age dynamics within 50m distance to the stream, overall riparian width defined by observational and hydric conditions within the soil zone, and future recruitment of dominant tree species. Tree-ring analyses were used to evaluate annual tree basal growth relative to the flow regime. Sampled tree ring widths were used to develop a long-term basal increment (BI) (mm/year) record for canopy trees (representing the dominant community species) throughout the riparian forest. Mean annual BI was evaluated relative to river discharge for long-term trends.

## BACKGROUND

In 2001 the Texas Legislature created the Texas Instream Flow Program (TIFP) to assess the amount of discharge rivers need to maintain in order to support a sound ecological environment. The lower San Antonio River and the Lower/Middle Brazos River were two of five priority river segments proposed for study by the TIFP (TIFP, 2011). Such river characteristics as aquatic life/habitat, water quality, nutrient/organism transport, channel formation, and relationship of river to surrounding habitat were designated for study. While the first three characteristics describe functions within the stream itself, the final two represent effects of river flow on surrounding landscapes. Riparian forests in particular are useful indicators of "healthy" stream flow because they can provide crucial information on the stream's ability to maintain plant vigor, biodiversity of species, recruitment, and the presence of species with frequent flooding needs/tolerances as well as root masses capable of withstanding high flows. Such traits in properly functioning riparian forests are essential in allowing the forest to provide a positive feedback benefit of further stabilizing the stream and preventing excessive erosion via soil maintenance and dissipation of energy during floods.

In order to determine whether a riparian forest and its associated stream are functioning in a sustainable manner it is necessary to determine both the vigor of the existing community as well as its ability to provide for the continued maintenance and recovery of desirable instream river traits in the future. To address future maintenance of this river, we must first fully understand the historical nature of the system, and how any current alterations have either benefited or impacted the riparian zone. While the spatial scale of riparian forest is often in a state of dynamic stability as the river experiences both longterm and episodic high/low flows, the temporal scale for determining riparian relationship to river flow is best examined in decades to centuries. Therefore in addition to studies that provide repeatability over multiple decades such as that in Bush *et. al.* (2006), the use of dendrochronology (Anderson and Mitsch, 2008) can provide a long-term examination of tree productivity and/or response to river flow.

The definition of a riparian zone is most often dependent on the purpose for which it is being described (Fischer *et. al.,* 2000), with no current universally-accepted description. From a geomorphological perspective, the riparian zone is defined as the portion of the stream channel that extends from lowest water level *up to* bankfull conditions (Hupp and Osterkamp, 1985). This physical view, which excludes wetlands and floodplains, places both strict spatial and functional limits to the riparian zone as a simple landform. Its scope reflects the similarly constrained view by past hydrologists of streamside vegetation as mechanical variables for changing water velocities or erosional impediments, but little interaction otherwise. A somewhat broader, but less quantitative, definition designates the riparian zone as that area along streams where the physiognomy of vegetation is different from adjacent patches in the surrounding landscape. The limitation of this definition is that it does not account for temporal and spatial variation in the riparian zone itself. Riparian species may vary considerably along the stream system as well as perpendicularly to the stream with changing water conditions so that a distinct boundary is not always easily discerned. Ecologists, recognizing the need to include the processes occurring within the riparian zone and floodplains, have developed a more functional characterization. It defines riparian zones as that part of the landscape whose surfaces are saturated *by* the bankfull discharge (Hupp and Osterkamp, 1996). A definition proposed by Ilhardt *et. al.* (2000), further defines the riparian zone as a three-dimensional ecotone extending down into the groundwater, above the canopy and thus including atmospheric influences, and across the floodplains, which interacts directly with the stream water. This eco-hydrological definition is comprehensive in that it conveys the importance of the riparian zone as both a recipient of stream influences as well as a contributor to instream processes; and necessitates consideration of both biological and non-physical components of the systems and their complex interactions.

Riparian zones are hydrologically linked to the natural stream system via the components of the hyporheic zone which is defined as consisting of >10% stream water (White, 1993), and parafluvial zones, areas of adjacent, unsaturated soils. The interconnectivity of riparian zone to stream is controlled by factors such as topography, bed-material composition and disturbance. Although the hyporheic zone is a spatially fluctuating interface between surface stream and deep groundwater (Boulton *et. al.,* 1998), the degree of exchange can vary widely. Generally, intermediate-scale reaches (Strahler, 1957) have greater hyporheic development while headwater streams and lowland rivers typically exhibit less hydrologic exchange (Junk *et. al.,* 1989) For large-scale rivers, the flow net connecting stream to floodplain suggests geomorphic control over the direction of exchange (Wondzell and Swanson, 1996) and provides a direct alluvial recharge to adjacent groundwater. Regardless of the size of hyporheic zone, it provides not only a water source to the plants, but adds another component to the ability of riparian plants to filter stream water as it meanders in and out of soil banks. Recognizing the functional definition of riparian zones, Hupp and Osterkamp (1996) argue that hydrogeomorphic processes (in particular the magnitude, frequency and durations of stream flow) have the most influence on riparian zone distributions.

Because the term 'riparian zone' has been so broadly used to describe various conditions, there is a great need for communication among the varied disciplines to coordinate a definition that is both universal and explicitly understood by all. According to this study, that definition must include the hydrogeomorphiccal influence of the stream and its direct contributions to both groundwater persistence and spatial partitioning of species within the community.

Another term that has seen broad and varying usage is 'floodplain'. Schmudde (1968) offers three definitions for floodplain, depending on the perspective: Topographically, it is flat and lies adjacent to a stream. Geomorphically, it is a landform composed primarily of unconsolidated depositional material derived from the stream. Hydrologically, it is a landform subject to periodic flooding by the stream. It is seen as an integral part of the stream system and the serves as an adjustment mechanism needed to meet the requirements of discharge and load imposed by the basin it serves. Leopold (1994) defines the floodplain as a level area near the river channel, constructed by the river, and overflowed during moderate flood events. He goes on to describe a period of 1.5 to 2 years as a reasonable average for which bankfull discharge should occur in the floodplain, and considers this as a key determinant factor for whether the floodplain is truly connected to the stream. In Texas bankfull discharge occurs at a period between 1 and 1.5 years. Summer (1991) suggests that floodplains that have been transformed by incised streams to a lower flood frequency into infrequently flooded surfaces are better referred to as 'flood terraces' (flood only on occasion). The term 'floodplain' is used throughout this study, recognizing that even though incision of the river channels may be compromising connectivity of a truly 'active' floodplain; the term still applies (we need to regulate for a floodplain rather than a flood terrace) if we are to meet the needs of the riparian key indicator species.

The Natural Resources Conservation Service (2010) segregates 'flood frequencies' into classes based on the number of times flooding occurs over a period of time (*e.g.* a 'frequent' flood is defined as "flooding is likely to occur often under usual weather conditions; more than a 50 percent chance of flooding in any year [i.e., 50 times in 100 years], but less than a 50 percent chance of flooding in all months in any year."). Additionally, NRCS classifies flood duration classes based on the average duration of inundation per flood occurrence. (*e.g.* 'very long' is considered >30 days). This is a useful refinement of Middleton's (2002) 'flood pulsing' and offers a valuable tool for managers in setting specific flow regimes that maintain healthy riparian habitats based on recommended water needs of species in this study.

STUDY AREA

Four sites representing the San Antonio River watershed were sampled. Three sites were located directly along the San Antonio River and one site was along Cibolo Creek (See Fig. 1)

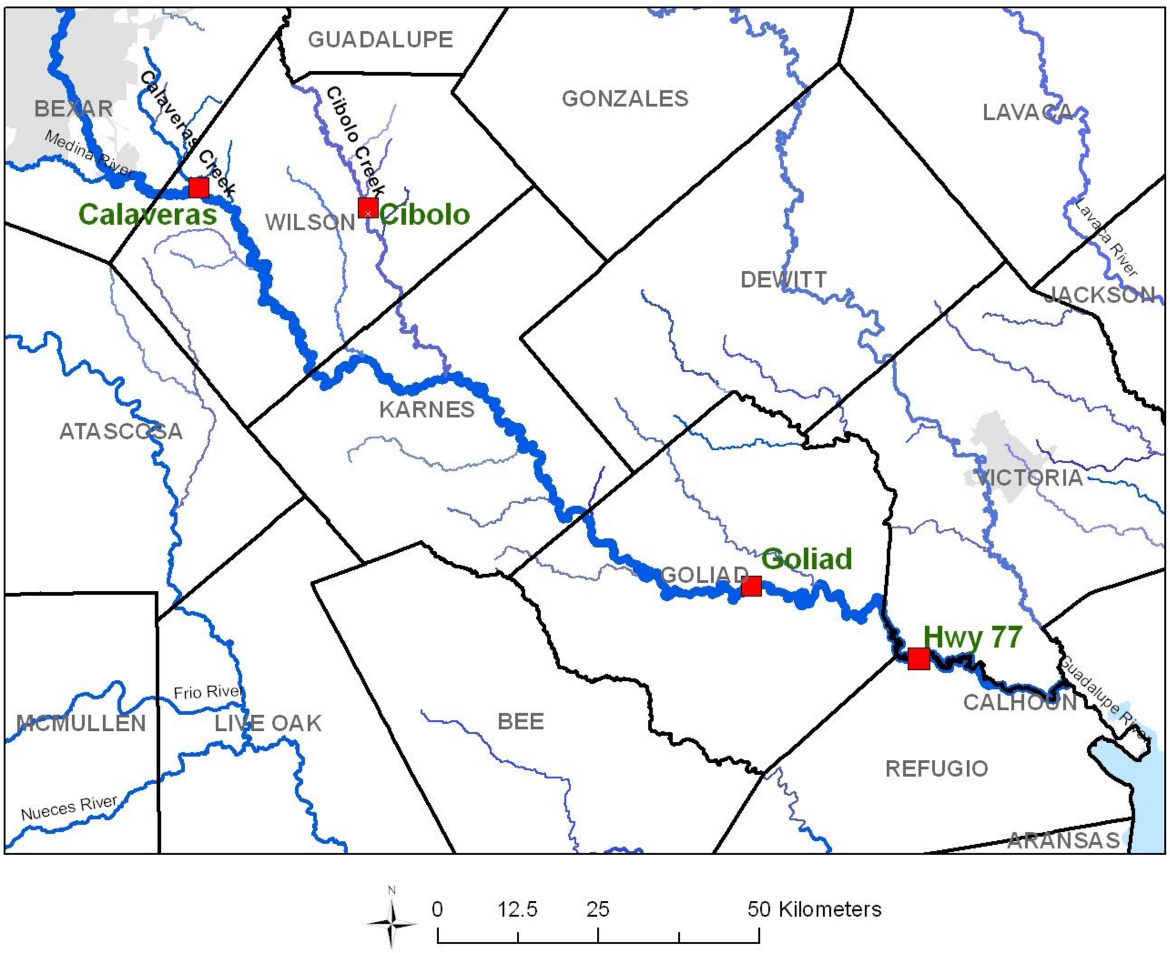


**Figure 1:** Study Sites for the San Antonio River

Location of the four sites, and their common references are given below.
1) Cibolo Site: located along Cibolo Creek, near Stockdale, TX in Wilson County; on private property.
2) Calaveras Site: located along the San Antonio River, just downstream of

Calaveras Creek inflow; near Elmendorf, TX in Wilson County; on San Antonio River Authority property, which will be a future park.
3) Goliad Site: located along the San Antonio River, in Goliad, TX in Goliad County; on Goliad State Park property.
4) Hwy 77 Site: located along the San Antonio River, near the Highway 239 and 77 interchange outside of McFaddin, TX in Refugio County; on private property.

Figures 2-5 show the location of 50m transects within each of the four San Antonio River sites above. Though the original study called for one transect per site and ~10 trees of the dominant species; to facilitate better characterization of riparian functioning, the number of transects for all sites was increased to three and the number of trees up to 30 trees (except for Cibolo which had two transects and ~10 trees).

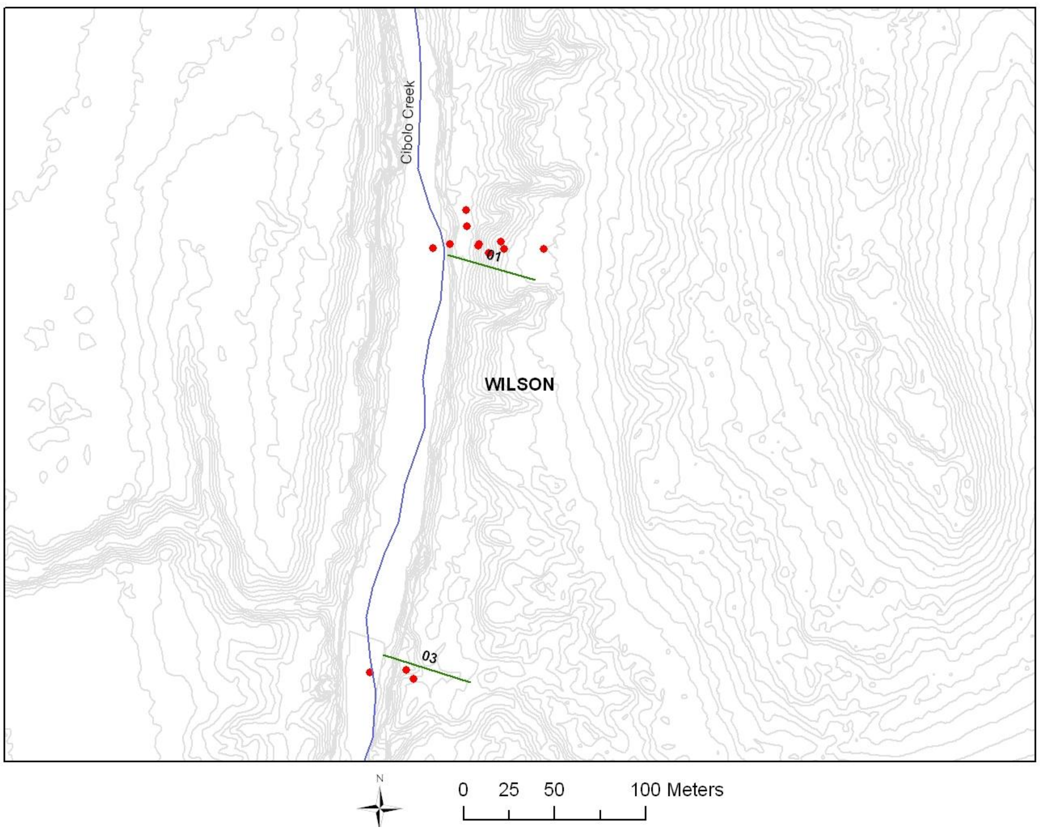


**Figure 2:** Location of two transects within the Cibolo Site

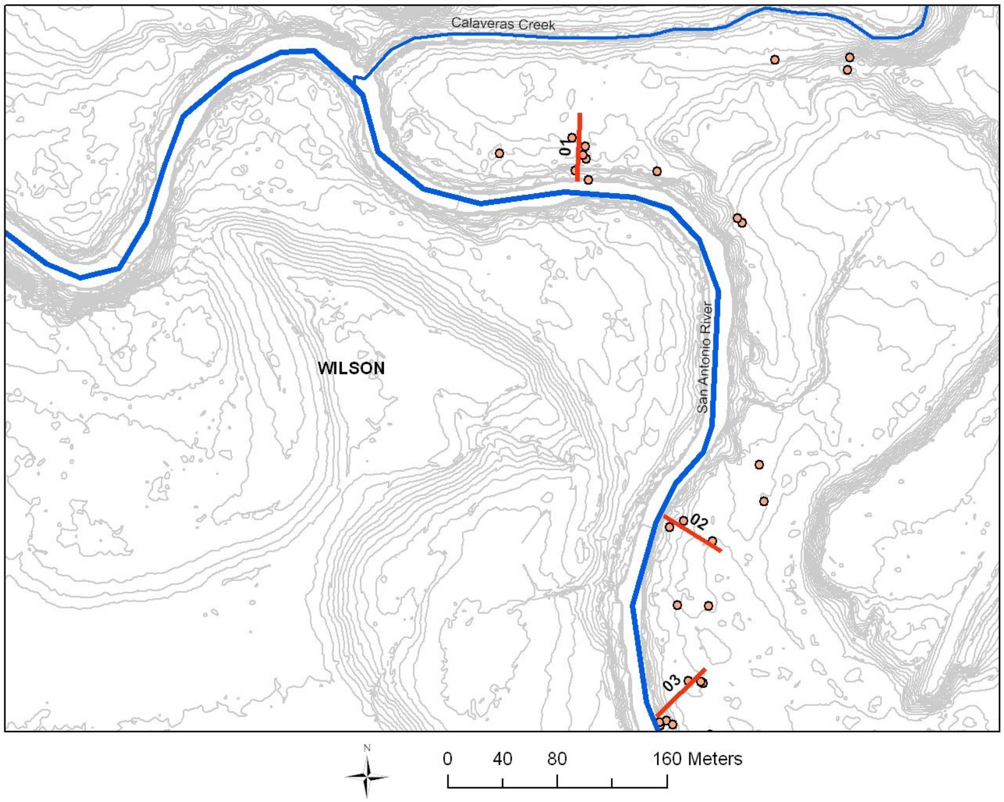


**Figure 3:** Location of three transects within the Calaveras Site

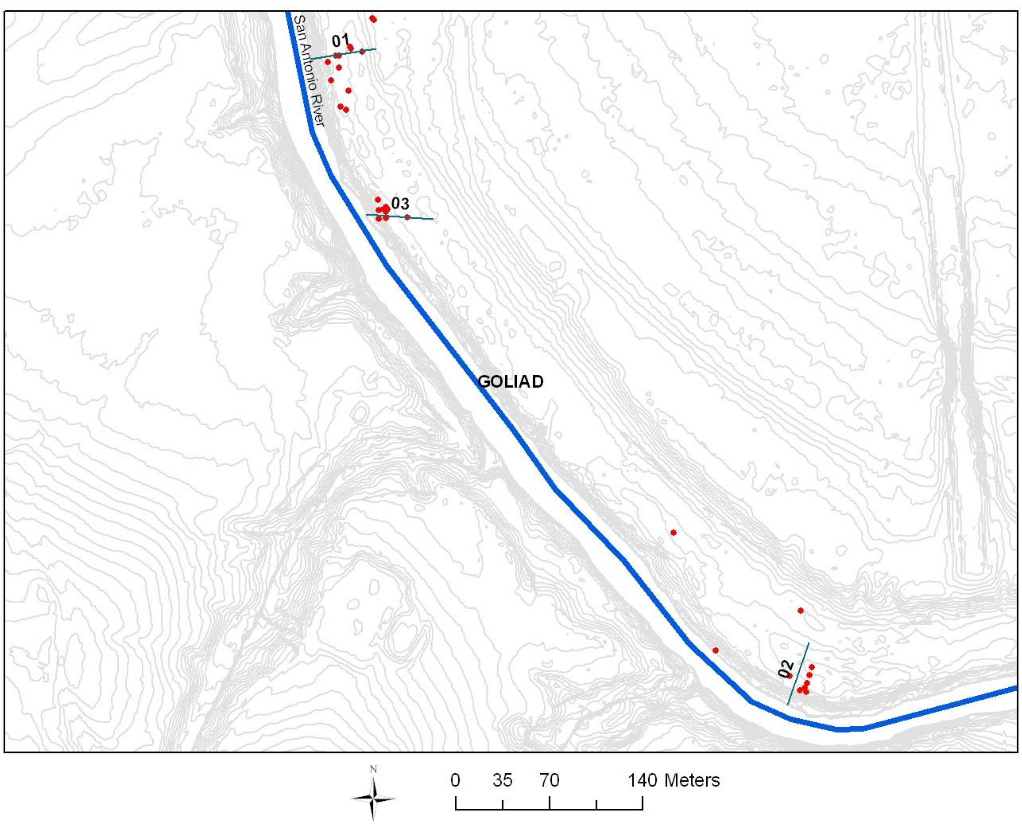


**Figure 4:** Location of three transects within the Goliad Site

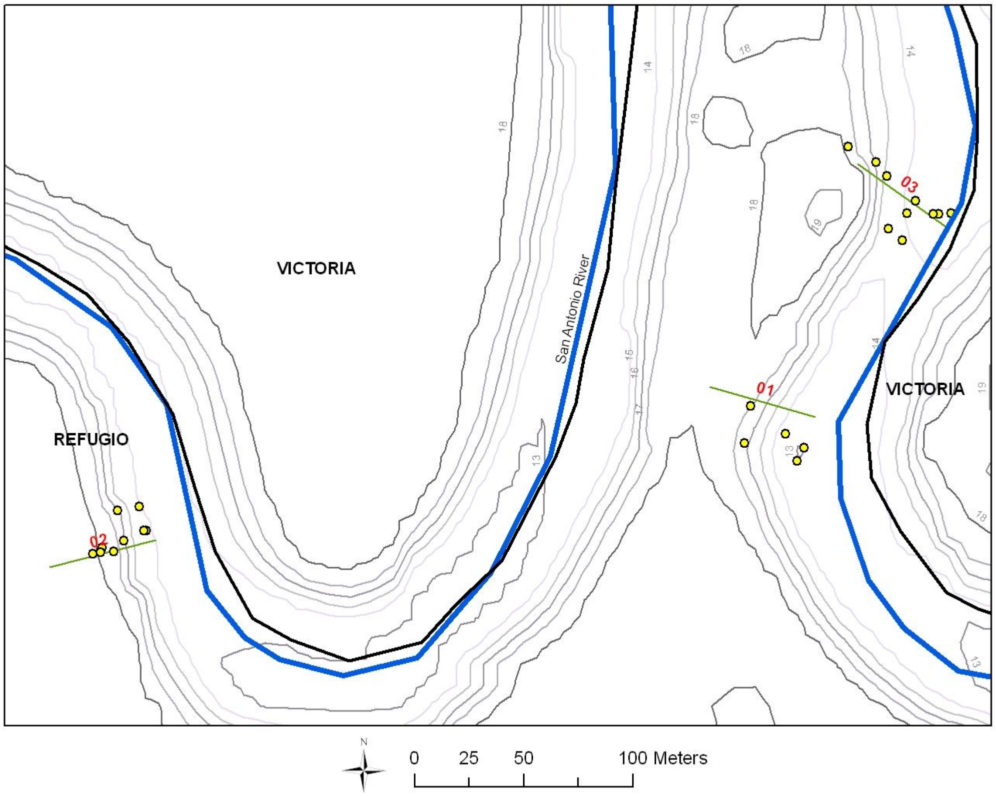


**Figure 5:** Location of three transects within the Hwy 77 Site.

Four Sites representing the Brazos River watershed were sampled, all along the Brazos River (See Fig. 6). The Snook Site actually consisted of two subsites, Snook 1 and Snook 2, which allowed for better spatial representation of the river continuum. Location of the sites, and their common references are given below:

1) Brazos Bend Site: located along the Brazos River, near Needleville, TX in Fort Bend County; inside Brazos Bend State Park property.
2) Hearne Site: located along the Brazos River, near Hearne, TX in Robertson County; on private property.
3) Marlin Site: located along the Brazos River, near Marlin, TX in Falls County; on private property.
4) Snook 1 Site: located along the Brazos River, near Snook, TX in Brazos County; on private property.
   Snook 2 Site: located along the Brazos River, near Navasota, TX in Waller County; on private property.

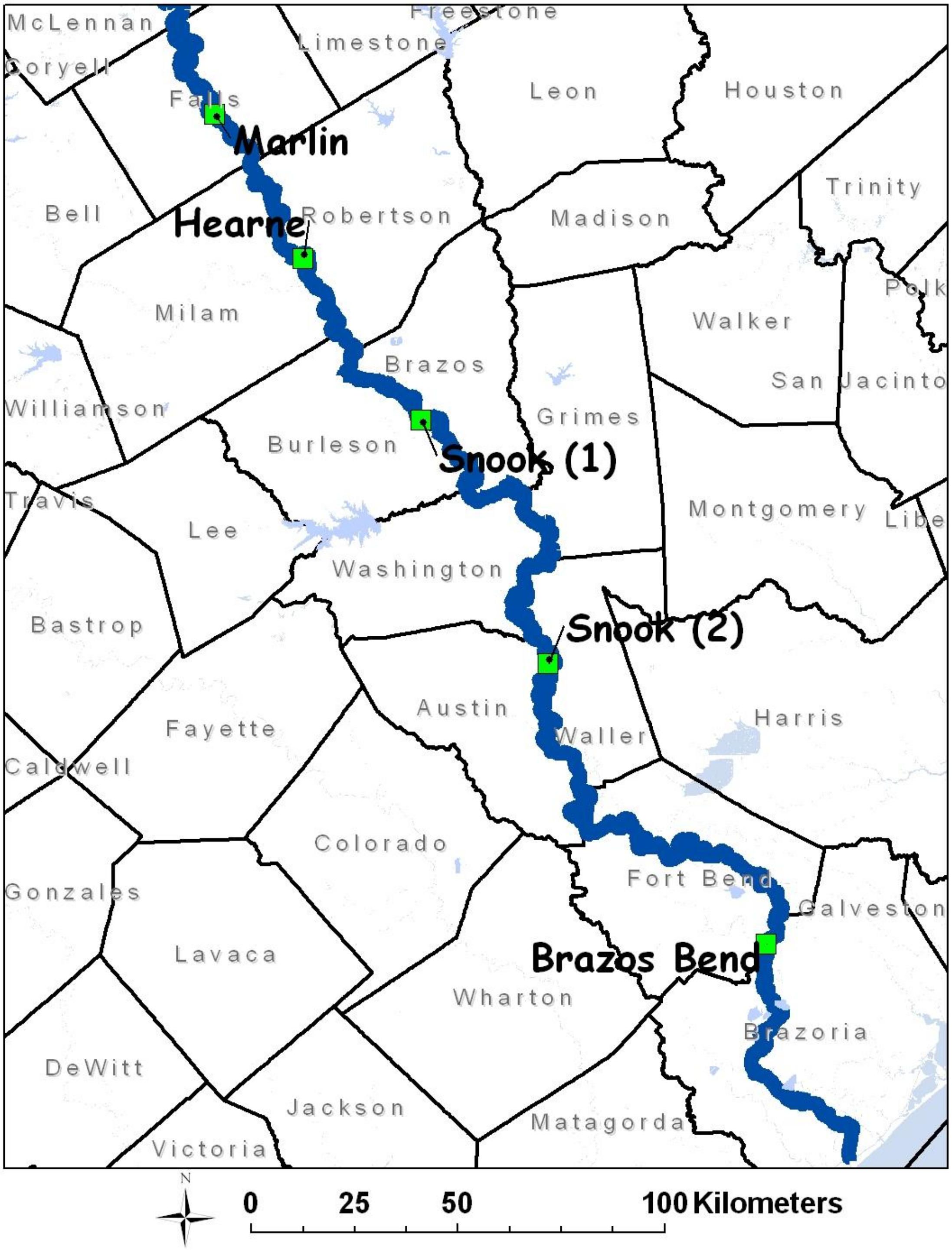


**FIGURE 6:** Location of the Brazos River Study Sites

Figures 7-10b show the location of 50+m transects within each of the four Brazos River sites above. Though the original study called for one transect per site and ~10 trees of the dominant species; to facilitate better characterization of riparian functioning, the number of transects for all sites was increased to three and the number of trees up to 30 trees.

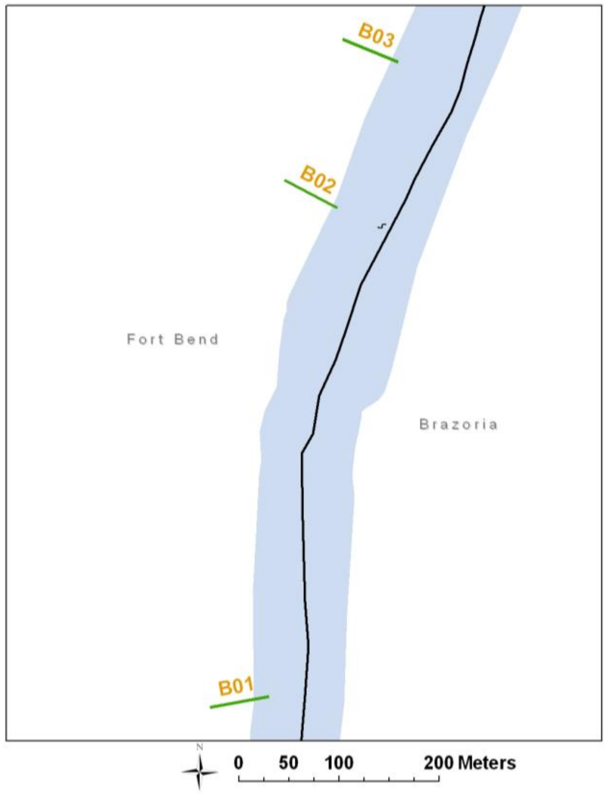


**Figure 7:** Location of three transects within the Brazos Bend Site.

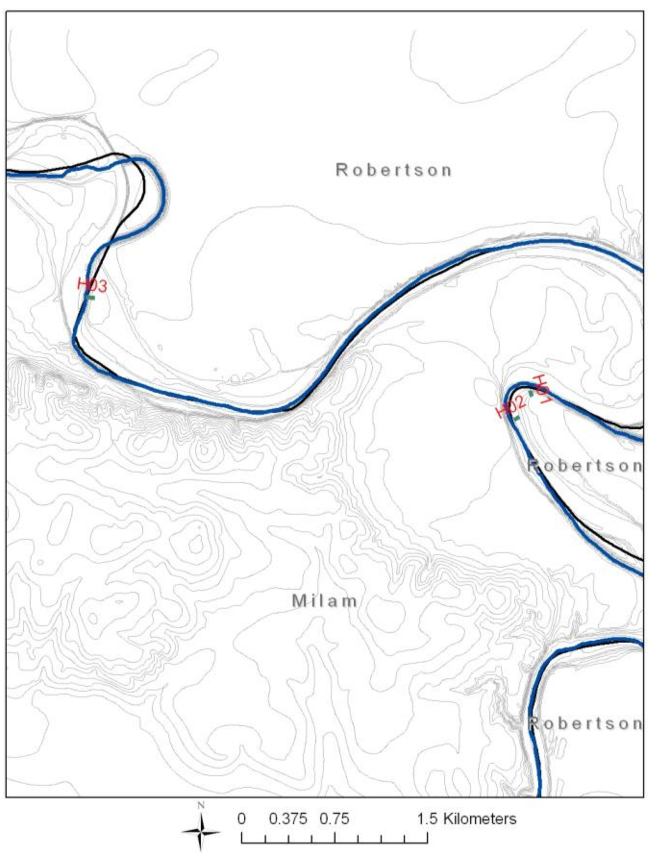


**Figure 8:** Location of three transects within the Hearne Site.

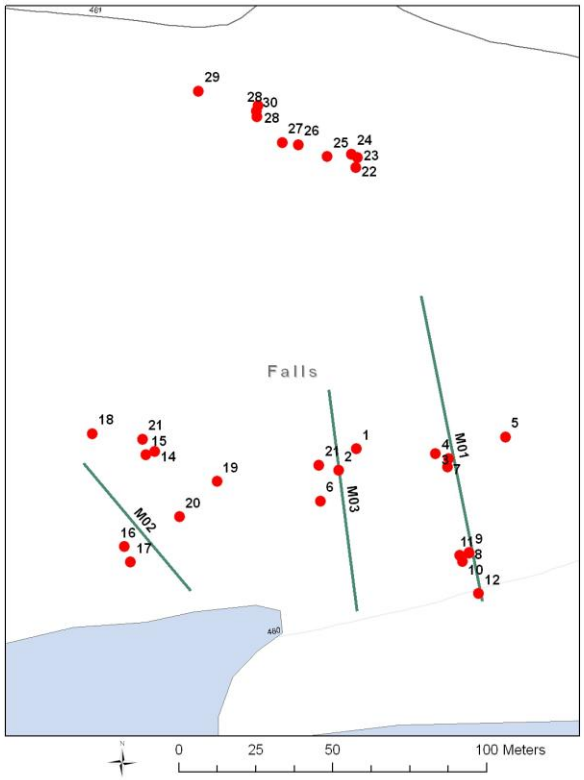


**Figure 9:** Location of three transects within the Marlin Site.

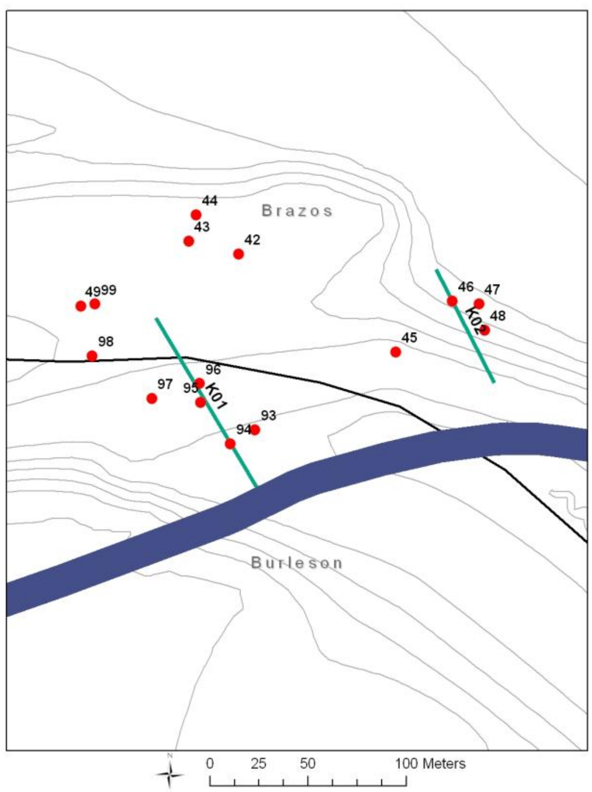


**Figure 10a:** Location of two transects within the Snook 1 Site.

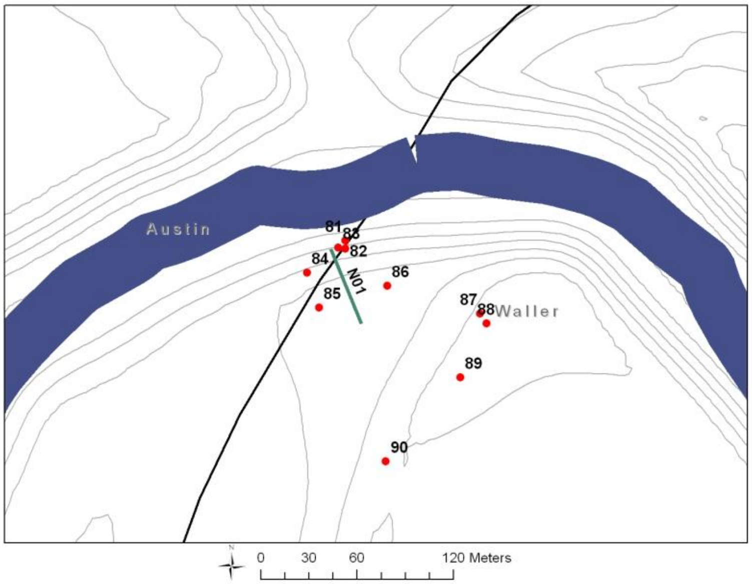

**Figure 10b:** Location of transect within the Snook 2 Site.

METHODS

## Field Sampling

### *Site Biodiversity*

For each site, 50m transects were laid perpendicular to one bank edge. A 5m width on each side of the transect (total of 10m) was used to count the total number of each woody species, according to its distance to the stream, at one meter increments. Each specimen was grouped according to its size:
1) seedling (less than 1cm stalk diameter)
2) sapling (1-5cm diameter at breast height (DBH))
3) mature (>5cm DBH). For this group DBH was recorded.

Percent composition (determined by the individual counts of a particular species as a percentage of the total number of trees) was determined for each transect, each overall site, and each river. General data about the riparian zone (overall channel width, steepness of slope, elevation, presence and type of understory vegetation along the channel slope) was recorded.

### *Saturated Soil Depth*

Along one of the transects for each site a hand soil auger was used at every 15m distance from the stream to determine the depth to hydric features, including general soil drainage class and depth to saturated soil water boundary. After initial sampling of the first site, it was determined that an additional recording at 5m would be more beneficial for determining water table depth in the near-channel area. The depth limitation of the soil auger was 4m, and it was assumed that a water table depth below this was outside the known range of most species in the zone, excepting those with the ability to readily form deep tap roots (see Table 7 for a list of rooting characteristics).

*Tree Coring*

Several species of the dominant riparian tree types from each plot were cored; up to 10 trees of each specie from each transect. As mentioned earlier data collection greatly exceeded initial proposal (for quality assurance purposes) and to allow for 1) better characterization of individual species responses and 2) selection of trees which best fit analysis (age, clear tree rings, etc.) For each tree, one core was extracted using a 5.1 mm Haglof increment borer. The increment borers were threaded into the tree at DBH or lower (when low branching prevented DBH penetration) to depth of the pith. The (5.1mm) tree core was extracted and the increment borer removed from the tree. Cores were temporarily stored in paper straws for drying and transport to the lab. Bore holes were immediately sprayed with pruning sealant, and trees were tagged with non-invasive metal tags attached via wire around a lower branch. Other measures (when specifically requested by property owners) included insertion of a wooden dowel with wood glue prior to spraying with pruning sealant. DBH, distance to stream and elevation were recorded (with a hand-held GPS unit).

**Stream Data Collection and Analysis**

USGS discharge data for the two rivers was downloaded from the USGS daily streamflow website (USGS, 2011). See Tables 2 and 11 for gage information. Stream height, along with surface elevations of the study site were used to estimate flooding inundation into the riparian zone. Monthly discharge data and stream elevation (when available) were determined to consider inundation into the floodplain**. Discharge data was used to determine the frequency and peak flow of floods for each growing season. A total number of flood days (individually determined for each gage) was determined for two longterm periods: 1960-1984 and 1985-2009 for each of the gages. The influence of high active channel flows was estimated for impact on soil water table depth. Select discharges (representing various high and low flow stages) were also considered for analysis of tree response.

**Biodiversity Analysis**

*GIS*

Geographic Information System (GIS) software and data were used to supplement, calibrate, and validate field recordings. Accuracy of transect elevation changes and cored trees within the study area as well as distance of cored trees (in cases when field data couldn't be assessed) were determined via GIS. Geospatial data included county and city boundaries, the National Elevation Dataset (NED), and hydrography databases. The primary datasets used in this study (Table 1) were either defined or reprojected to Stateplane Texas South Central 4204 foot coordinate system (North American Datum 1983). ESRI® ArcGIS 9.3 (Environmental

Systems Research Institute, Redlands, California) were used to modify these data for use in analyses and for creating maps of an overall map of each river showing the 4 sampling sites along Cibolo Creek and the San Antonio and Brazos Rivers, as well as maps of each individual site showing the location of each transect and plotting the cored trees.

Transects were mapped in ArcMap using GPSed coordinates, and elevation data from nearest contour interval was extrapolated at 1 m interval spacing. NED 1/9 Arc-Second (~ 3 m resolution), converted to 2 ft contours using LIDAR data was used for the upper three SA River sites. Because LIDAR data was not available for the Hwy 77 site, 1/9 arc-second NED data were downloaded from USGS and used to create 2 foot contour intervals with the Spatial Analyst extension for ArcMap (ESRI). The 50 points along each transect were then joined to the elevation data for each transect and exported to Excel for use in further analysis. For the Brazos River, no such data existed, so more detailed GPS data were taken in-field and calibration/verification included using DEM data for the sites. Elevations for each cored tree were obtained using the same method employed in transect elevations, for comparison to field GPS data. Distance of cored trees to the upper bank/bank full width were measured.

| Data | Source | Resolution |
|---|---|---|
| Political boundaries (City and County) | The Strategic Mapping Program (StratMap): Texas Natural Resource Information System (TNRIS) | 1:24,000 |
| Streams and Rivers | Flowlines from the National Hydrography Dataset (NHD): U.S. Geological Survey (USGS) | 1:24,000 |
| Soils | SSURGO Soil Classes | 1:24,000 |
| Elevation : | | |
| RASTER (DEM) Refugio County | National Elevation Dataset (NED-USGS) | 1/9 arc-second (~3m) cell size |
| VECTOR(Contours) Other Counties | Texas Water Development Board | 2 ft contour intervals |

**Table 1:** Source and Description of Geodatabases

*Species' Ranges*

Species ranges (distance and elevation) for each of the top 6-7 genera were calculated, according to the three age classes: seedlings, sapling and mature; though in some sites, less than six species were found.

*Mature Tree Stand Ages*

Age classes for dominant trees were estimated using a multiplication factor for each species based on cored tree data (see Table 3). Though these multiplication factors are a general estimate of age on the limited dataset from this study, and are river-specific, the information is valuable for being able to relate general tree community age distributions to past river conditions.

**Tree Core Analysis**

Once fully dried, cores were mounted to wooden bases, sanded with 1200 grit sandpaper and annual basal increments (BI) (mm/yr) were measured for each tree, dating back to pith of the tree, using a Velmex staging system and Measure J2X software. To ensure proper dating/measurements and correct for discrepancies each core was read in triplet by three different individuals.

*Relationship to Stream Flow*

Tree productivity (BI) was compared to river flow using a number of parameters (select flood events *vs* BI, growing season *vs* BI, total annual flow *vs* BI) to determine the best method for gauging riparian responses, and total annual flow *vs* BI was found to be both most useful and most consistent between species. When individual trees from a specie were comparable in age, yearly tree rings for all trees were averaged and the stand response for that specie was measured against total annual discharge. If tree age was considerably different then the youngest tree(s) would be excluded to prevent young-stand rapid growth from obscuring river/productivity relationships of the overall stand.

*Relationship to Water Table Depth*

Water table depths at 15m intervals were compared against tree ranges for dominant species to determine relationships between depth to saturated soil and spatial location for each species.

# Chapter 2
# San Antonio River

RIVER FLOW

Table 2 shows the USGS gauging stations used for comparison to tree ring growth, and the sites to which each gauge correlated. The length of recorded discharge and elevation data are indicated for each site.

| USGS # | Location | Discharge Data | Gage Height | Correlates to Site(s) |
|---|---|---|---|---|
| 8186000 | Cibolo Ck nr Falls City | 1925-2009 | 2005-2009 | Cibolo Creek |
| 8188500 | SA at Goliad | 1924-2009 | 1990-2009 | Calavares and Goliad |
| 8181800 | SA nr Elmendorf | 1962-2009 | 1986-2009 | Hwy 77 near McFaddin |

**Table 2:** USGS Gauging Stations for the San Antonio River

The annual discharge for USGS Gage #08186000 from 1930 to 2009 is shown in Figure 11. Latitude for this station is 29°00'50", longitude is97°55'48", and the gage datum is 80.56m above sea level. It is located in Karnes County, TX and has a drainage area of 2142 $km^2$.

Prior to 1970 total annual flows rarely exceeded 0.30 $km^3$/y, but since 1970 seven years have exceeded it. Additionally, five years since 1970 have had a total discharge in excess of 0.38 $km^3$/y, four of those post-1990.

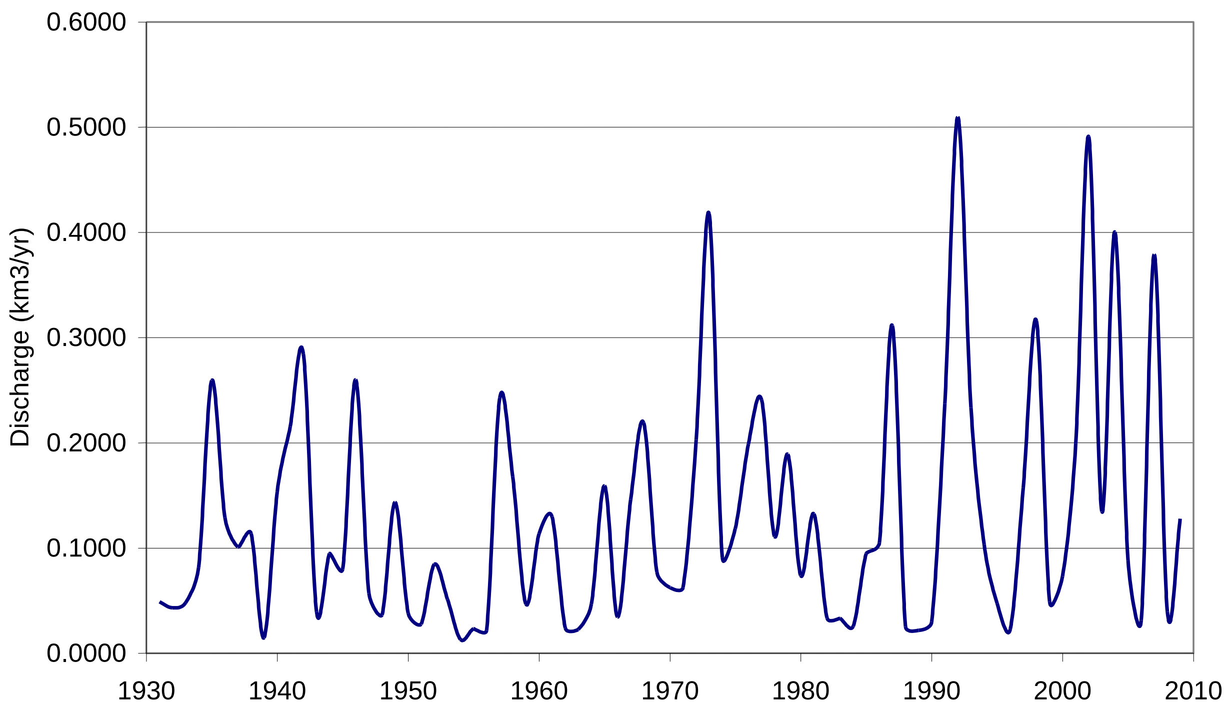


**Figure 11:** USGS Gage #8186000

Figure 12 shows the comparison of the Cibolo Creek daily discharge to elevation height. Because gage height elevation records extend back only to 2005, this relationship was used to create the mathematical formula for generating elevation estimates pre-2005. Excluded from the trend were the outliers at 35m corresponding to very low discharge (which appear to be obvious recorder mis-readings.

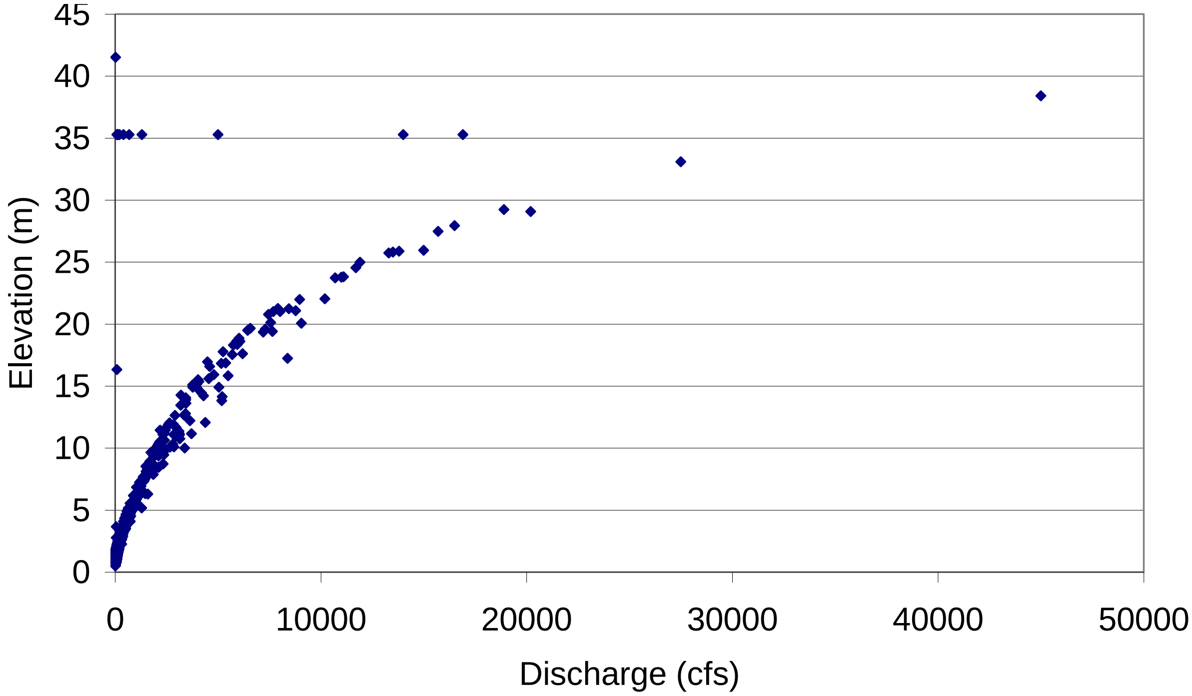


**Figure 12:** Cibolo Creek correlation between river discharge and gage elevation.

Figures 13a–d show the monthly average gage height elevations, grouped into 20 yr increments, from 1931 to 2009 respectively. Prior to 1970 only one flood event, in 1968, caused the monthly average to exceed a height of 2.5m. Post-1970 10 months averaged this height. Post-1990 four months averaged almost 4m height.

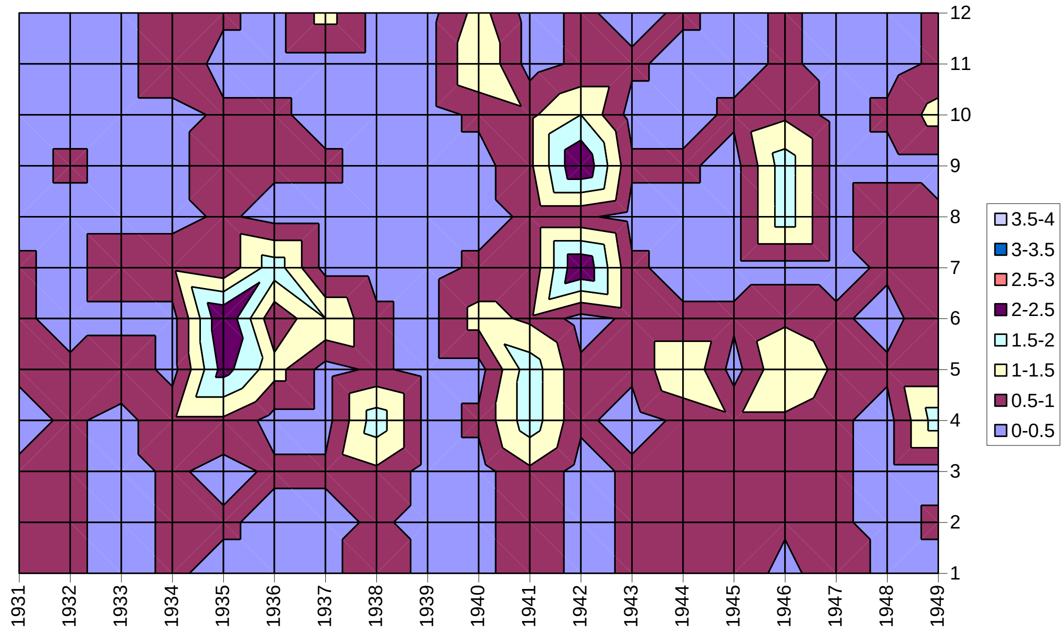


**Figure 13a:** Cibolo Creek monthly elevation surface map from 1931-1949. Months are represented numerically and elevation is in meters.

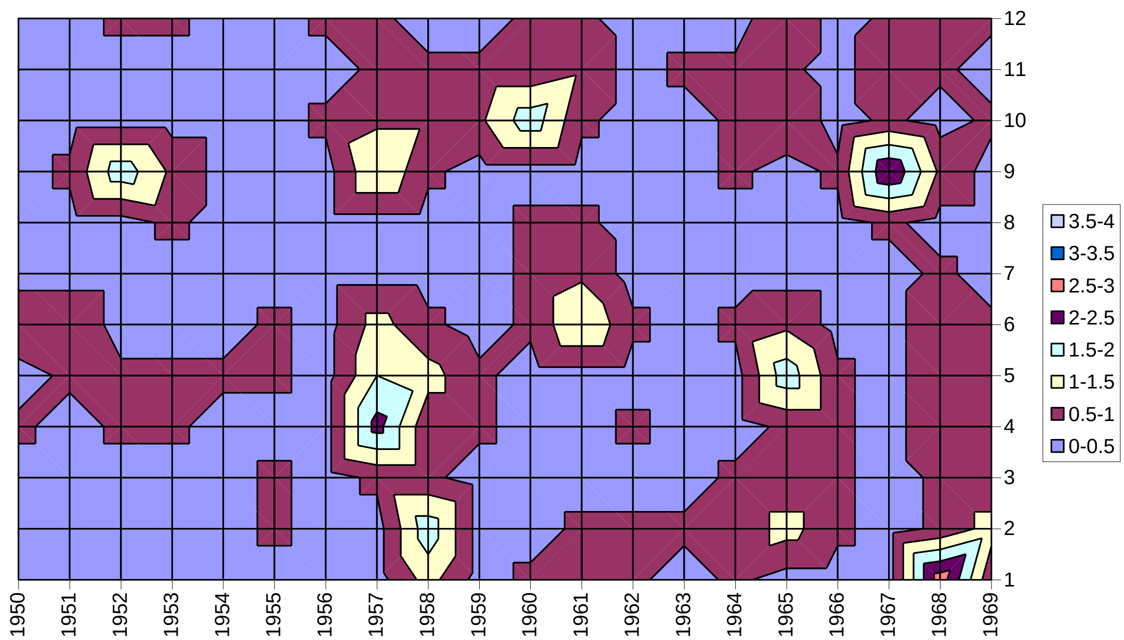


**Figure 13b:** Cibolo Creek monthly elevation surface map from 1950-1969. Months are represented numerically and elevation is in meters.

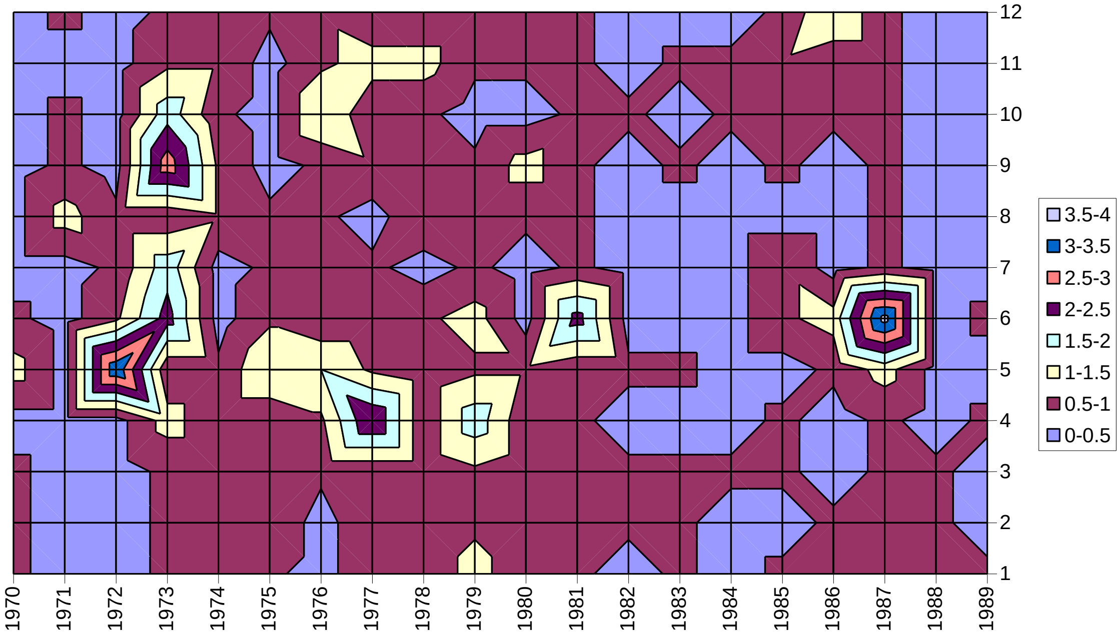


**Figure 13c:** Cibolo Creek monthly elevation surface map from 1970-1989. Months are represented numerically and elevation is in meters.

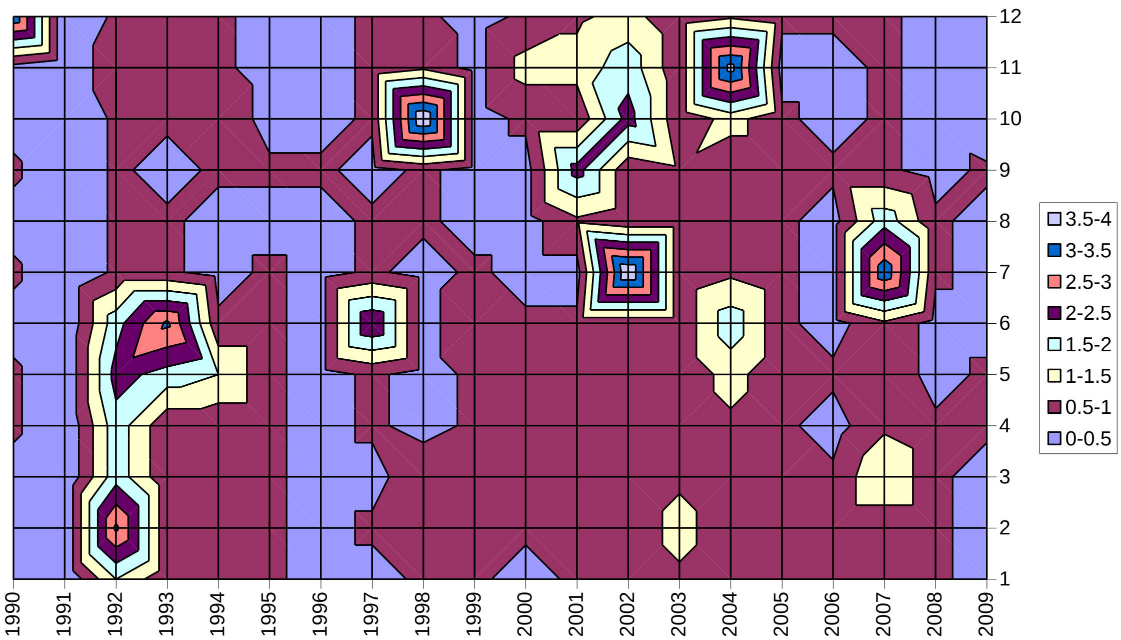


**Figure 13d:** Cibolo Creek monthly elevation surface map from 1990-2009. Months are represented numerically and elevation is in meters.

Annual discharge for USGS Gage #08188500 from 1938 to 2009 is shown in Figure 14. Latitude for this station is 28°38'57.43", longitude is 97°23'05.49", and the gage datum is 27.76m above sea level. It is located in Goliad County, TX and has a drainage area of 10,155 $km^2$. Prior to 1985 total annual flows exceeded 0.13 $km^3/y$ only once (in 1972), but since 1986 five years have exceeded that amount.

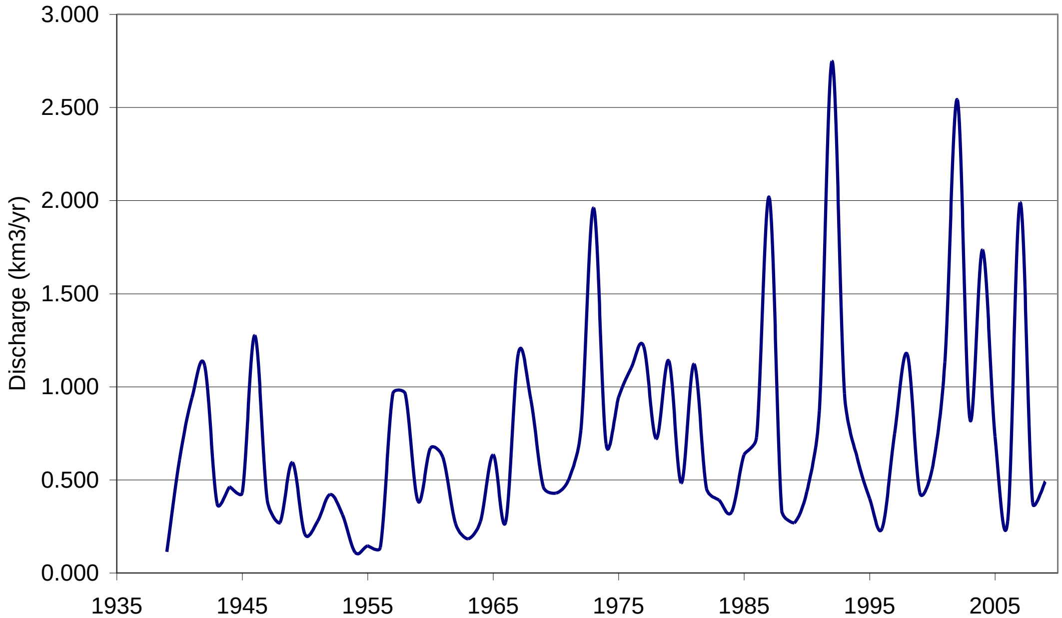


**Figure 14:** USGS Gage #8188500

Figure 15 shows the comparison of SA River at Goliad daily discharge to elevation height. Because gauge height elevation records extend back only to 1990, this relationship was used to create the mathematical formula for generating elevation estimates pre-1990.

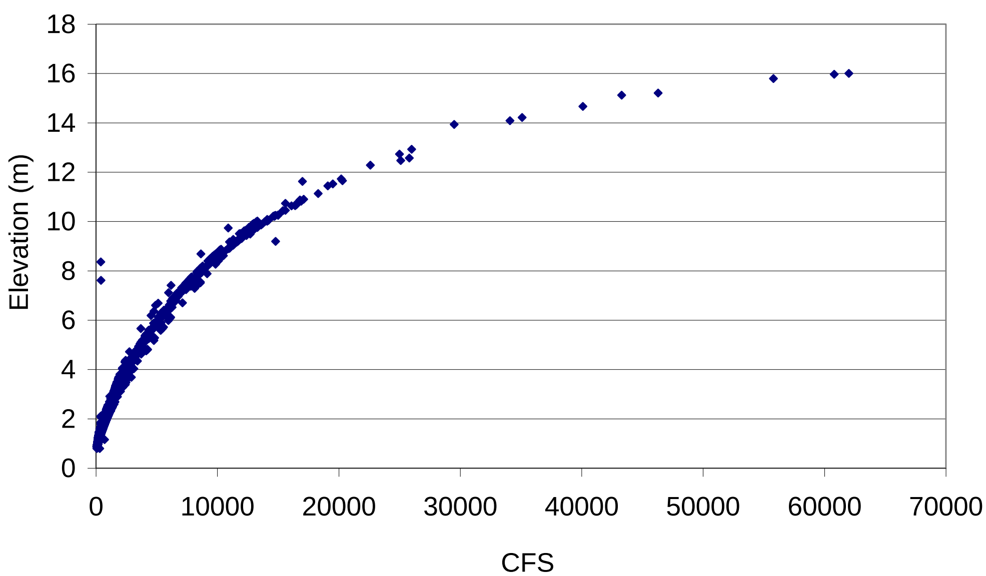


**Figure 15:** Flow vs. Elevation – San Antonio River at Goliad

Figures 16a – c show the average monthly gage height elevation, grouped into 20-yr increments, from 1950 to 2009 respectively, and illustrate that large flood events resulted in monthly average gage elevations in excess of 6m, some as great as 10-11m for the months in which those events occurred.

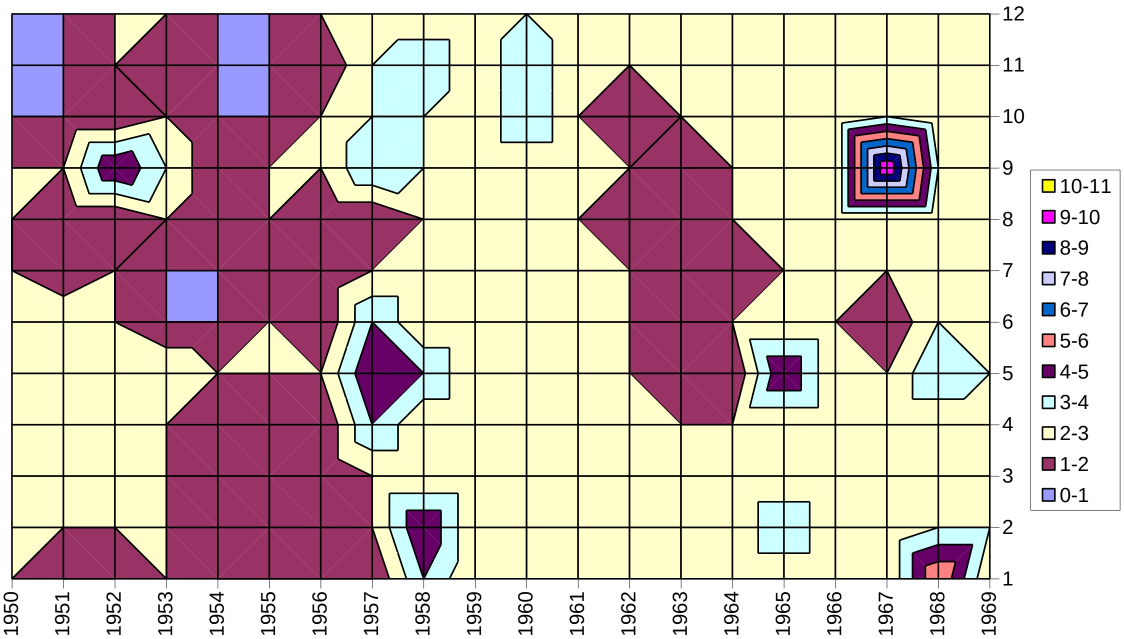


**Figure 16a:** SA River at Goliad monthly elevation surface map from 1950-1969. Months are represented numerically and elevation is in meters.

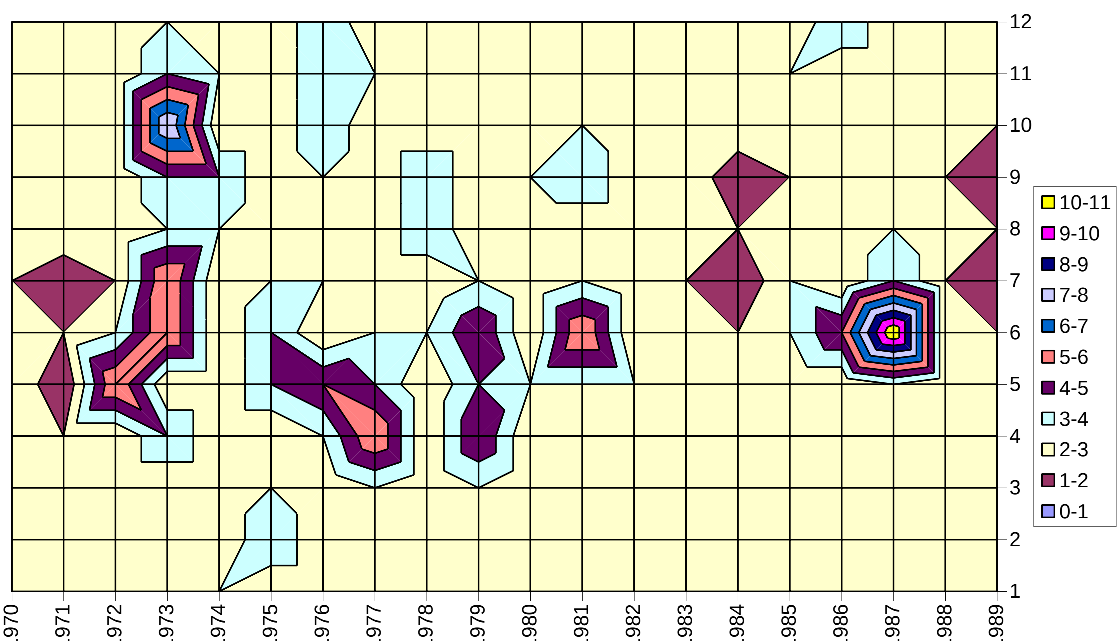


**Figure 16b:** SA River at Goliad monthly elevation surface map from 1970-1989. Months are represented numerically and elevation is in meters.

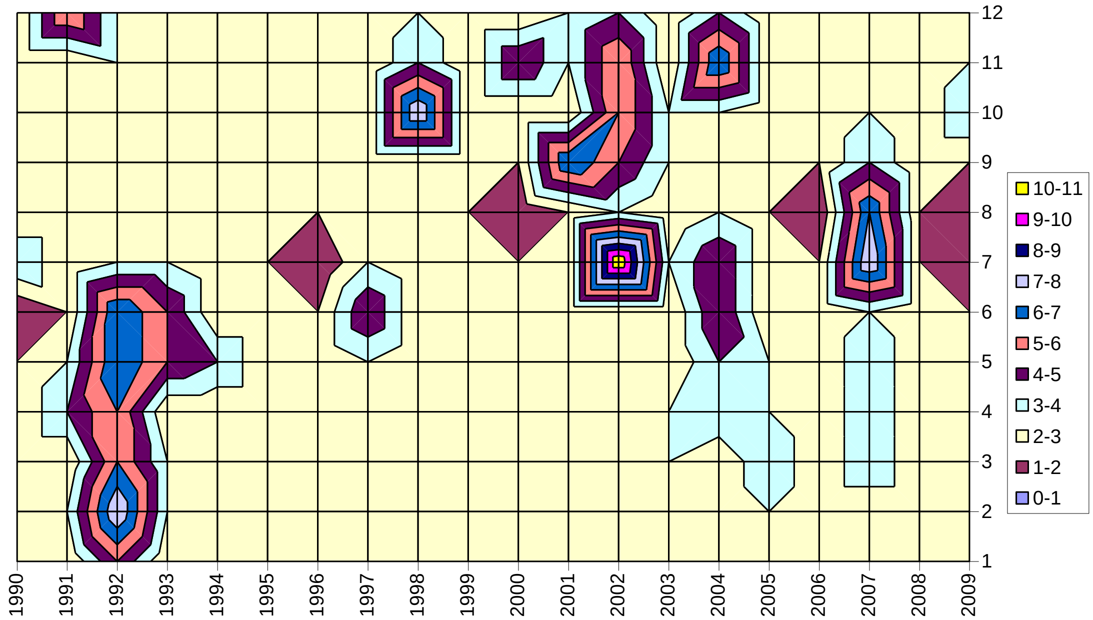


**Figure 16c:** SA River at Goliad monthly elevation surface map from 1990-2009. Months are represented numerically and elevation is in meters.

The annual discharge for USGS Gage #08181800 from 1962 to 2009 is shown in Figure 17. Latitude for this station is 29°13'19", longitude is 98°21'20", and the gage datum is 115.8m above sea level. It is located in Bexar County, TX and has a drainage area of 4514 km$^2$.Prior to 1985 only one year exceeded >1.0km$^3$/y (1972). Post-1985 five years did so, one (2002) in excess of 1.75 km$^3$/y.

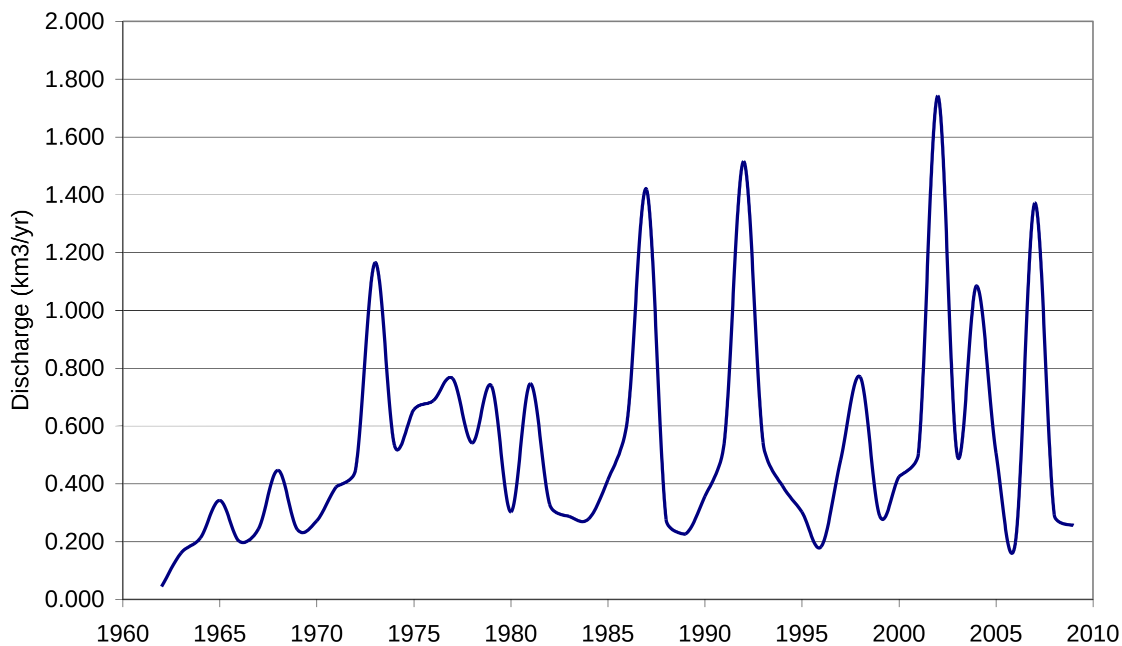


**Figure 17:** USGS Gage #8181800 Total Annual Discharge

Figure 18 shows the comparison of SA River near Elmendorf daily discharge to elevation height. Because gage height elevation records extend back only to 1986, this relationship was used to create the mathematical formula for generating elevation estimates pre-1986.

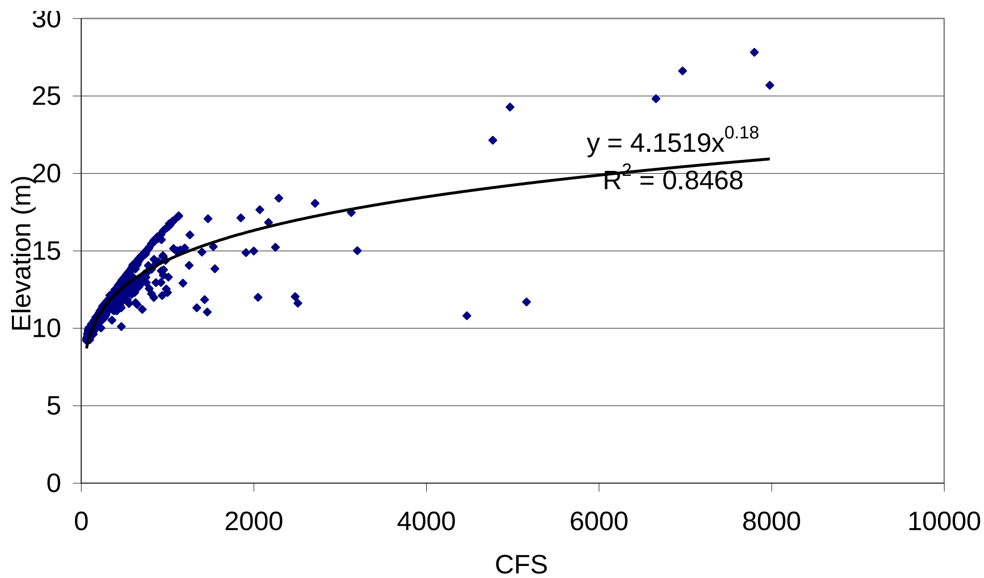


**Figure 18:** Flow vs Elevation for SA River Near Elmendorf

Figures 19a and b show the monthly average gage height elevation from 1970 to 2009, grouped into 20 yr increments, and show that large flood events averaged monthly gage heights of 6-8m.

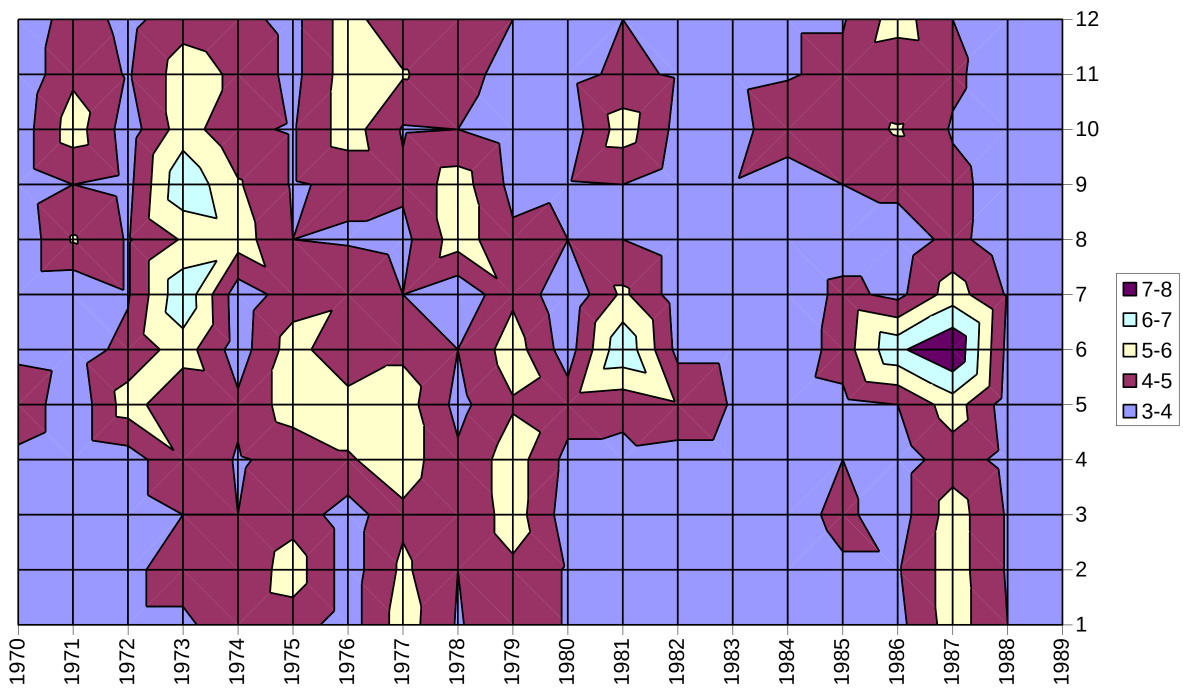


**Figure 19a:** SA River near Elmendorf monthly elevation surface map from 1970-1989. Months are represented numerically and elevation is in meters.

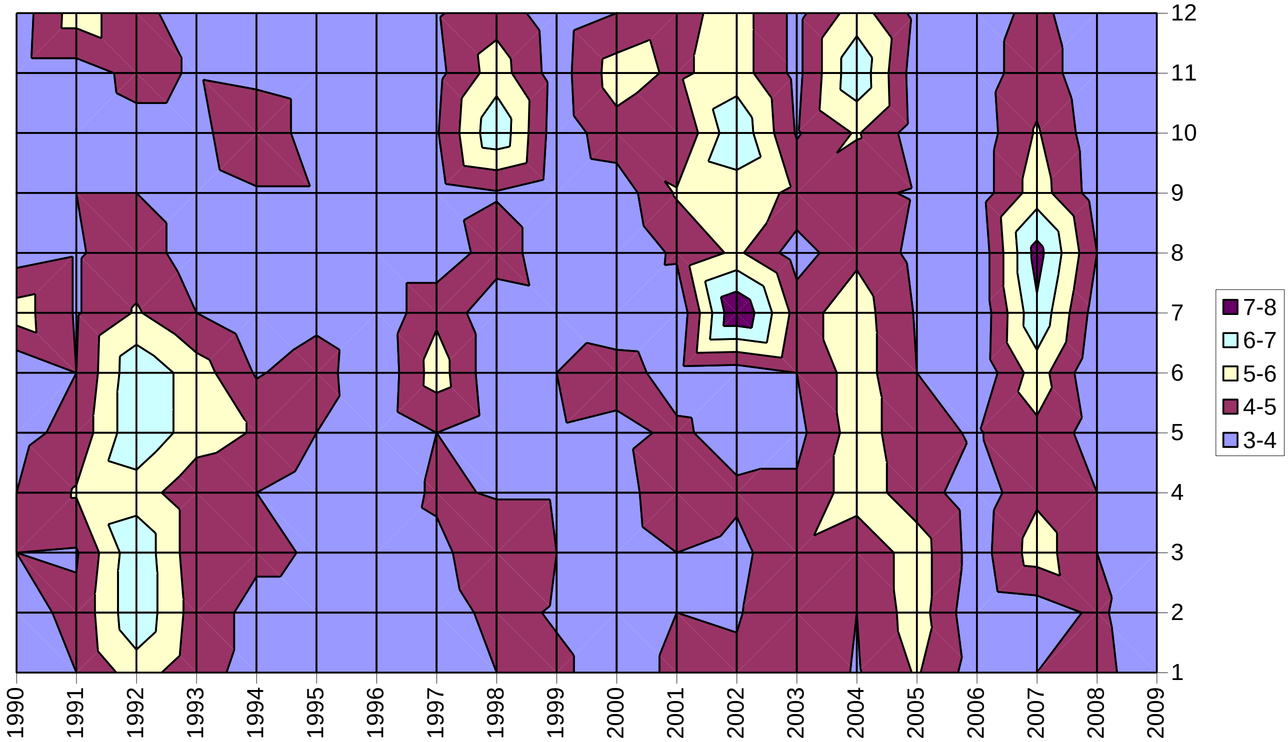


**Figure 19b:** SA River near Elmendorf monthly elevation surface map from 1990-2009. Months are represented numerically and elevation is in meters.

Figures 11 through 19b indicate that clearly the San Antonio River and Cibolo Creek are undergoing marked changes to their flow regimes. Not only are flood events becoming more frequent, but their seasonal patterns are shifting to include more winter months and their overall discharge rates are increasing, causing water to persist further into the floodplains. While some of this change may be explained because of increased pumping from the Edwards Aquifer at the headwaters of the San Antonio River, not all changes would be the effect of such (e.g. seasonal flooding alterations or increases along Cibolo Creek). However, such practices appear to be magnifying other climatic changes the river may be undergoing. Regardless, these increases in water have the potential not only to increase down cutting along the river, but also alter the riparian ecosystem along its banks. Discussions of such will be included below.

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Shown in Table 3 are the four sampled sites, their sample dates, and river discharge and USGS flood stage on the sample date (refer to Table 2 for corresponding USGS gages). The bank-bank distance for each transect represents the top of the channel bank, determined as where channel slope sharply decreased/became more horizontal. The channel height indicates the vertical distance to the top of the channel, and channel angle represents the degree of rise from water's edge to top of the channel. Most sites, though steeply sloped, had understory coverage along the channel slope. Overall, Goliad and Calaveras sites were less diverse than the other two sites. While no apparent explanation is known for Goliad, the Calaveras site has been heavily maintained for distances greater than ~20m distance to the stream. Recent mowing of much of the flood plain appears to be a normal routine – likely to continue as San Antonio River Authority (SARA) personnel indicate plans for a park along the river are in progress.

| Site Name | Trans # | Bank-Bank Dist (m) | Channel Ht (m) | Angle (deg) | Dominant Understory Along Channel Slope | Sample Date | Gauge Elev (m) | Dischg CFS | Flood Stg (m) |
|---|---|---|---|---|---|---|---|---|---|
| Calaveras | | | | | | | | | |
| | 1 | 39 | 5.5 | 17.9 | *Ambrosia trifida* | 6/15/10 | 1.9 | 774 | 7.7 |
| | 2 | 35 | 5.5 | 20.1 | *Ambrosia trifida* | 6/15/10 | 1.9 | 774 | 7.7 |
| | 3 | 28 | 6.2 | 20 | *Ambrosia trifida* | 6/15/10 | 1.9 | 774 | 7.7 |
| Cibolo Creek | | | | | | | | | |
| | 1 | 45 | 5 | 16.4 | Very little/no understory | 6/10/10 | 0.4 | 75.0 | 5.2 |
| | 2 | 44 | 5 | 12.8 | *Toxicodendron radicans* | 6/10/10 | 0.4 | 75.0 | 5.2 |
| Goliad | | | | | | | | | |
| | 1 | 54 | 6.7 | 31.3 | *Ambrosia trifida* | 5/26/10 | 2.1 | 946 | 7.7 |
| | 2 | 40 | 5.6 | 19.3 | *Ambrosia trifida* | 5/26/10 | 2.1 | 946 | 7.7 |
| | 3 | 49 | 6.1 | 25.1 | *Ambrosia trifida* | 5/27/10 | 2.1 | 946 | 7.7 |
| Hwy 77 | | | | | | | | | |
| | 1 | 35 | 7 | 13.6 | *Toxicodendron radicans* | 6/14/10 | 3.8 | 490 | 10.8 |
| | 2 | 44 | 8 | 17.1 | Very little/no understory | 6/14/10 | 3.8 | 490 | 10.8 |
| | 3 | 42 | 5 | 16.4 | *S. nigra* seed/saplings | 6/14/10 | 3.8 | 490 | 10.8 |

**Table 3:** San Antonio River Sites and their general characteristics

## Percent Composition

The percent composition for all seedlings are shown in Table 4. *U. crassifolia* was the dominant seedling for Cibolo, Calaveras, Hwy 77 and for all sites combined. It was second most common at Goliad, behind *C. laevigata*, which was second most dominant for most other sites and for all sites combined. Three other dominant species overall were *S. nigra*, *A. negundo* and *F. pennsylvanica*. The Goliad site had no seedlings present for *S. nigra*, *A. negundo* or *F. pennsylvanica*. The Calaveras site, while lacking seedlings for *A. negundo* and *F. pennsylvanica* did have several *S. nigra* seedlings.

**Seedlings**

| Tree | Cibolo Count | Cibolo % | Goliad Count | Goliad % | Calaveras Count | Calaveras % | Hwy 77 Count | Hwy 77 % | All Sites Count | All Sites % |
|---|---|---|---|---|---|---|---|---|---|---|
| *Acer negundo* | 6 | 1.0 | 0 | 0.0 | 9 | 2.3 | 95 | 12.4 | 110 | 3.89 |
| *Bumelia lycioides* | 1 | 0.2 | | 0.0 | | 0.0 | | 0.0 | 1 | 0.04 |
| *Carya illinoiensis* | | 0.0 | 1 | 0.1 | 89 | 22.5 | 3 | 0.4 | 93 | 3.29 |
| *Celtis laevigata* | 128 | 21.5 | 726 | 67.4 | 116 | 29.4 | 79 | 10.3 | 1049 | 37.05 |
| *Cornus drummondii* | | 0.0 | | 0.0 | | 0.0 | 3 | 0.4 | 3 | 0.11 |
| *Diospyros virginiana* | 1 | 0.2 | | 0.0 | | 0.0 | | 0.0 | 1 | 0.04 |
| *Ehretia anaqua* | | 0.0 | | 0.0 | | 0.0 | 42 | 5.5 | 42 | 1.48 |
| *Fraxinus pennsylvanica* | 5 | 0.8 | | 0.0 | 2 | 0.5 | 86 | 11.2 | 93 | 3.29 |
| *Ilex vomitoria* | 1 | 0.2 | | 0.0 | | 0.0 | | 0.0 | 1 | 0.04 |
| *Populus deltoides* | | 0.0 | | 0.0 | 2 | 0.5 | | 0.0 | 2 | 0.07 |
| *Ptelea trifoliate* | | 0.0 | 1 | 0.1 | | 0.0 | | 0.0 | 1 | 0.04 |
| *Quercus macrocarpa* | | 0.0 | | 0.0 | | 0.0 | 2 | 0.3 | 2 | 0.07 |
| *Salix nigra* | | 0.0 | | 0.0 | 146 | 37.0 | 26 | 3.4 | 172 | 6.08 |
| *Sapium sebiferum* | | 0.0 | | 0.0 | | 0.0 | 4 | 0.5 | 4 | 0.14 |
| *Ulmus crassifolia* | 437 | 73.6 | 349 | 32.4 | 31 | 7.8 | 424 | 55.4 | 1241 | 43.84 |
| *Ulmus fulva* | 8 | 1.3 | | 0.0 | | 0.0 | 1 | 0.1 | 9 | 0.32 |
| *Unknown* | 7 | 1.2 | | 0.0 | | 0.0 | | 0.0 | 7 | 0.25 |
| **Total** | **594** | | **1077** | | **395** | | **765** | | **2831** | |

**Table 4:** Percent Compositions for Seedlings at each site and all sites combined.

The percent compositions for all saplings are shown in Table 5. *A. negundo* was the most common sapling for all sites combined, followed by *C. laevigata* and *S. nigra*. Calaveras site was less diverse; again, likely because of general maintenance along the river; however saplings were present, if not abundant, for all major dominant species. Saplings along Goliad show that even though few seedlings were present, generally recruitment has been strong in recent years.

**Saplings**

| Tree | Cibolo Count | Cibolo % | Goliad Count | Goliad % | Calaveras Count | Calaveras % | Hwy 77 Count | Hwy 77 % | All Sites Count | All Sites % |
|---|---|---|---|---|---|---|---|---|---|---|
| *Acer negundo* | 72 | 31.7 | 6 | 7.0 | 87 | 41.4 | 13 | 31.0 | 178 | 31.5 |
| *Carya illinoiensis* | | 0.0 | | 0.0 | 2 | 1.0 | 1 | 2.4 | 3 | 0.5 |
| *Celtis laevigata* | 81 | 35.7 | 9 | 10.5 | 60 | 28.6 | 3 | 7.1 | 153 | 27.1 |
| *Cornus drummondii* | | 0.0 | | 0.0 | | 0.0 | 4 | 9.5 | 4 | 0.7 |
| *Ehretia anaqua* | | 0.0 | | 0.0 | | 0.0 | 8 | 19.0 | 8 | 1.4 |
| *Fraxinus pennsylvanica* | 1 | 0.4 | 5 | 5.8 | 3 | 1.4 | 4 | 9.5 | 13 | 2.3 |
| *Fraxinus texensis* | | 0.0 | 7 | 8.1 | | 0.0 | | 0.0 | 7 | 1.2 |
| *Morus alba* | | 0.0 | 2 | 2.3 | | 0.0 | | 0.0 | 2 | 0.4 |
| *Myrica cerifera* | 9 | 4.0 | 0 | 0.0 | | 0.0 | | 0.0 | 9 | 1.6 |
| *Platanus occidentalis* | | 0.0 | 12 | 14.0 | | 0.0 | | 0.0 | 12 | 2.1 |
| *Populus deltoides* | | 0.0 | | 0.0 | 1 | 0.5 | | 0.0 | 1 | 0.2 |
| *Salix nigra* | 15 | 6.6 | 26 | 30.2 | 57 | 27.1 | 1 | 2.4 | 99 | 17.5 |
| *Sapium sebiferum* | | 0.0 | | 0.0 | | 0.0 | 2 | 4.8 | 2 | 0.4 |
| *Ulmus crassifolia* | 33 | 14.5 | 19 | 22.1 | | 0.0 | 6 | 14.3 | 58 | 10.3 |
| *Ulmus fulva* | 2 | 0.9 | | 0.0 | | 0.0 | | 0.0 | 2 | 0.4 |
| *Ungnadia speciosa* | 3 | 1.3 | | 0.0 | | 0.0 | | 0.0 | 3 | 0.5 |
| *Unknown* | 11 | 4.8 | | 0.0 | | 0.0 | | 0.0 | 11 | 1.9 |
| Total | **227** | | **86** | | **210** | | **42** | | **565** | |

**Table 5:** Percent Compositions for Saplings at each site and all sites combined.

The percent compositions for all mature trees are shown in Table 6. Most dominant among all sites combined were *C. laevigata, A. negundo, U. crassifolia,* and *S. nigra*, respectively. These four species were also the dominant four species in Cibolo and Hwy 77, as well as Calaveras with the exception of *P. deltoides*. Goliad had *C. illinoinensis* as one of its top four species and was lacking mature trees of both *S. nigra* and *U. crassifolia*. One note: though not encountered in the sampled transects, members of both species *were* observationally observed in the area.

The only *P. deltoides* encountered (both experimentally and observationally) were a single young stand along the Calaveras site. In discussions with SARA personnel regarding the observation that several of the trunks had been recently burned by a fire, it was mentioned that a brush pile in that area had been burned for maintenance purposes. Because of their general lack of presence along the entire river, it is highly recommended that this stand be actively maintained for future persistence of the tree along this river. Also of note, no naturally occurring *T. distichum* were observed in any of the four sites. The one tree encountered at the Calaveras site had been planted recently along the bank (one of several) by SARA.

**Mature**

| Tree | Cibolo Count | Cibolo % | Goliad Count | Goliad % | Calaveras Count | Calaveras % | Hwy 77 Count | Hwy 77 % | All Sites Count | All Sites % |
|---|---|---|---|---|---|---|---|---|---|---|
| *Acer negundo* | 4 | 4.4 | 3 | 4.8 | 2 | 5.1 | 45 | 40.9 | 54 | 17.9 |
| *Carya illinoiensis* | 1 | 1.1 | 14 | 22.6 | 6 | 15.4 | 4 | 3.6 | 25 | 8.3 |
| *Celtis laevigata* | 29 | 32.2 | 37 | 59.7 | 2 | 5.1 | 9 | 8.2 | 77 | 25.6 |
| *Cornus drummondii* | | 0.0 | | 0.0 | | 0.0 | 4 | 3.6 | 4 | 1.3 |
| *Ehretia anaqua* | | 0.0 | | 0.0 | | 0.0 | 3 | 2.7 | 3 | 1.0 |
| *Fraxinus pennsylvanica* | 1 | 1.1 | 5 | 8.1 | 1 | 2.6 | 5 | 4.5 | 12 | 4.0 |
| *Morus rubra* | 1 | 1.1 | 3 | 4.8 | | 0.0 | | 0.0 | 4 | 1.3 |
| *Myrica cerifera* | 1 | 1.1 | | 0.0 | | 0.0 | | 0.0 | 1 | 0.3 |
| *Platanus occidentalis* | 1 | 1.1 | | 0.0 | | 0.0 | | 0.0 | 1 | 0.3 |
| *Populus deltoides* | 2 | 2.2 | | 0.0 | 14 | 35.9 | | 0.0 | 16 | 5.3 |
| *Quercus macrocarpa* | | 0.0 | | 0.0 | | 0.0 | 4 | 3.6 | 4 | 1.3 |
| *Salix nigra* | 13 | 14.4 | | 0.0 | 9 | 23.1 | 15 | 13.6 | 37 | 12.3 |
| *Sapium sebiferum* | | 0.0 | | 0.0 | | 0.0 | 5 | 4.5 | 5 | 1.7 |
| *Taxodium distichum* | | 0.0 | | 0.0 | 1 | 2.6 | | 0.0 | 1 | 0.3 |
| *Ulmus crassifolia* | 33 | 36.7 | | 0.0 | 4 | 10.3 | 15 | 13.6 | 52 | 17.3 |
| *Ulmus fulva* | | 0.0 | | 0.0 | | 0.0 | 1 | 0.9 | 1 | 0.3 |
| *Ungnadia speciosa* | 4 | 4.4 | | 0.0 | | 0.0 | | 0.0 | 4 | 1.3 |
| Total | **90** | | **62** | | **39** | | **110** | | **301** | |

**Table 6:** Percent Compositions for Mature Trees at each site and all sites combined

## Tree Characteristics

Characteristics of the dominant tree species are shown in Table 7. Those trees that depend on seed dispersal via water, at least in part, include, *C. illinoinensis, C. laevigata, F. pennsylvanica, P. occidentalis, P. deltoides,* and *S. nigra.* Those plants whose seedlings are either tolerant of or need considerable flooding (up to 30 days) and/or require saturation in order to germinate include *A. negundo, C. illinoinensis, F. pennsylvanica, P. occidentalis, P. deltoides* and *S. nigra.* Once established, tolerance to both flooding and drought vary considerably between species. Those with known shallow roots (<3m) include *A. negundo, F. pennsylvanica, S. nigra* and *U. crassifolia.* *C. illinoinensis, C. laevigata* and *P. deltoides* are known to develop deep tap roots, especially when soil water conditions are dry to access saturated soil zones. This makes them much more tolerant to fluctuating stream influences and drought conditions.

| Species | Common Name | Life Span (yrs) | Reproductive Maturity | Seed Dispersal | Germination Needs | Seedling Drought / Water Tolerance | Drought / Water Tolerance | Rooting Depth (m) |
|---|---|---|---|---|---|---|---|---|
| *Acer negundo* | Box Elder | 75-100 | 8-11 yrs, annual | Wind | Overwinter | Flood tolerance < 85 days, or up to 50% of growing season | Both, once estab; flooding for entire growing season | shallow, spreading; fibrous |
| *Carya illinoinensis* | Pecan | 100+ | 20 yrs, opt=75-225 | Water, animal | Moisture, Overwinter to April | Low drought tolerance, flood tolerant 1-4 wks | Low drought; req.well drained soils; no prolonged flooding | Deep tap, fibrous w/ maturity |
| *Celtis laevigata* | Hackberry | 150 | 15 yrs, opt=30-70 | Water, animal | dormancy at41F | Flood intolerance | Fair drainage, flooding 1-4 wks (10% growing season) | 3-6, occasional taproot |
| *Fraxinus pennsylvanica* | Green Ash | 30-50 | Unk | Wind, water | 50% immed, 50% OW; | up to 30 days shallow flooding tolerance | Tol of flood <40% growing season; Intol of shading | 2-3m |
| *Morus rubra* | Red Mulberry | Unk | 10 | Animal | Overwinter | Moderate flood tolerance | Moderate flood tolerance | Unk |
| *Platanus occidentalis* | American sycamore | 250+ | 25 yrs, opt=>50 | Water, wind | Moisture, direct light; <2" soil | flood tolerance ~30 days | Tolerates saturation 2-4 mos; Riverbottoms | Wide, strongly branched |
| *Populus deltoides* | Eastern Cottonwood | 100-200 | 5-10 yrs, opt=35 yrs | Wind, water | must reach bed 1-2 wks; Immed germ | Req frequent flooding; flood tolerance to 50% of growing season | Req periodic flooding; mod drought; roots die if sat >1 mo. | 3-5 (avg=2.5) |
| *Salix nigra* | Black Willow | 40-100, 65 avg | 10-30 yrs, annual | Water, wind | must reach bed 12-24 hrs; Immed germ | Dies if >5 dry days | Drought intolerance; survives >30 days of saturation | Shallow, extensive |
| *Ulmus crassifolia* | Cedar Elm | 100 | Unk | Wind | Overwinter | Highly adaptable | Highly drought tolerant once estab; mod water tolerance | Shallow, spreading |

**Table 7:** General Tree Characteristics for Dominant Trees in the Study Area

Commonly riparian trees are grouped into general wetland classes (obligate, facultative wetland, facultative uplands, etc.) One of the disadvantages of this method is that in lumping together trees so broadly it does not take into account their unique differences in life stage water needs (e.g. *P. deltoides* must reach a suitable, moist bed within 1-2wks, needs frequent flooding as a sapling, but develops a deep tap root upon maturity). While there are uses for such groupings (simplification of reporting, generalization of trends), such groupings also have the potential to obscure any one of those grouped species' predictive ability as a key indicator species. For example the differing water needs of *P. deltoides* at different life stages makes them a great indicator of historical stream conditions: recruitment along a stream is indicative of frequent, small-duration flood events, while the presence (and distance) of mature trees are indicators of shallow water tables, that are either hyporheically connected, or once may have been connected to a previous stream channel that has since shifted.

**Species' Ranges**

Shown in Figures 20-22 are the distance and elevation ranges of seedlings, saplings and mature trees, respectively, for major species found within the Calaveras Site.

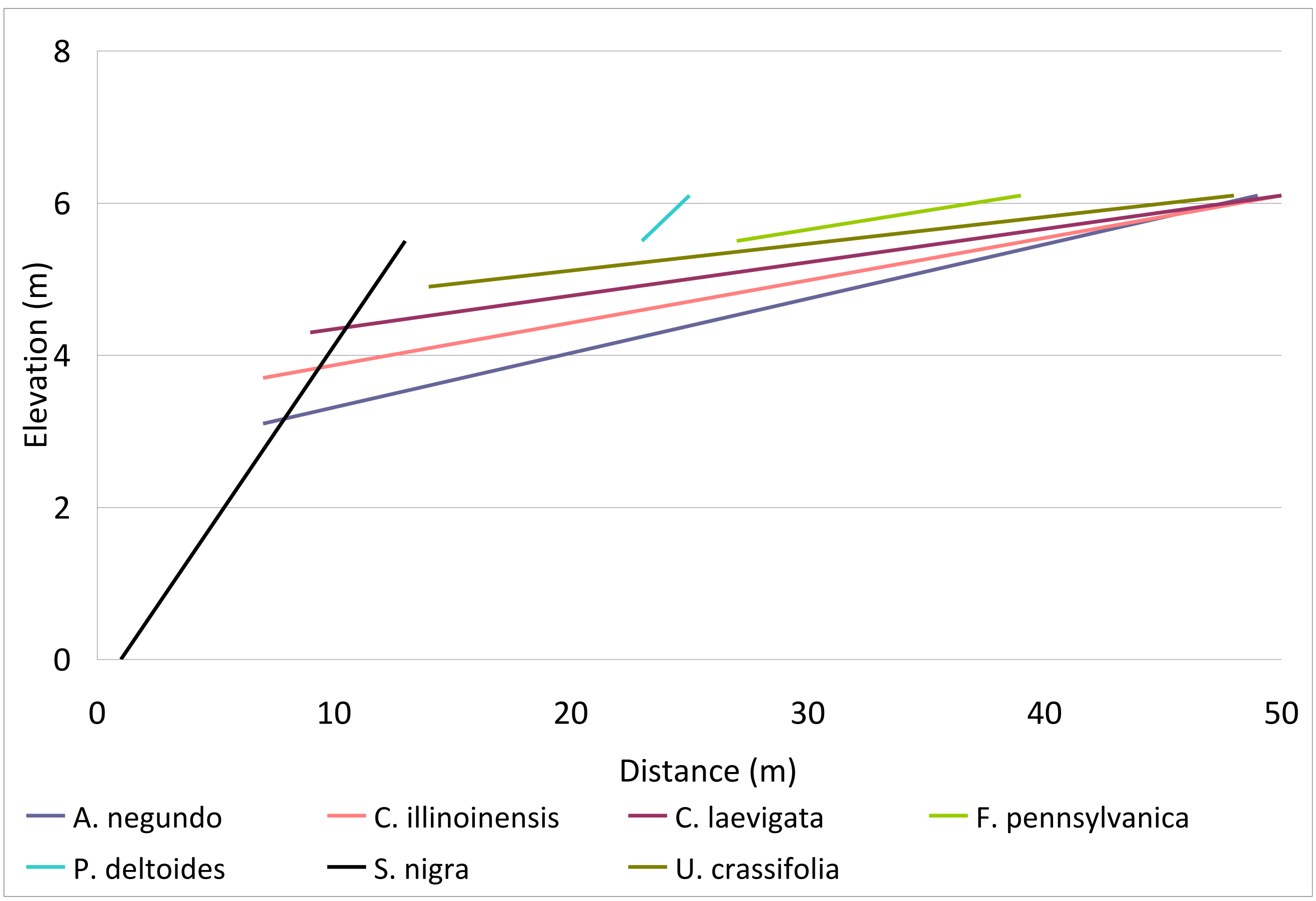


**Figure 20:** Calaveras Seedling Ranges

Members of all seven of the dominant species (according to percent compositions) were found at Calaveras (Fig. 20), along with the young stand of *P. deltoides* that was found in one very small, isolated patch ~25m distance and 6m above water's edge. *S. nigra* seedlings were the only species found along the channel slope itself. All other species were located outside the channel bank and in excess of 45m (with the exception of *F. pennsylvanica* seedlings which limited to within ~40m).

Only four of the dominant species were found as saplings within the Calaveras Site (Fig. 21). Of those, *S. nigra, F. pennsylvanica* and *A. negundo* were limited mainly to the channel slopes. For *S. nigra* the pattern of seedlings and saplings overlapped, but while no *F. pennsylvanica* and *A. negundo* seedlings were found along channel slopes, saplings were limited to them.

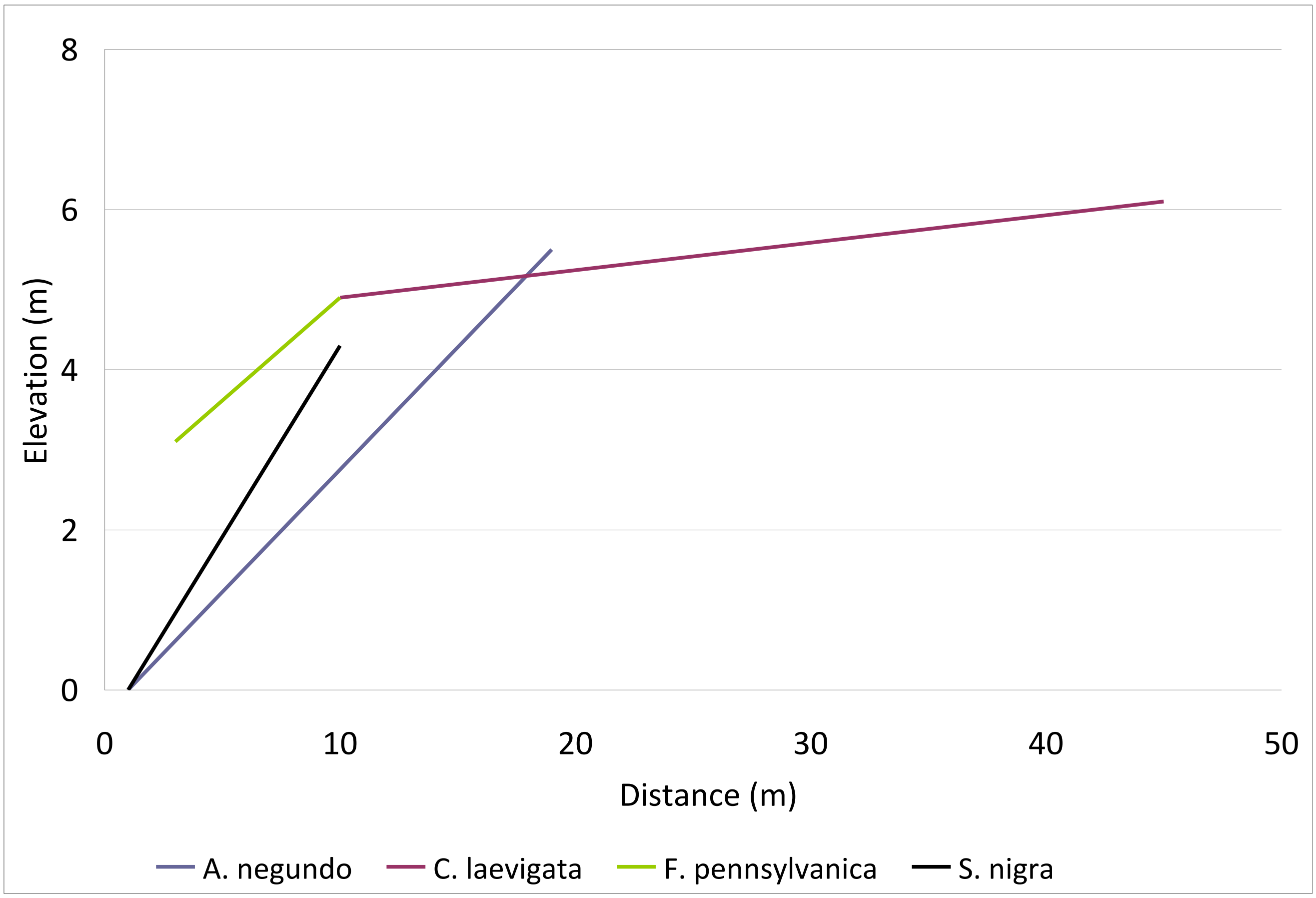


**Figure 21:** Calaveras Sapling Ranges

Only three dominant species were found as mature trees (>5cm DBH), along with the *P. deltoides* (Fig. 22). Mature trees of *S. nigra* were constrained to a general distance of 5-10m distance and 3.5-4.2m elevation. This indicates that while recruitment/seed dispersal occurs along the entire channel slope and outer bank edges, trees of this species having reached maturity are constrained to a narrow placement relative to the river. Additionally, no mature trees of *C. illinoinensis* or *C.*

*laevigata* were seen closer than 15m distance to or lower than 3.8 m height above the stream.

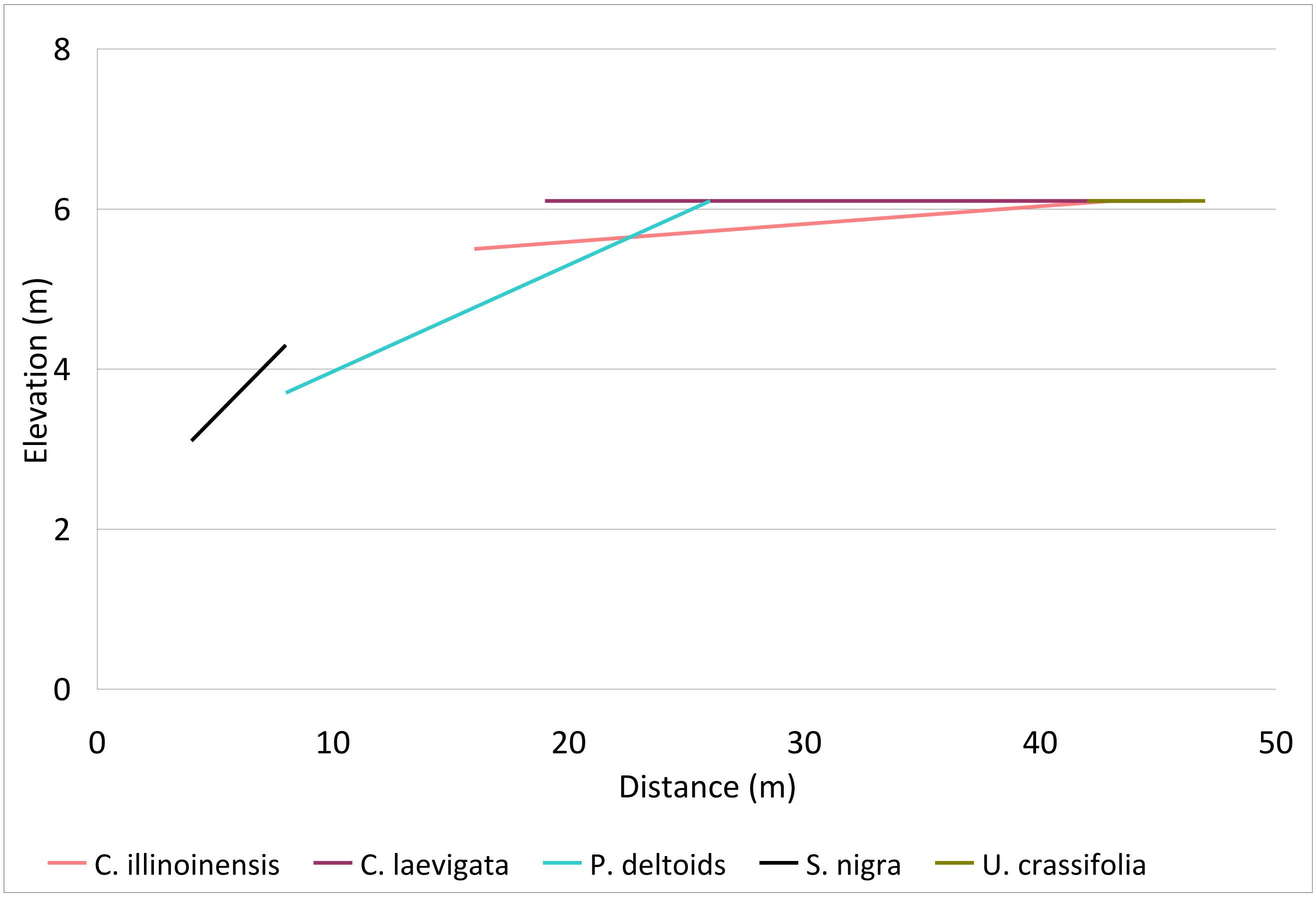


**Figure 22:** Calaveras Mature Tree Ranges

Clear patterns emerge concerning *F. pennsylvanica*. Though no mature trees were found in the sampled site, saplings were found 3-10m distance, but seedlings were encountered only from 25-40m. Such far-reaching seedling placement, and lack of adults in the nearby areas, may be an indication that the increased flow is both limiting nearby survival and increasing seed dispersal to (though not necessarily longterm survival in) more distant locations. *A. negundo* seedling and sapling dispersals follow a similar pattern, though saplings aren't as distantly located.

Shown in Figures 23-25 are the distance and elevation ranges of seedlings, saplings and mature trees respectively, for major species found along the Cibolo Creek Site. While no woody species were found less than ~7m distance or 2m height from water's edge, seedlings for all major species began occurring very soon thereafter (Figure 23). *A. negundo* was limited to 15m distance and 4m height, as was *U. fulva*, (but with a height limitation of 8m). *C. laevigata* and *U. crassifolia* extended the full 50m sampled.

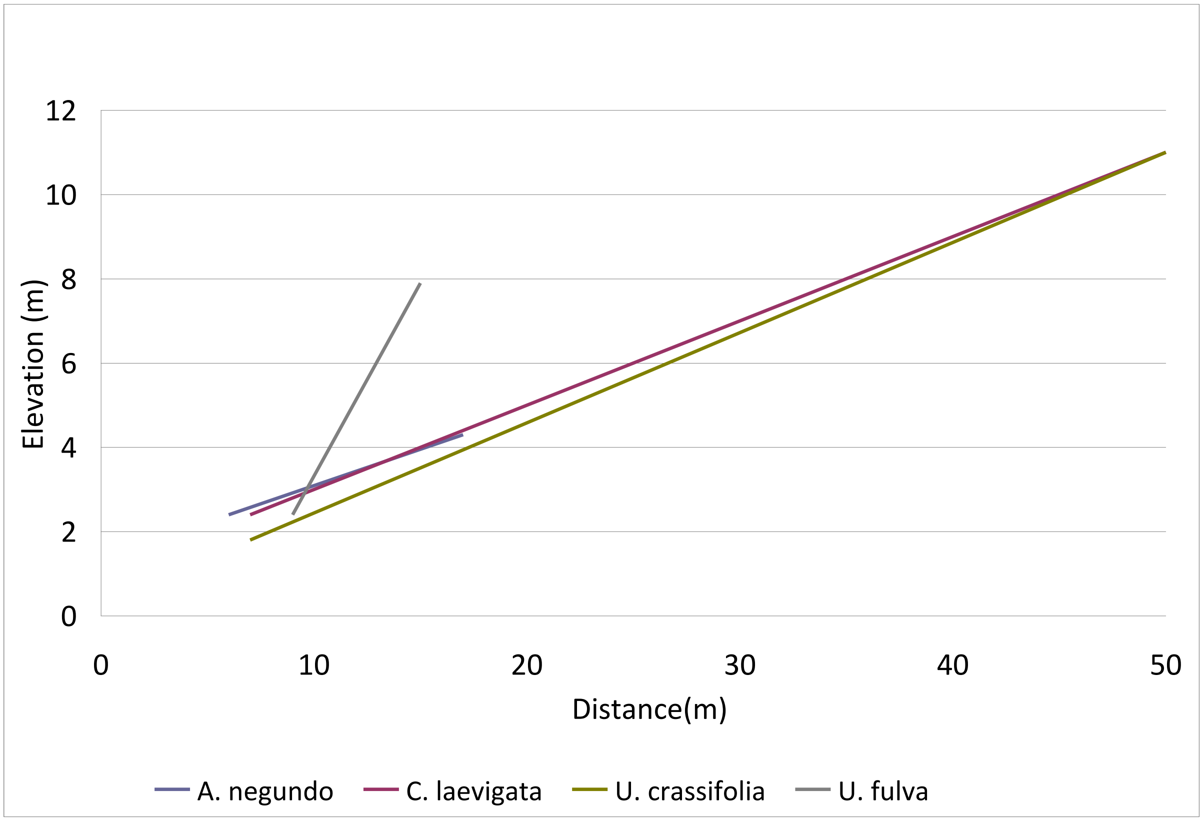


**Figure 23:** Cibolo Creek Seedling Ranges

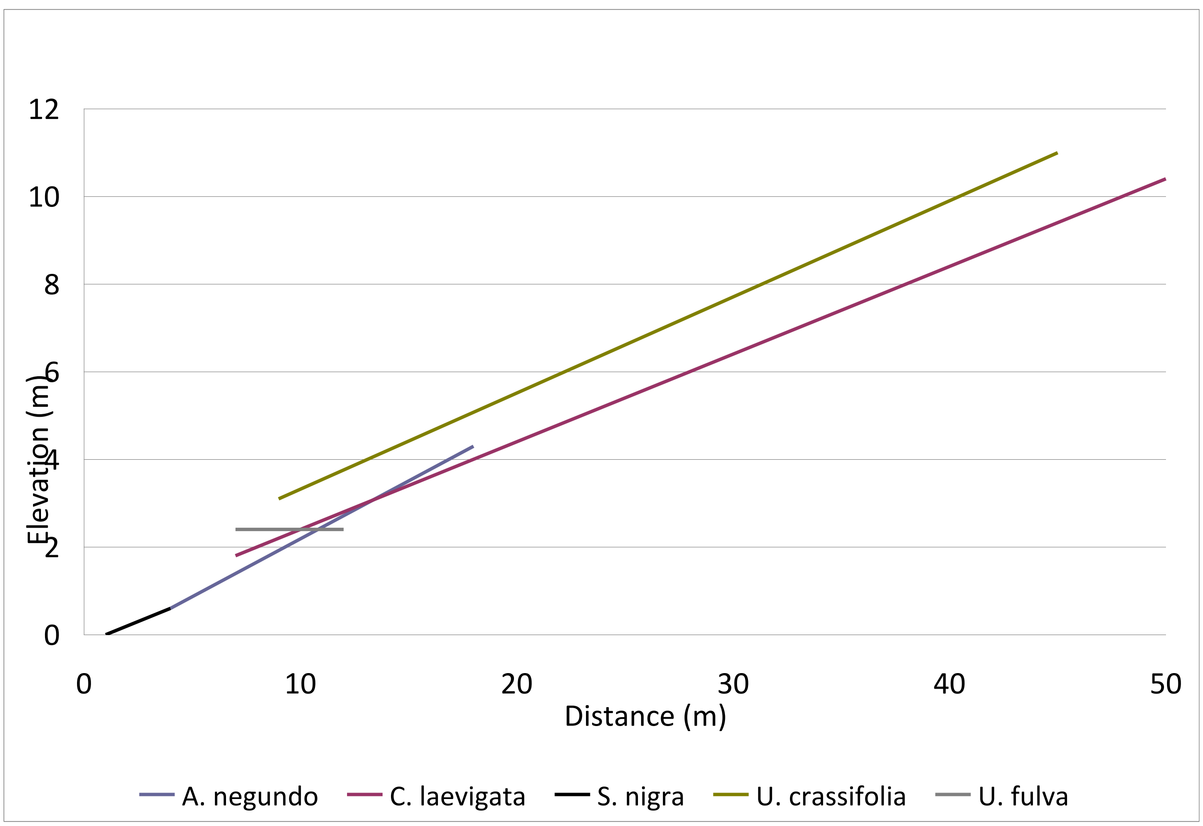


**Figure 24:** Cibolo Creek Sapling Ranges

Saplings for all major trees with seedlings present were seen within this site (Fig. 24), in addition to *S. nigra* saplings, which occurred at less than 5m distance and 1m elevation to the stream. *A. negundo* sapling distribution very much followed seedling distribution.

For mature tree ranges (Fig. 25) *S. nigra* were still constrained to less than ~5m distance but were seen in excess of 2m height above stream. Mature *A. negundo* were limited to 5-10m distance and ~2m elevation, compared to their seedling sapling ranges of 15m distance and 4m elevation. *U. crassifolia* and *C. laevigata* extended the full 50m transect, similar to their seedling and sapling ranges.

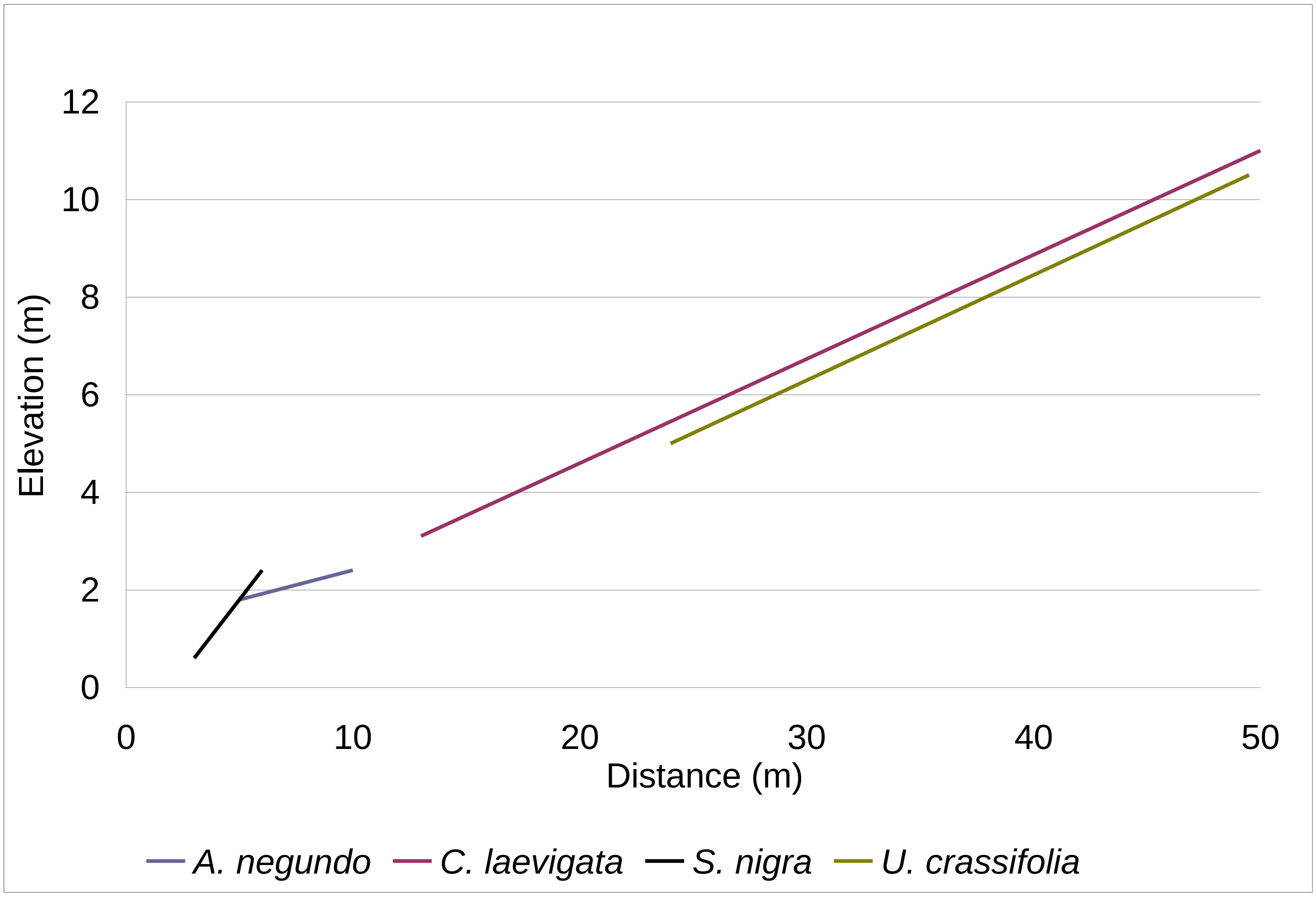


**Figure 25:** Cibolo Creek Mature Tree Ranges

Shown in Figures 26-28 are the distance and elevation ranges of seedlings, saplings and mature trees respectively, for major species found along the Goliad Site. Figure 26 highlights the lack of several major species' seedlings. *C. laevigata* and *U. crassifolia* heavily populated the area. One surprise given its dominance in mature trees, was a lack of *C. illinoinensis* seedlings. Several hiking trails were seen throughout the study area and may have contributed to reduced biodiversity. Another factor may have been the sampling date being too early in the season to have seen the emergence of seedlings for many species. Because saplings of *S. nigra* and *A. negundo* were found (Fig. 27), recruitment, at least in recent years, was indicated.

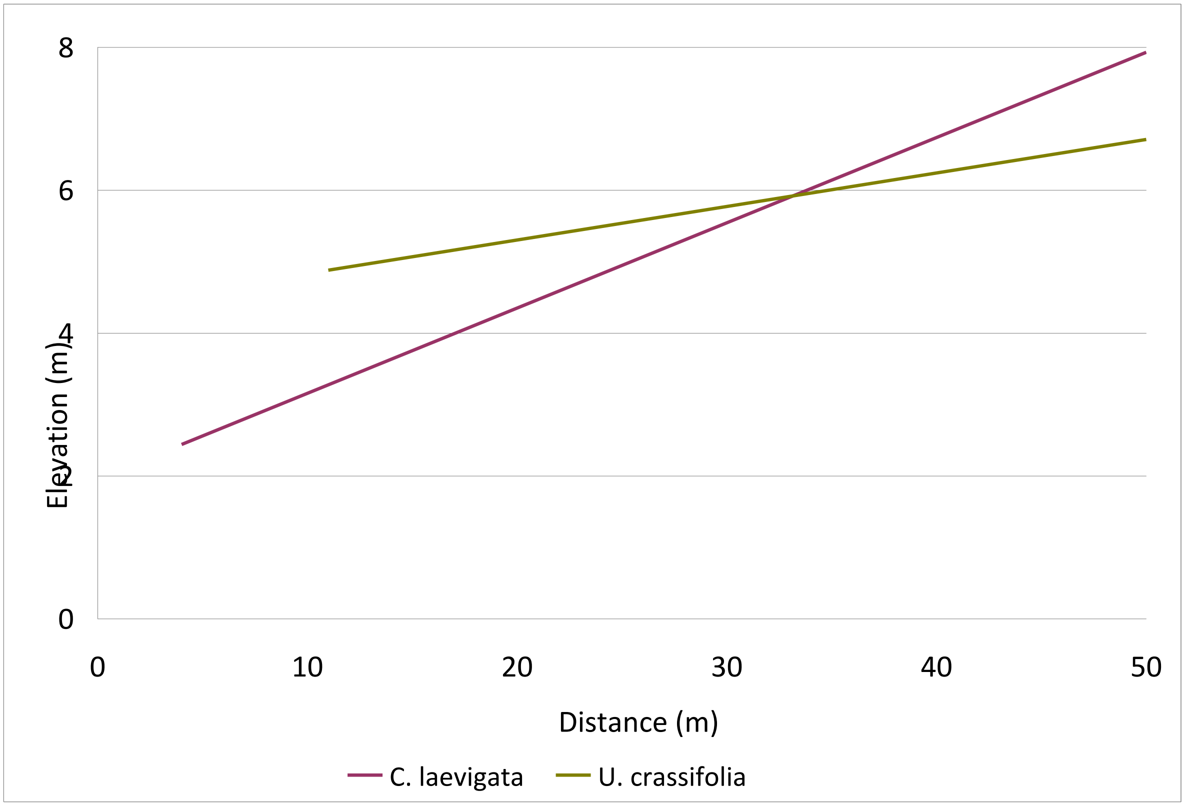


**Figure 26:** Goliad Seedling Ranges

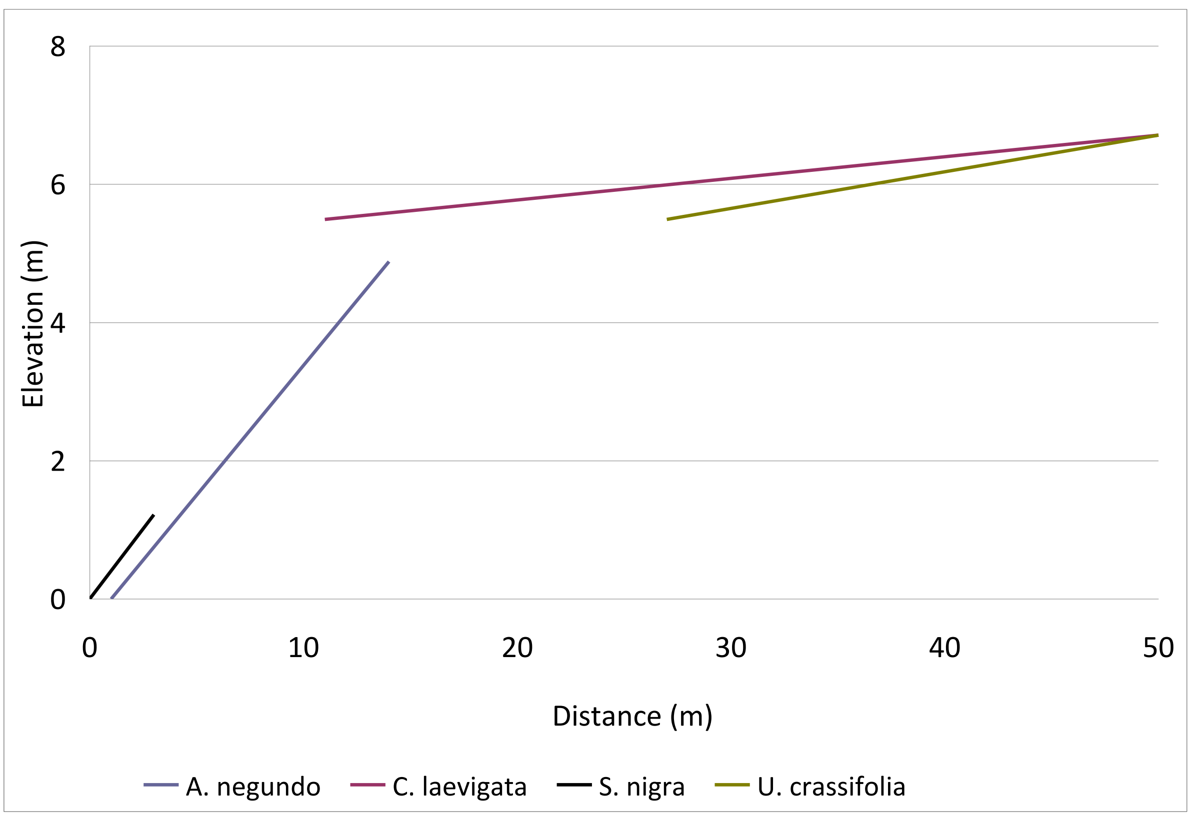


**Figure 27:** Goliad Sapling Ranges

Saplings of *A. negundo* and *S. nigra* were found very near water's edge along the channel slopes. Though *S. nigra* was limited to 4m distance and 1m elevation, *A. negundo* persisted into the near bank edges at 15m distance and 5m elevation (Fig. 27).

Figure 28 indicates that other than *F. pennsylvanica*, no mature trees were found closer than 10m distance or 4m elevation to the water's edge. Interestingly, while *A. negundo* saplings were found less than 10m height and 4.5m elevation, mature trees were located at distances and elevations *outside* those ranges. Clearly, recent recruitment patterns vary spatially from mature trees. Also of note is the lack of any *F. pennsylvanica* seedlings or saplings in the site though mature trees were present.

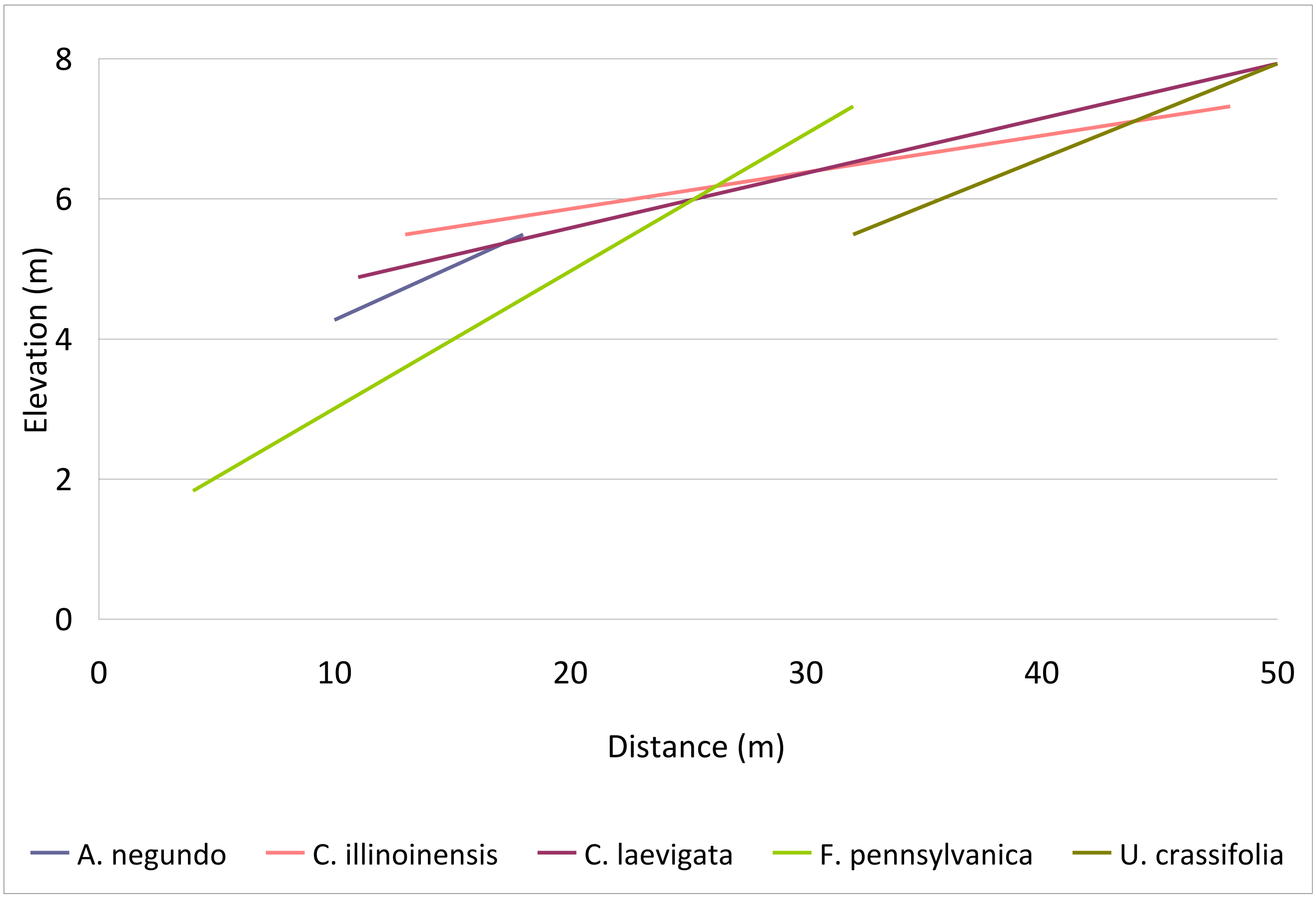


**Figure 28:** Goliad Mature Tree Ranges

Shown in Figures 29-31 are the distance and elevation ranges of seedlings, saplings and mature trees, respectively for major species found within the Hwy 77 Site. *S. nigra* and *A. negundo* seedlings occurred along the channel slope, with *A. negundo* persisting the full 50m distance (Fig. 29). All other species were generally limited to above 3.5m and further out than 10m, though *F. pennsylvanica* seedlings did appear on upper channel slopes.

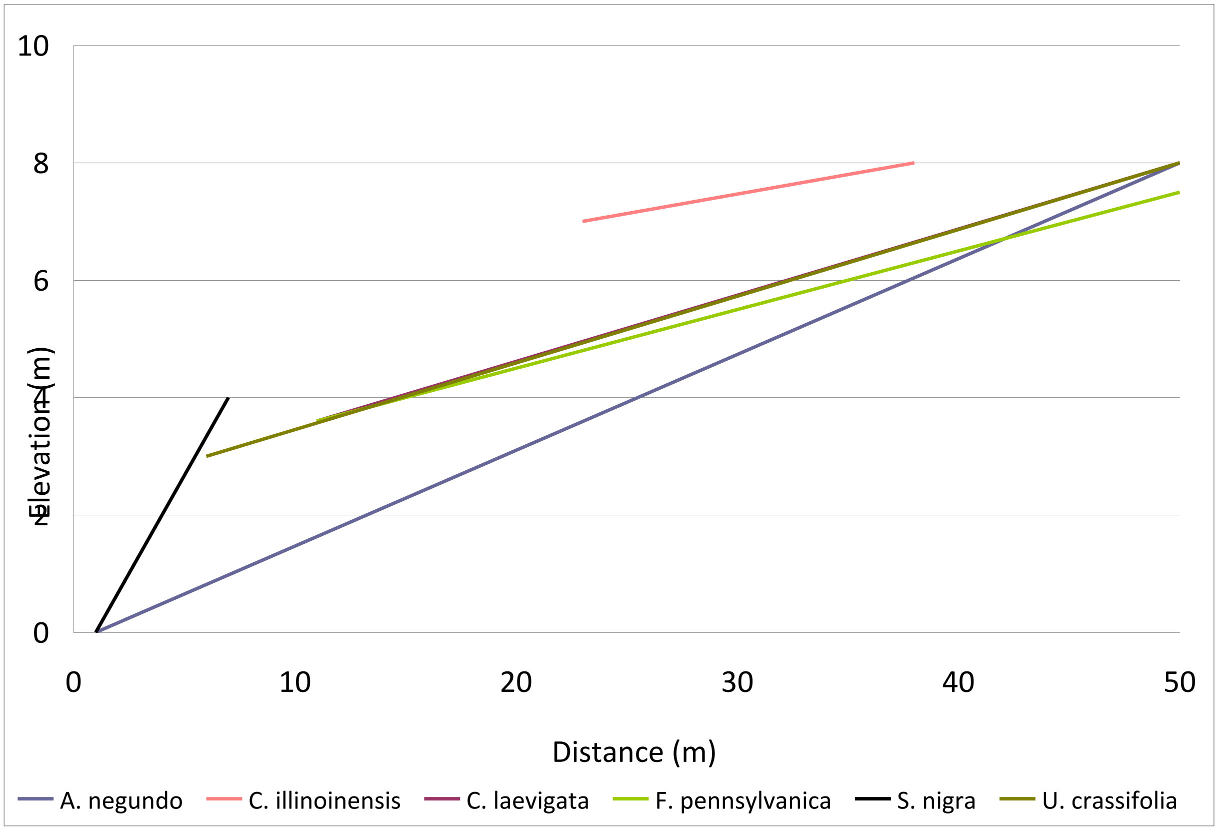


**Figure 29:** Hwy 77 Seedling Ranges

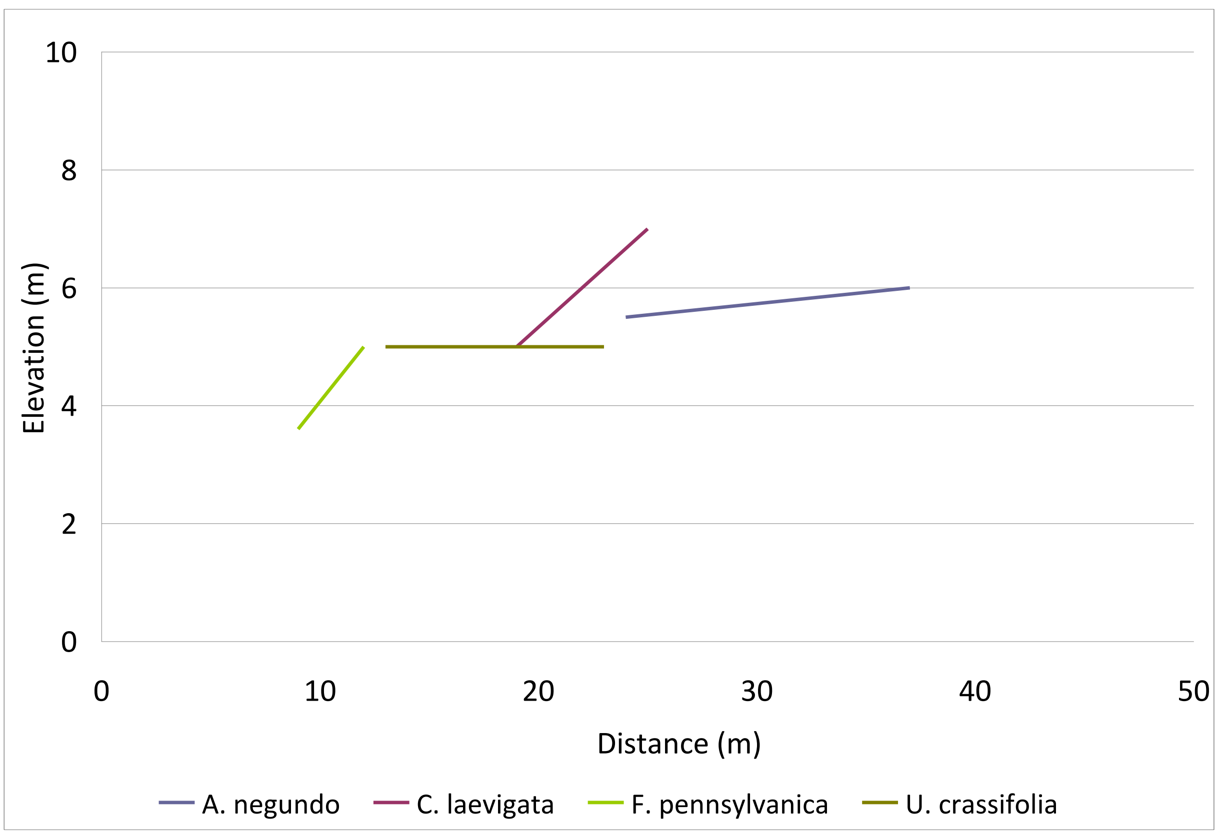


**Figure 30:** Hwy 77 Sapling Ranges

Saplings of *F. pennsylvanica* were spatially limited in comparison to seedlings, as were other species (Figure 30). However, Figure 31 shows a broader spatial coverage of mature trees. *S. nigra* persisted as far away as 12m and as high as 4.3m. *A. negundo* could be seen from ~7m through 50m. One exception: mature *F. pennsylvanica* were generally located 10-20m distance and 4.5m elevation, the same general location as, though much more tightly constrained than, their seedlings.

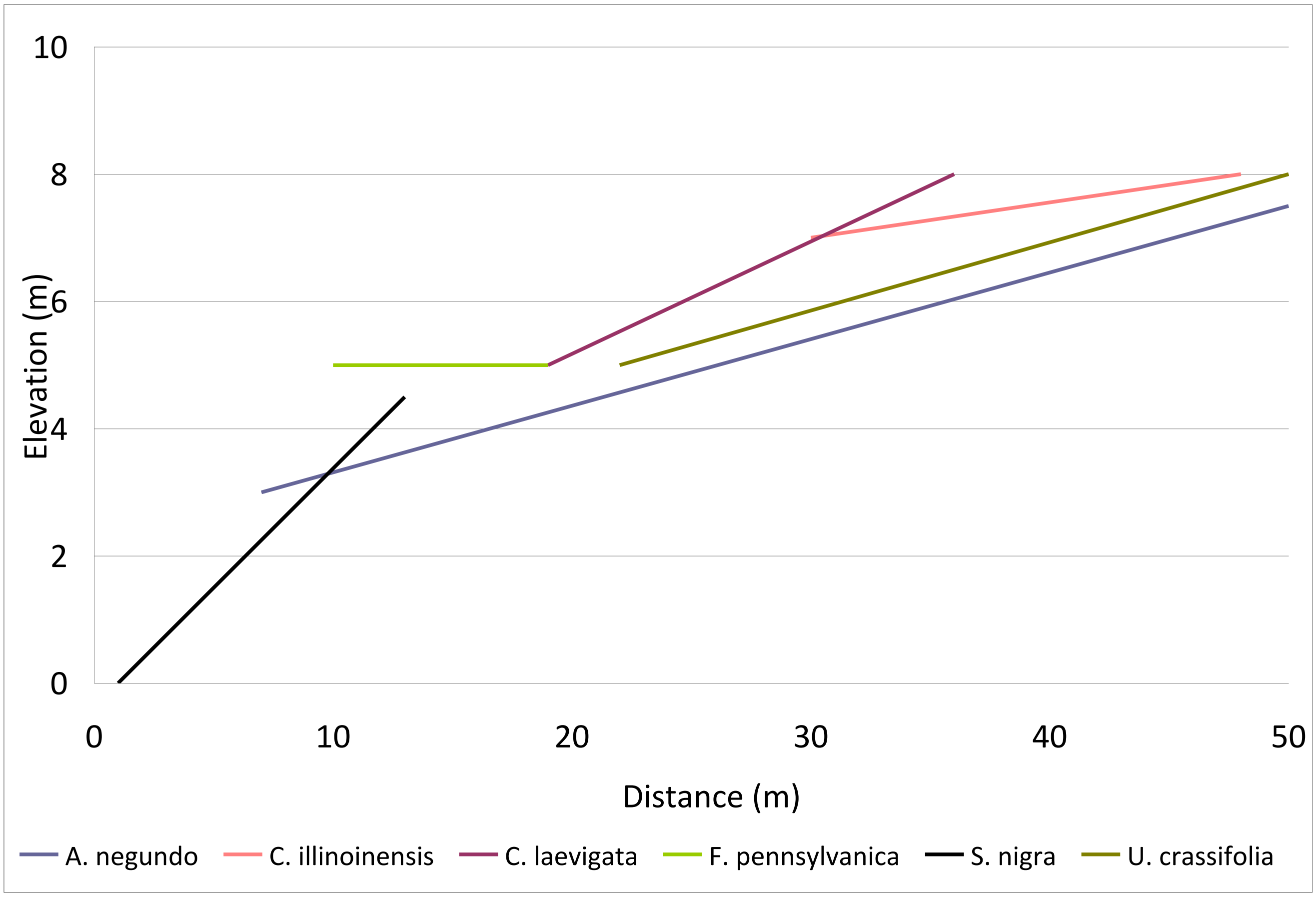


**Figure 31:** Hwy 77 Mature Tree Ranges

Shown in Figures 32-34 are the distance and elevation ranges of total seedlings, saplings and mature trees, respectively, for the dominant species found along the San Antonio River. According to Figure 32 *S. nigra* seedlings are dispersed from near water's edge, up along the channel slopes, and in the near-bank regions, and appear to be the only species limited to specific near-stream areas. Given their germination need for wet soils and high tolerance for flooding, this would indicate that frequent wetting of the soils has recently occurred in the 5m height along the channel slope. *A. negundo* seedlings are also dispersed near water's edge but extend as far away as 50 m. While highly tolerant of flooding, A. *negundo* seedlings have no stringent soil wetting needs, explaining their ability to germinate such far distances. *C. illinoinensis*, *C. laevigata, F. pennsylvanica, U. crassifolia* and *U. fulva* seedlings are dispersed from the tops of the channel banks and can be found throughout the floodplain.

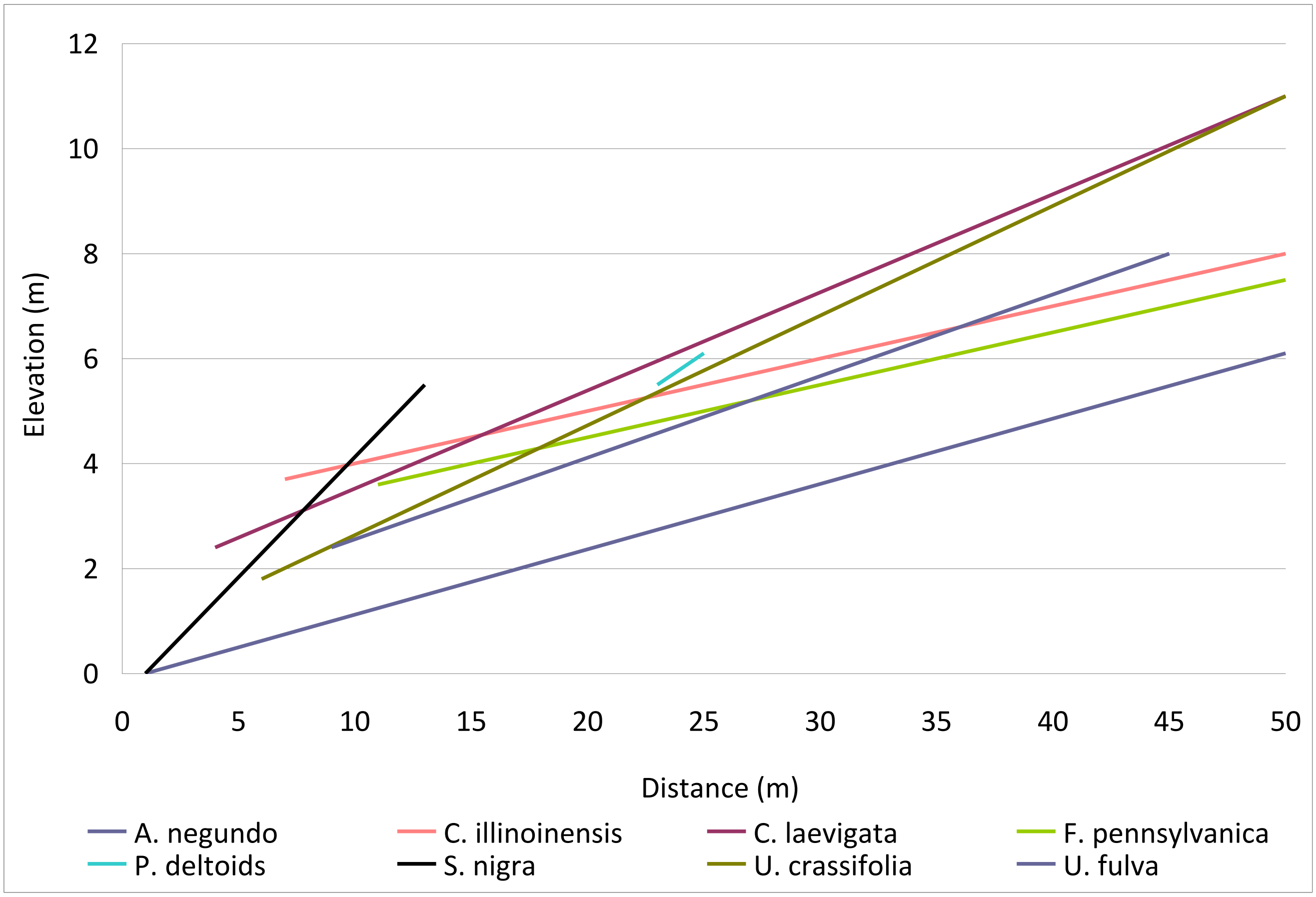


**Figure 32:** All Sites Combined Seedling Ranges

Figure 33 shows that sapling distribution of *S. nigra* becomes more constrained toward the river, as location narrows from a seedling distance/height of 13m/5.5m to a 9m/4.5m for saplings. This may be an indication of a) saplings are less tolerant of drier conditions than seedlings or b) the most recent year had more consistently wet conditions, allowing the latest seedlings to disperse slightly further than previous years. *A. negundo* saplings still reach a height of 5m, but are found within 35m of stream. *C. laevigata* and *U. crassifolia* show no difference in seedling dispersal and sapling distribution. *C. illinoinensis* and *U. fulva* saplings have much smaller distributions than their seedling counterparts, and *F. pennsylvanica* is the only specie to have sapling distributions both closer and at lower elevations than its seedlings.

The mature trees shown in Figure 34 indicate that even though *S. nigra* adult trees appear to follow the same lower elevation pattern as their saplings, they can be found the full range of seedling dispersal. Therefore, the limitations to distribution of this specie in the community would suggest that seed dispersal/survivability is a determining factor, which may be further constrained by rooting depth limitations of more mature trees as the distribution of more mature individuals appear to be confined to lower elevations than seedling dispersal would dictate. Survivability of *A. negundo* adults along the river show that even though seed/sapling distributions occur along the channel slopes, contributing to understory vegetation of the slopes, rarely do adult members persist near water's edge. They are able to inhabit some of the upper channel slope edges, particularly when a gentler slope is found - rather than a sheer cut bank feature - as well as much of the extent of the forested community.  Their adaptive tolerance, once established, to both flooding and drought likely explain their broader distribution than their fellow channel-slope dwellers, *S. nigra*.

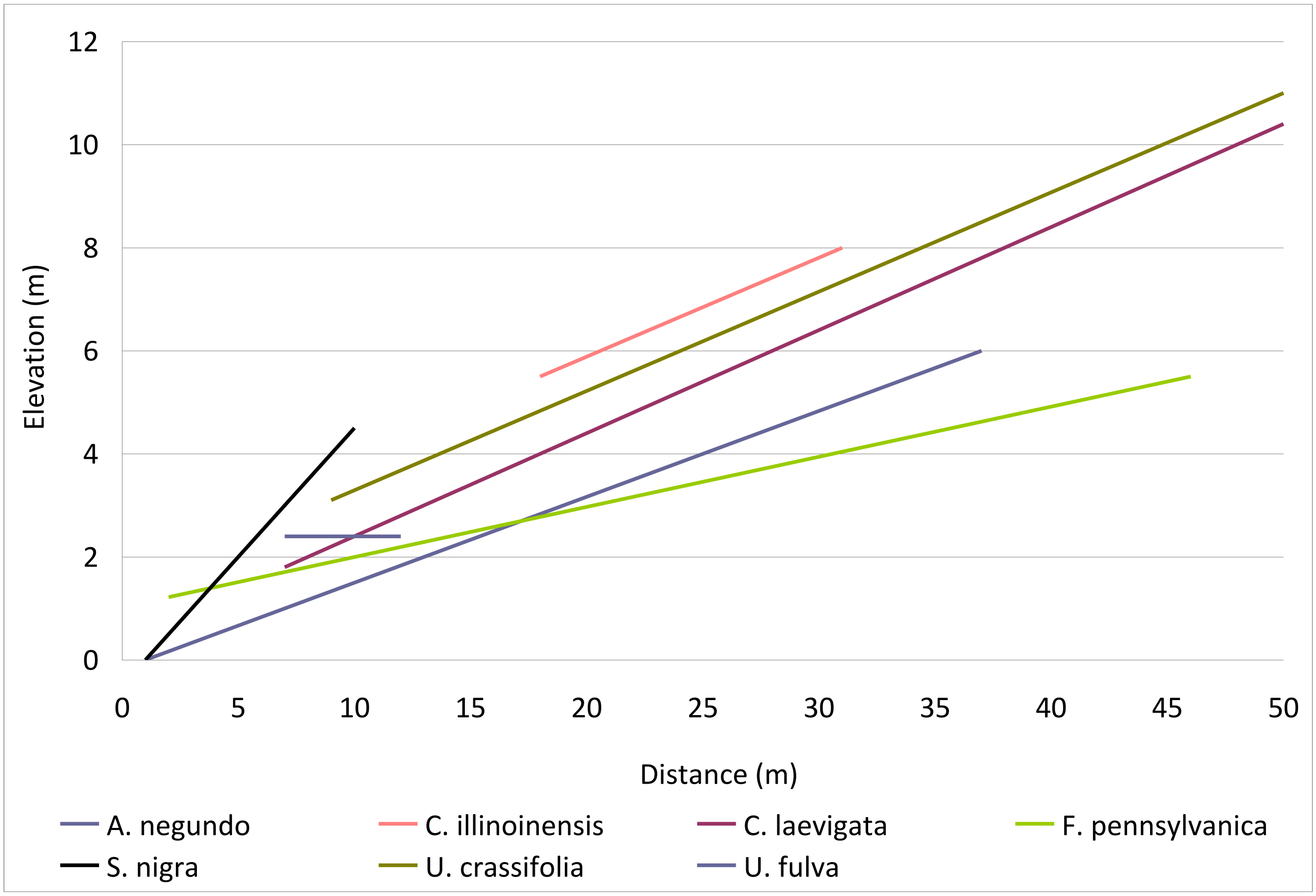


**Figure 33:** All Sites Combined Sapling Ranges

Also able to inhabit channel slopes were *F. pennsylvanica* adult trees, though they too had a lower limit (4m distance and 2m height) than their sapling ranges.  In comparison to their seedling/sapling distributions, their adult range appears to be seedling dispersal driven, as sapling distribution fully encompassed mature.  Why no recent seedlings were found in the lowest reaches could not be explained from this sampling, and may need to be monitored with future recruitment studies.  However, the presence of saplings would indicate the anomaly is either very recent and/or simply not a previously long-term occurrence.  Given their seedling intolerance of saturation more than 30 days, perhaps the wetter conditions that favor *A. negundo* and *S. nigra* seedlings are limiting to *F. pennsylvanica*.

All other species appeared to be limited to set distances/heights away from the stream.  *C. illinoinensis*, though able to inhabit ranges as close as 7m/4m (distance/height) when young, showed adults to be limited to 12m/5.5m.  *C. laevigata* adults were further located than either their seedling/sapling counterparts, as was *U. crassifolia* which went from a distance/height in seedlings of 5m/2m to an adult range of 22m/5m.

What cannot be stated in this study is whether the consistent pattern for so many trees (adults being more distantly constrained than original seedling distribution) is an indication of mature tree water needs/limitations, or whether riparian invasion along the closer reaches is occurring.

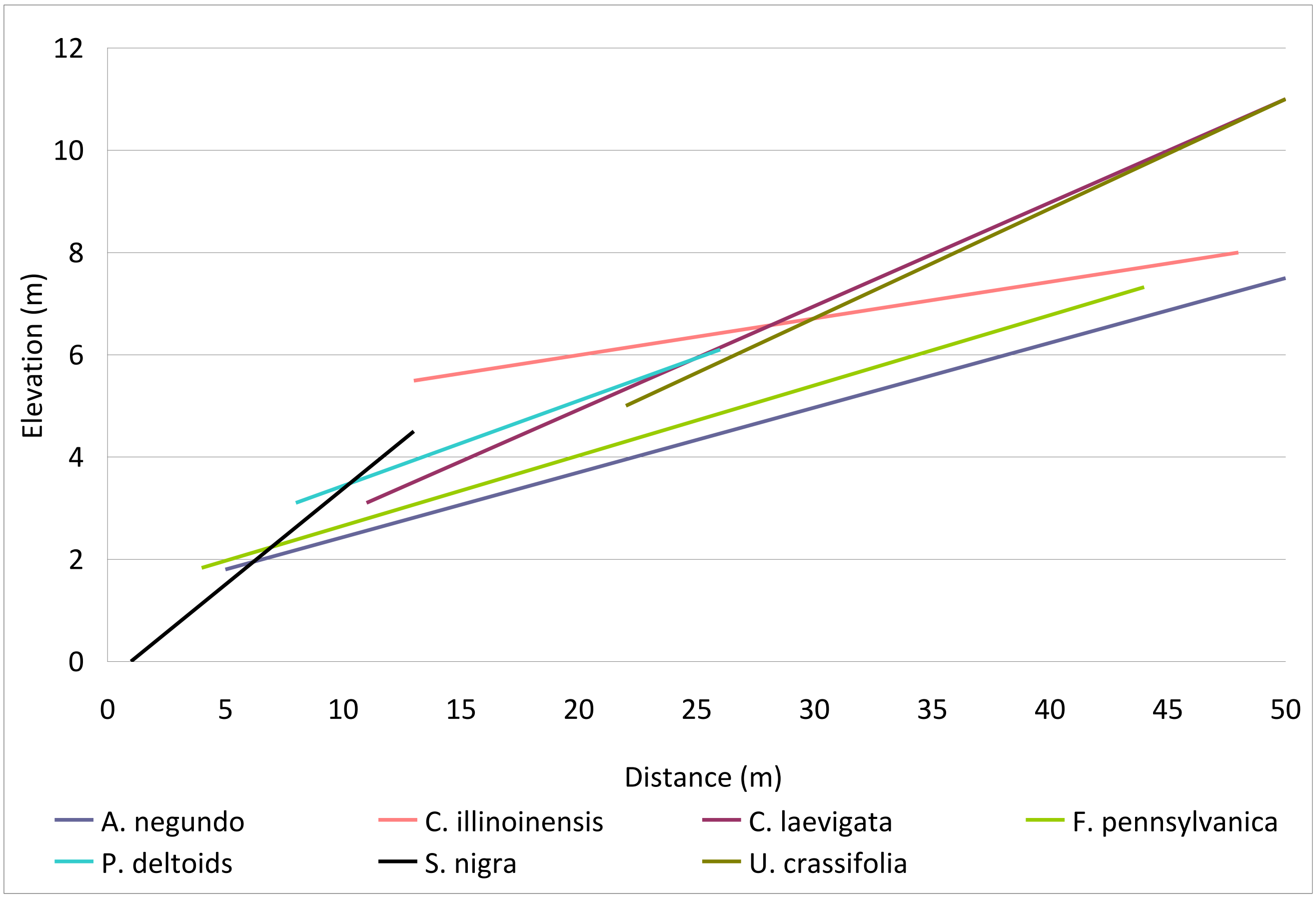


**Figure 34:** All Sites Combined Mature Tree Ranges

## Mature Tree Stand Age Distribution

Table 8 shows species represented in cored samples for both the San Antonio and Brazos River, and the number of each species collected. Also shown are the age range, average age, and average growth per year. The Factor Column includes an index used as the multiplication factor to estimate the age of trees sampled in the biodiversity study, based on DBH. Of note in the data are the differences in growth between two dominant riparian species, *A. negundo* and *S. nigra* between the two rivers. Trees of those species tend to have larger basal productivity along the Brazos River in comparison to the San Antonio River. This would indicate that differences seen in timing/duration of floods along these rivers may allow Brazos River conditions to be more conducive to productivity, an area that warrants further exploration, especially in light of the *increasing* water flows in the San Antonio over the past decades.

| Species | San Antonio River Age Range | Avg Age | Ave Growth | # of Trees | Factor* | Brazos River Age Range | Avg Age | Ave Growth | # of Trees | Factor* |
|---|---|---|---|---|---|---|---|---|---|---|
| *Acer negundo* | 17-71 | 41 | 0.371 | 16 | 0.742 | 19-61 | 35 | 0.598 | 11 | 1.196 |
| *Carya illinoinensis* | 10-68 | 44 | 0.491 | 16 | 0.982 | 20-101 | 75 | 0.472 | 7 | 0.944 |
| *Celtis laevigata* | 14-80 | 48 | 0.381 | 15 | 0.762 | 17-74 | 39 | 0.587 | 13 | 1.174 |
| *Ehretia anaqua* | 60 | 60 | 0.318 | 1 | 0.636 | | | | | |
| *Fraxinus americana* | | | | | | 12-20 | 15 | 0.694 | 3 | 1.388 |
| *Fraxinus pennsylvanica* | 25-62 | 50 | 0.484 | 7 | 0.968 | 15-36 | 23 | 0.931 | 3 | 1.862 |
| *Fraxinus texensis* | | | | | | 34-64 | 31 | 0.527 | 3 | 1.054 |
| *Morus rubra* | 22-30 | 27 | 0.590 | 4 | 1.179 | | | | | |
| *Platanus occidentalis* | 55-95 | 75 | 0.315 | 2 | 0.630 | 24-66 | 45 | 0.615 | 10 | 1.230 |
| *Populus deltoides* | 17-32 | 22 | 0.953 | 4 | 1.906 | 9-66 | 37 | 0.956 | 27 | 1.912 |
| *Quercus macrocarpa* | 44-58 | 51 | 0.439 | 2 | 0.878 | | | | | |
| *Salix nigra* | 6-28 | 20 | 0.900 | 18 | 1.800 | 8-37 | 18 | 1.222 | 31 | 2.444 |
| *Ulmus americana* | | | | | | 18 | 18 | 0.686 | 1 | 1.372 |
| *Ulmus crassifolia* | 37-89 | 58 | 0.313 | 7 | 0.626 | 27-49 | 37 | 0.469 | 3 | 0.938 |
| *Ulmus fulva* | 40 | 40 | 0.494 | 1 | 0.988 | 11-46 | 29 | 0.695 | 8 | 1.390 |
| **Total** | | | | **93** | | | | | **120** | |

* Used to estimate the age of a tree based on its diameter (divide DBH by Factor)

**Table 8:** Summary of Cored Trees for San Antonio and Brazos Rivers

*P. occidentalis* and *F. pennsylvanica* also appear to follow the pattern of larger growth among Brazos populations, though the large difference in average age between the two rivers' sampled trees is probably a contributing factor, as younger trees will generally have slightly larger growth rings than older trees. For *C. Illinoinensis*, much older age of some of the Brazos trees is also probably a contributing factor to the smaller annual growth. Both *C. laevigata* and the *Ulmus* species show this same pattern of an overall larger ring width in comparison to San Antonio River trees.

Age classes for dominant species along the San Antonio River, based on the multiplication factor of Table 8 are shown in Figure 35. *A. negundo* appear to be an expanding group, with very few individuals found older than half the 75 yr lifespan for this specie and very strong seedling/sapling counts. *C. illinoinensis* ages span its usual lifespan, though there was a complete lack of trees surviving to adulthood in 5-15 yr range and very few saplings were found. This may indicate that though seedlings were abundant, persistence of the tree in the future may be declining. Given *C. illinoinensis'* mature tree intolerance for saturated soils, the increased flow along the San Antonio River may be limiting its longterm survivability. When the ranges for this specie are considered, the pattern becomes clear that the seedlings and saplings are being dispersed at shorter distances to the stream than adults are located and/or are surviving.

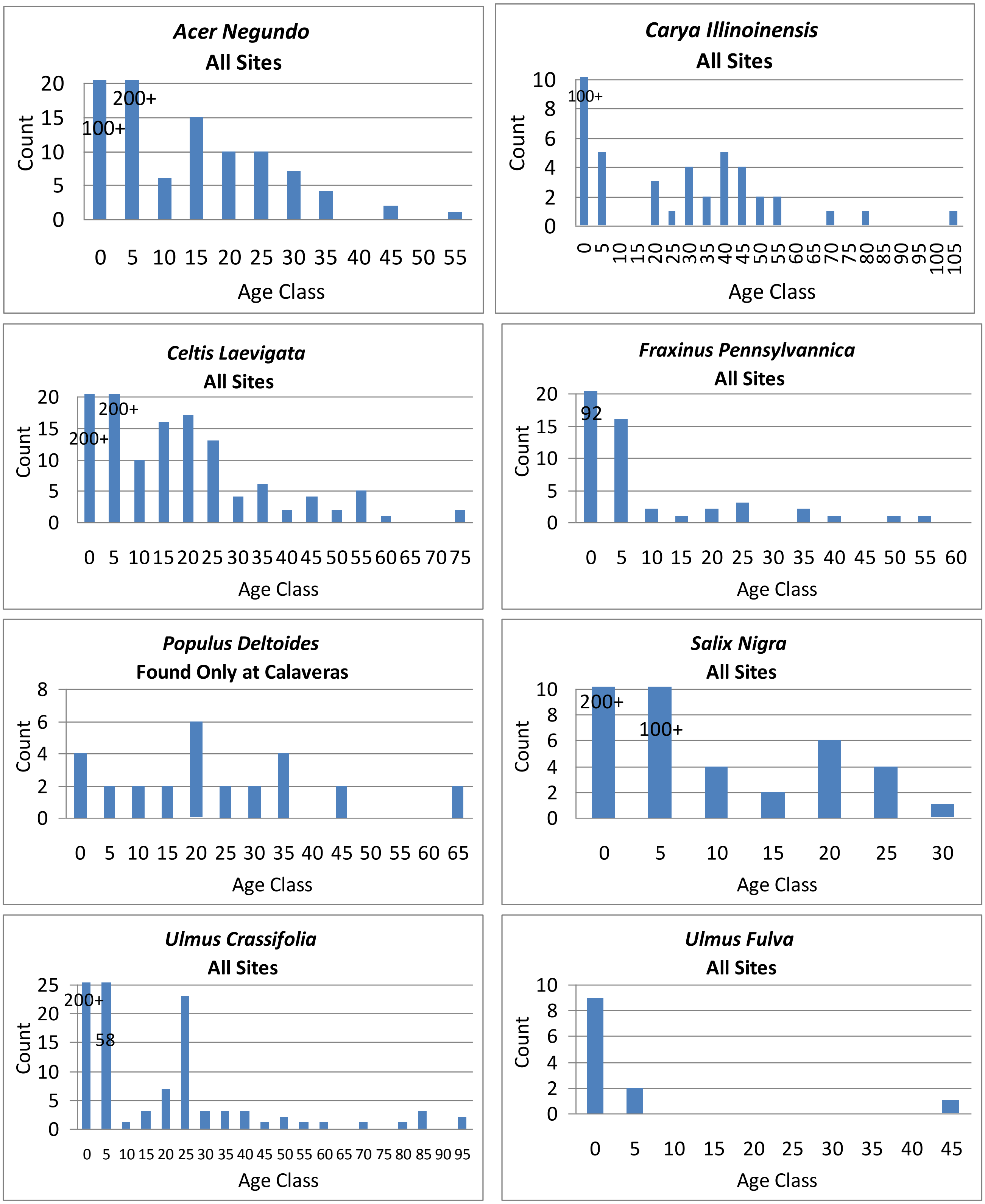


**Figure 35:** Age Classes for Several Dominant Species Along the San Antonio River

*C. laevigata* appear to be expanding (as their distribution is pyramid shaped). *U. crassifolia* are stable (bullet-shaped for replacement and older trees). *F. pennsylvanica*, while not very abundant, does appear to have trees across multiple ages and though saplings are limited, seedlings are abundant. Interestingly, past studies on San Antonio River communities make no mention of this specie, so it is possible it is a relative newcomer along this river (Bush and Van Auken, 1984; and Bush *et. al,* 2006). Longterm monitoring of this specie for adequate replacement of reproductively active trees may be necessary to ensure its persistence in the future. The very rare occurrence of *P. deltoides* along the river continuum, coupled with very low recruitment rates of the one observed stand indicates it is not a highly dominant specie along the San Antonio River. Mention of its prevalence in past studies (Bush and Van Auken, 1984; and Bush *et. al,* 2006) indicate it was fairly common in the early 1980's but not documented at those same sites in a follow-up study in 2005. *U. fulva* has limited age distribution and low recruitment indicating that though it is often present, it too is not highly dominant along the river.

*S. nigra* age distributions indicate that very few trees reach half their expected lifespan. Given their close proximity to the water's edge, loss of trees to high water flows probably explains their short life spans (lost to erosion before they can reach their full age potential). This is likely the case for *A. negundo* as well. Because recruitment is strong, *S. nigra* appears to be relatively stable, though not expanding as there are low numbers of trees of early replacement age (5-15 years). Overall, the majority of trees (excepting *P. deltoides* and *C. illinoinensis*) appear stable enough to maintain themselves and/or recover future episodic flooding or drought events.

## SOIL HYDRIC CONDITIONS

### Water Table Depth

Figures 36 through 39 show the depth to water table for selected transects within the four sites; and a summary of sites, soil classes and observed soil characteristics is given in Table 9. A 'star' in Figures 36-39 indicates the water table (saturated soil) was reached for that depth.

Figure 36 indicates that at 5m distance to the stream water table depth was 1.5m, at 15m: 2.5, 30m: 2.8, and 45m: 2.5m depth in the Calaveras Site. When compared to Figure 22 (mature tree ranges) it appears that persistence of the shallowest water table corresponds with *S. nigra*, as it grows only where the water table was known to be shallower than 2m. While *P. deltoides* extends out to 30m, that still represents lower/gradually changing elevation of groundwater. Other species' spatial distribution appears to be independent of a shallow water table.

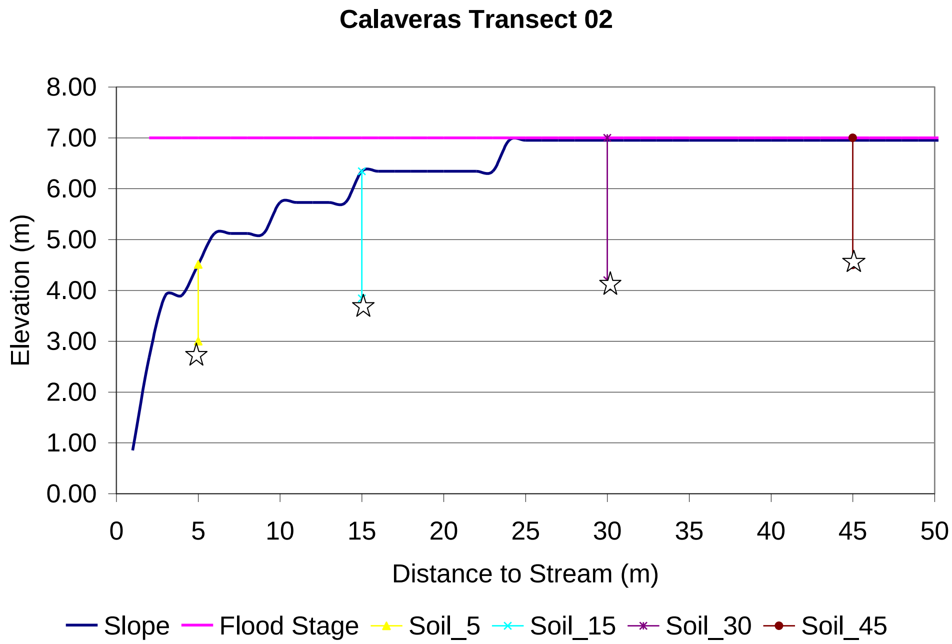


**Figure 36:** Augured Soil Depths for Transect 02 in the Calaveras Site

Figure 37 shows that water table depth is 1.2m at 5m distance and 3.2m at 15m distance at Cibolo. At 30m it was lower than 4mdepth. No sample was taken at 45m as a strong thunderstorm necessitated leaving the study site early and an ensuring flood prevented further access to the site during the scheduled trip to collect that site's data. Comparing these data to Figure 25 (mature tree ranges for the site) indicate that *S. nigra* grows at sties where groundwater is less than 2m deep and *A. negundo* less than 3m. Other tree distributions are independent of shallow (<4m) water table depths.

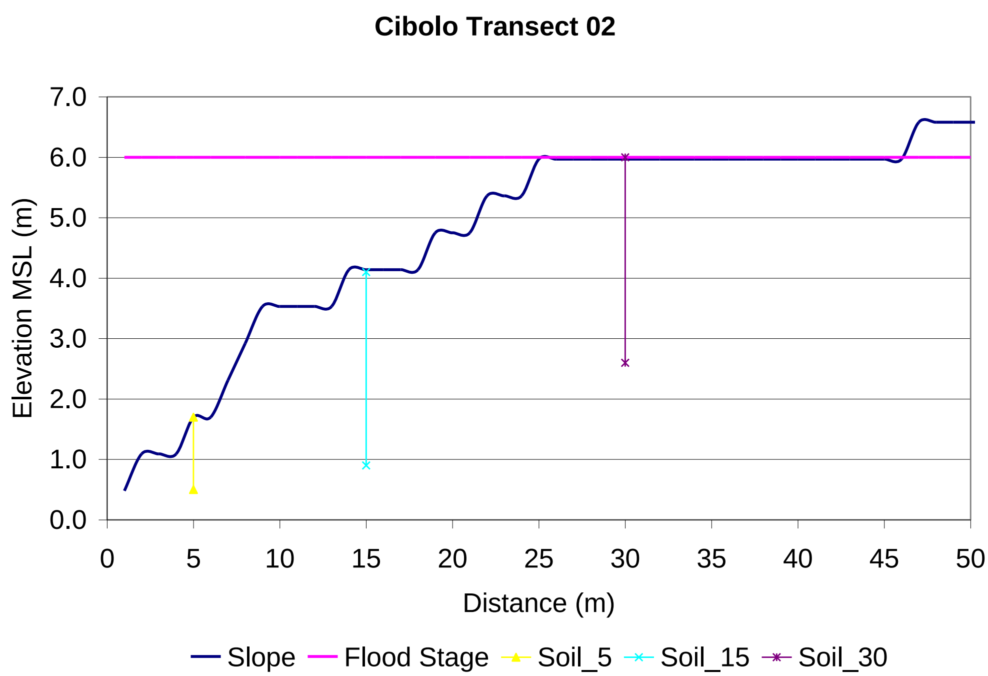


**Figure 37:** Augured Soil Depths for Transect 02 in the Cibolo Creek Site

Figure 38 indicates that at 5m distance water table depth was 1.6m but beyond that it was below 4m at Goliad. Comparison of water table depth in the Goliad site to mature tree ranges (Figure 28) indicates that all sampled species' distributions were independent of a shallow water table.

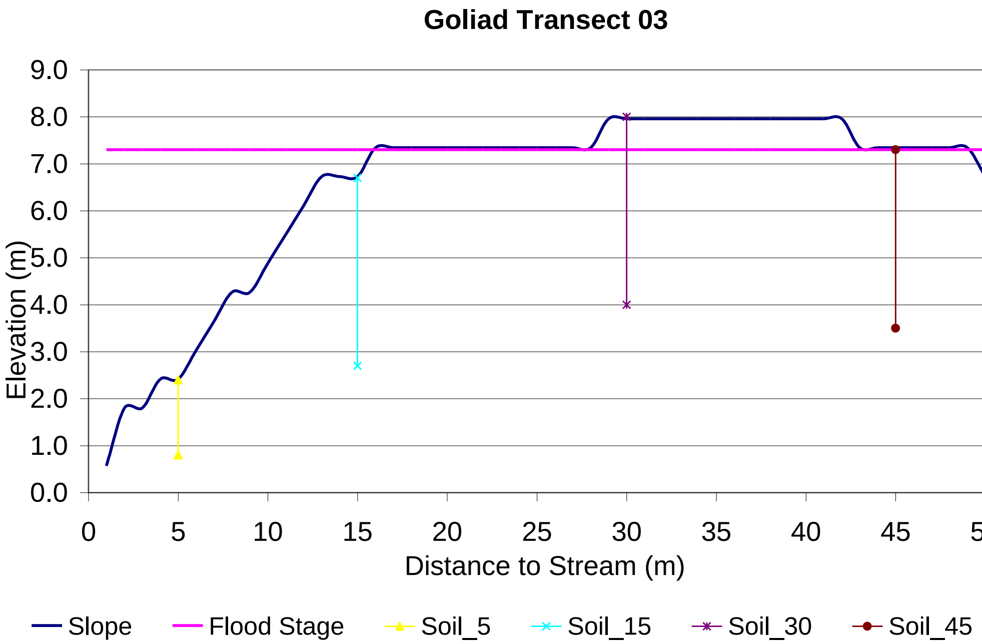


**Figure 38:** Augured Soil Depths for Transect 03 in the Goliad Site

However, no *S. nigra* were measured in any of the biodiversity samples (preventing examination of their spatial location to the water depth), and the distantly located *F. pennsylvanica* were in a semi-manicured area toward the outer edge of one of the transects near a parking lot and picnic tables. It *may* be possible that this area receives supplemental watering that could influence the survival of *F. pennsylvanica* so distantly located to the stream.

Figure 39 shows the water table depth at the Hwy 77 Site was 2m at 5m distance, and 3.5m at 15m distance to the stream, with further distances below 4m. When compared to mature tree ranges (Figure 31), *S. nigra* shows a distribution as far away as 15m and 4m above the stream. *F. pennsylvanica*, located at a range of 10-20m, tends to grow near the 3.5m deep water table. All other tree distributions appear independent of changing water tables.

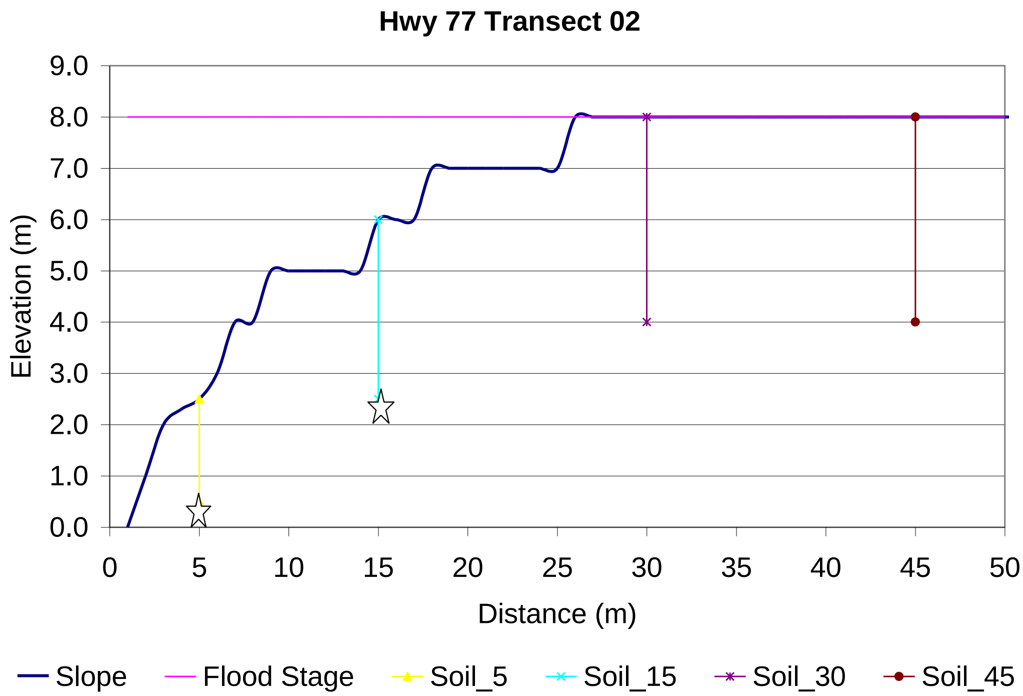


**Figure 39:** Augured Soil Depths for Transect 02 in the Hwy 77 Site

Summaries of soil characteristics are shown in Table 9. A 'Y' in the depth column indicates groundwater table was penetrated. An 'N' denotes it was not reached.

| Site Descriptions | Distance 5m | 15m | 30m | 45m |
|---|---|---|---|---|
| **Calaveras** | | | | |
| *SSURGO Soil Classes* | Silty Clay Loam | Silty Clay Loam | Silty Clay Loam | Silty Clay Loam |
| *Observed Soil Characteristics* | Sandy Clay | Up - Sand Low - Clay | Up - Sand Low - Clay | Loamy Clay |
| *Depth (m) / Water* | 1.5 / Y | 2.5 / Y | 2.8 / Y | 2.5 / Y |
| **Cibolo** | | | | |
| *SSURGO Soil Classes* | Fine Sandy Loam | Fine Sandy Loam | Fine Sandy Loam | Fine Sandy Loam |
| *Observed Soil Characteristics* | Collapsing Sand | Up- Sand/Clay Low - Clay | Up - Clay Low - Clay/Gravel | N/A |
| *Depth (m) / Water* | 1.2 / Y | 3.2 / Y | 4 / N | N/A |
| **Goliad** | | | | |
| *SSURGO Soil Classes* | Silty Clay Loam | Silty Clay Loam | Silty Clay Loam | Silty Clay Loam |
| *Observed Soil Characteristics* | Silt/Sand | Up - Sand Low - Sand/Clay | Up - Sand/Clay Low - Clay/Gravel | Up - Sand/Clay Low - Clay/Gravel |
| *Depth (m) / Water* | 1.6 / Y | 4 / N | 4 / N | 3.8 / N |
| **Hwy 77** | | | | |
| *SSURGO Soil Classes* | Clay Loam | Clay Loam | Clay Loam | Clay Loam |
| *Observed Soil Characteristics* | Fine Sand | Collapsing Fine Sand | Up - Sandy Low - Clay | Up - Sandy Low - Clay/Gravel |
| *Depth (m) / Water* | 2 / Y | 3.5 / Y | 4 / N | 4 / N |

**Table 9:** Table of Soil Hydric Conditions for All Sites

## Relationship of Species Range to Soil Water Depth

One of the major limitations to the soil study was the broad spatial scale between transects (this was recognized early on and the 5m distance was added), as well as depth limitations to hand auguring. Thus there are limitations in making fine-scale conclusions about water table and tree distribution. Modifications for future studies would be to refine the spatial distribution, allow for deeper penetration into soils, and repeatability for persistence of water table depth.

However, despite the limitations, conclusions can be made: when considered as a continuum community along the river, the combined results of water table measurements indicate that *S. nigra* appears the only species that was consistently limited to regions where the water table was more shallow than 3m (though *A. negundo* and *F. pennsylvanica* had varying results. Of course what cannot be separated from these results would be the wetting potential of higher stream flows. Because of the shallow roots of trees such as *S. nigra, A. negundo* and *F. pennsylvanica*, their distribution could also be highly influenced by stream bank wetting when soil water tables were receding and/or out of root reach.

RIVER FLOW AND TREE PRODUCTIVITY

Table 10 is a summary of all dominant cored trees and their relationships (both individually and as a community) to total annual river flows at their corresponding river gauges. All flows are represented as discharge in cubic kilometers per year ($km^3/y$). This discharge was calculated by taking the average daily flow in cfs, scaling it up to a 24-hour period and converting it to cubic kilometers. The sum of daily flows were taken as the yearly flow. Two responses are given: flows at which growth was suppressed, and flows at which the trees showed exceptional growth. A discussion of each specie in each site will follow below.

| **Species, Relationship to River Flow** | **Calavares (in km3/yr)** | **Cibolo (in km3/yr)** | **Goliad (in km3/yr)** | **Hwy 77 (in km3/yr)** |
|---|---|---|---|---|
| *Acer negundo* | | | | |
| Growth suppressed | >2.0 | <0.08 and >0.4 | <0.4 and >2.0 | <0.22 and >1.8 |
| Exceptional Growth | 0.25 - 1.8 | 0.21-0.4 | 0.4 - 1.8 | 1.2 - 1.6 |
| *Carya illinoinensis* | | | | |
| Growth suppressed | >2.0* | N/A | >1.9 | <0.22 and >1.1 |
| Exceptional Growth | 0.7 - 1.1 | N/A | 0.25 - 1.1 | 0.35 - 0.9 |
| *Celtis laevigata* | | | | |
| Growth suppressed | <0.75 | <0.1 and >0.37 | >1.0 | >0.8 |
| Exceptional Growth | >1.5 | 0.12 - 0.27 | <0.5 | 0.22 - 0.75 |
| *Fraxinus pennsylvanica* | | | | |
| Growth suppressed | >2.5 | N/A | >2.0 | <0.3 and >1.5 |
| Exceptional Growth | 0.8 - 1.8 | N/A | 0.40 - 1.5 | 0.9 - 1.5 |
| *Populus deltoides* | | | | |
| Growth suppressed | <0.5 and >2.5 | N/A | N/A | N/A |
| Exceptional Growth | 1.25 - 2.1 | N/A | N/A | N/A |
| *Salix nigra* | | | | |
| Growth suppressed | <0.5 | <0.08 | < 0.30 | <0.22 |
| Exceptional Growth | >1.2 | >0.32 | >1.1 | >0.8 |
| *Ulmus crassifolia* | | | | |
| Growth suppressed | <0.4 | >0.20 | N/D** | >1.0* ~ |
| Exceptional Growth | >1.75 | <0.08 | N/D** | 0.7 - 0.8 |
| *Morus rubra* | | | | |
| Growth suppressed | N/A | N/A | <0.40 and >4.0 | N/A |
| Exceptional Growth | N/A | N/A | 0.45 - 1.2 | N/A |
| **Community Ranges** | | | | |
| Growth suppressed | <0.4 and >2.0 | <0.08 and >0.4 | <0.3 and >2.0 | <0.22 and>0.8 |
| Exceptional Growth | 0.25 - 2.5 | Up to 0.40 | 0.25 - 1.8 | 0.22-1.5 |

* Overall growth supperssed post-1985

**No relationship detected - trees demonstrating complacency

~*Ulmus fulva*

**Table 10:** Summary of Tree Response to River Flow

When taken as a community, trees in the Calaveras Site had broad ranges for both exceptional and suppressed growth. Trees experienced growth suppression in flows ranging from less than 0.4 and in excess of 2.0 $km^3/y$. Yet some trees also showed exceptional growth at the lowest flows and highest flows recorded. This demonstrates a major limitation of the method of using general riparian classes for determining riparian functionality and health. A better approach may be to determine one or two key indicator species, and use them to determine long-term past maintenance as a way to predict future maintenance. That said, there are some useful observations that can be made from within the community. Trees that generally indicate a healthy riparian forest (*A. negundo, F. pennsylvanica*) exhibit similar responses: suppression with too high flows. Trees that would be indicators of upland expansion/invasion into the riparian zone show no such response; yet so does S. *nigra*, typically an indicator of riparian health.

Taken as a community, trees from the Cibolo Creek Site showed that productivity was highest with flows between 0.08 and 0.40 $km^3/y$, but generally showed suppression when discharge was outside that range. While *A. negundo* was suppressed by high flows, *S. nigra* growth showed its greatest potential when flows exceeded 0.32 $km^3/y$. The Goliad community showed suppression of growth below 0.3 and above 2.0, with optimal growth in between – with the exception of *S. nigra* which showed no adverse effects to high flows. The community response to river flow at the Hwy 77 site showed optimum growth of all trees between 0.2 and 1.5 $km^3/y$, with suppression of flows below 0.2, and for some species above as little as 0.8 $km^3/y$. *S. nigra* was the only specie that showed no suppression with increased flow along the river for all sites.

Response of *U. crassifolia* was notable because of its extreme variability and lack of direct response to water flows. Obviously factors controlling this specie's productivity include those other than simply water availability (e.g. sunlight penetration, root competition, etc.) that both influence its growth pattern more strongly and cannot be determined by this study. *C. illinoinensis* appears to not only be suppressed by too-high flows, but in the Calaveras Site, the community productivity has greatly subsided in the past 25 years. Because of this specie's lack of tolerance to saturated soils, coupled with the fact that many of them are located in what were previously planted orchards in low-lying fields along the floodplains, these trees may be exhibiting stress to soils that are no longer draining adequately with the increased river flows. Below are data for and a discussion of the response by specie, grouped by site.

## Calaveras

Figures 40a-d illustrate the data summarized in Table 10 for the key indicator species along the San Antonio River (*A. negundo, F. pennsylvanica, S. nigra,* and *C. laevigata*). Non-indicator species were not shown individually. Each graph is a comparison of total annual river discharge for that site's gauging station (refer to Table 2) vs. basal growth for that same year. The green masking corresponds to discharge that resulted in highest productivity, while the red masking corresponds to discharge associated with reduced and/or inversely proportional tree growth. The pink line indicates one standard deviation of ring width (with the center dot showing medium ring width) for which 76% of all that specie's BI falls within, and was used to examine significantly high and low productivity years.

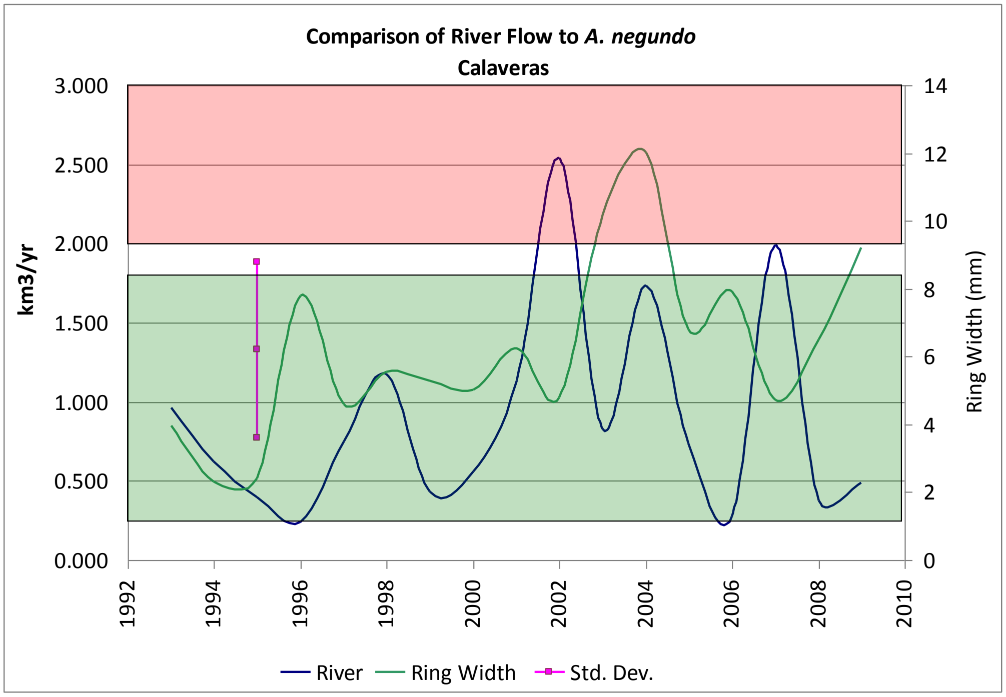


**Figure 40a:** Annual River Flow vs *A. negundo* Productivity

The highest productivity for *A. negundo* (Fig. 40a) was seen with flows up to 1.8 km$^3$/y. There was no low flow level associated with low growth, however the two flows in excess of 800K km$^3$/y cause flows to be greatly reduced.

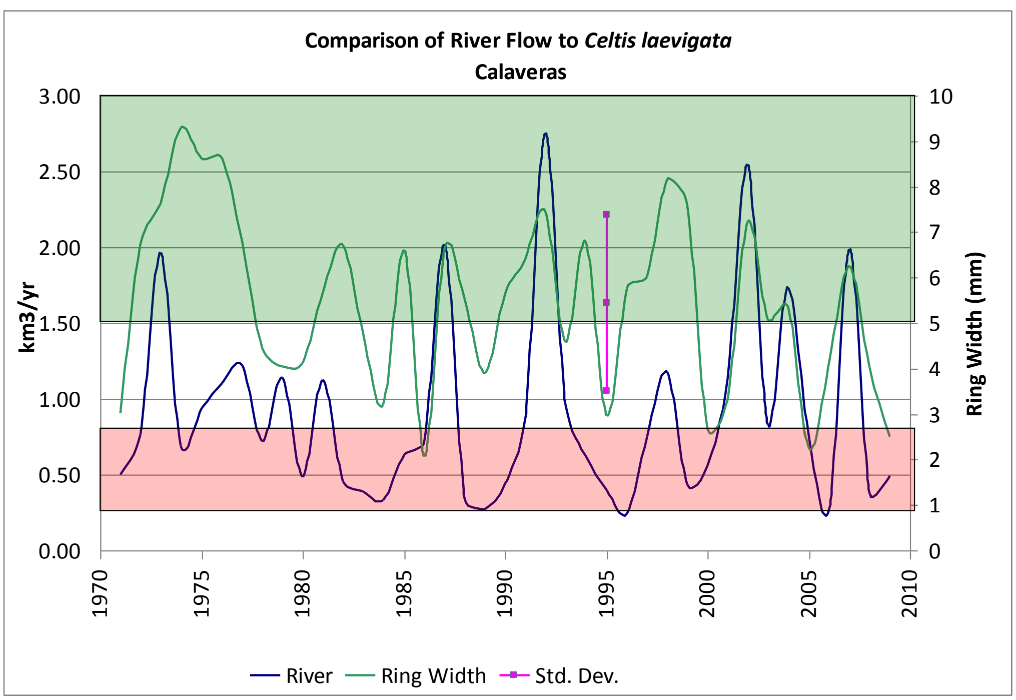


**Figure 40b:** Annual River Flow vs *C. laevigata* Productivity

Flows less than 0.75 km$^3$/y tended to suppress growth in *C. laevigata* (Fig. 40b) while flows in excess of 1.5 stimulated the most productive growth. This response is likely due in part to the fact that while they were within 50m the river, trees of this specie were chosen specifically because of their exceptional elevation above the stream (they were perched on a nearby high hill above the floodplain), and provided the opportunity to examine trees in the area that were clearly well outside of the river's influence.

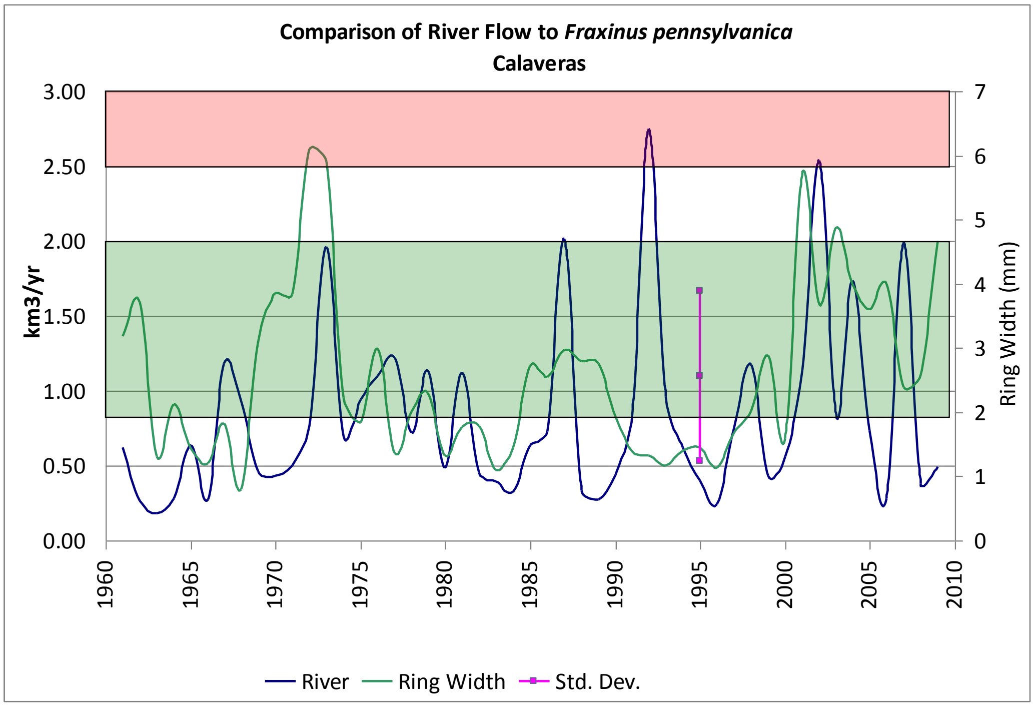


**Figure 40c:** Annual River Flow vs *F. pennsylvanica* Productivity

Figure 40c shows that while *F. pennsylvanica* experiences its best growth between 0.8 and 1.8 km$^3$/y, and doesn't appear to be affected by low flows, flows in excess of 2.5 km$^3$/y cause a reduction in BI.

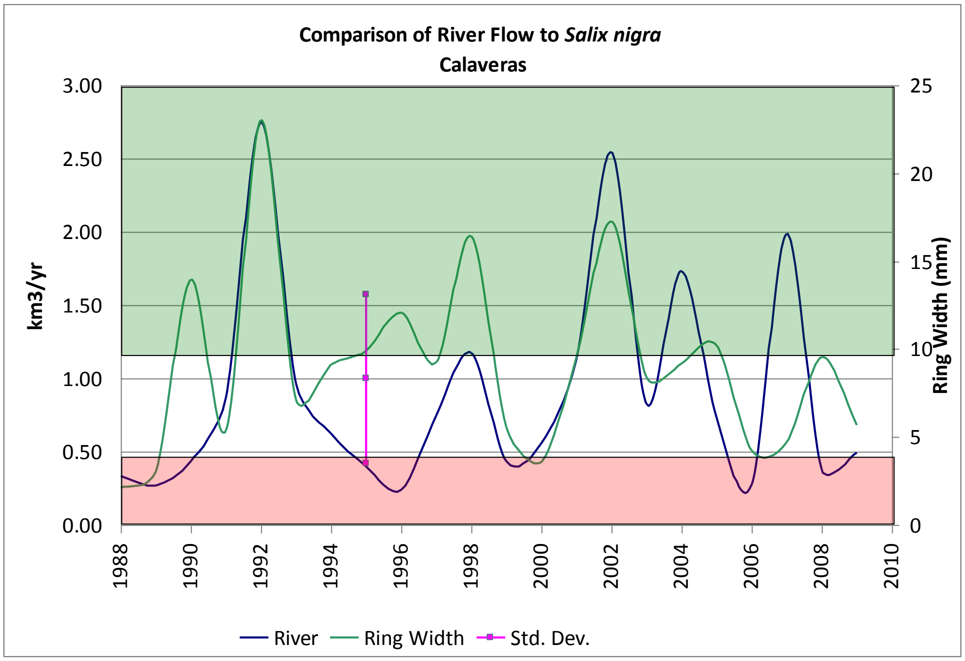


**Figure 40d:** Annual River Flow vs *S. nigra* Productivity

Figure 40d shows that *S. nigra* suffers when flows are less than 0.5 $km^3/y$ but no upper limit, as high productivity was seen with flow above 1.2 $km^3/y$.

## Cibolo Creek

Figures 41a-c illustrate the data for key indicator species (*A. negundo, S. nigra,* and *C. laevigata*) summarized in Table 10. Each graph is a comparison of total annual river discharge for that site's gauging station (refer to Table 2) vs. basal growth for that same year. The green masking corresponds to discharge that resulted in highest productivity, while the red masking corresponds to discharge associated with reduced and/or inversely proportional tree growth. The pink line indicates one standard deviation of ring width (with the center dot showing medium ring width) for which 76% of all that specie's BI falls within, and was used to examine significantly high and low productivity years.

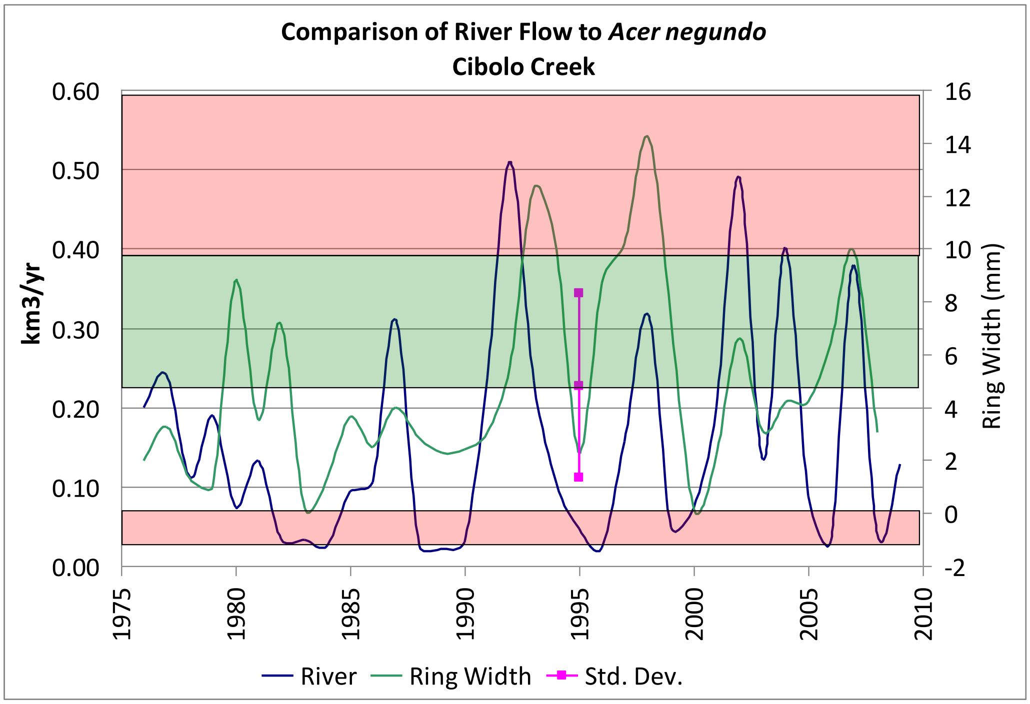


**Figure 41a:** Annual River Flow vs *A. negundo* Productivity

Flows below 0.075 and above 0.40 km$^3$/y tended to suppress growth in *A. negundo* (Fig. 41a). The specie showed best growth from 0.21 – 0.40 km$^3$/y.

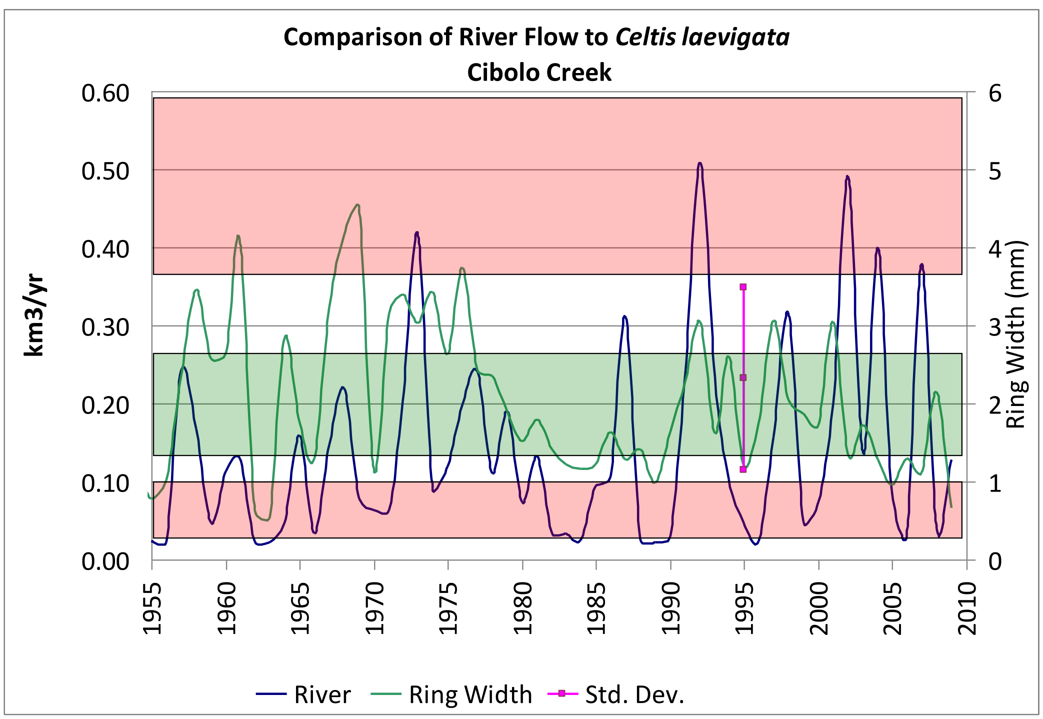


**Figure 41b:** Annual River Flow vs *C. laevigata* Productivity

Flows below 0.10 and above 0.37 km$^3$/y tended to suppress growth in *C. laevigata* (Fig. 41b) with the exception of 1992 discharge. The specie showed best growth from 0.12 – 0.27 km$^3$/y.

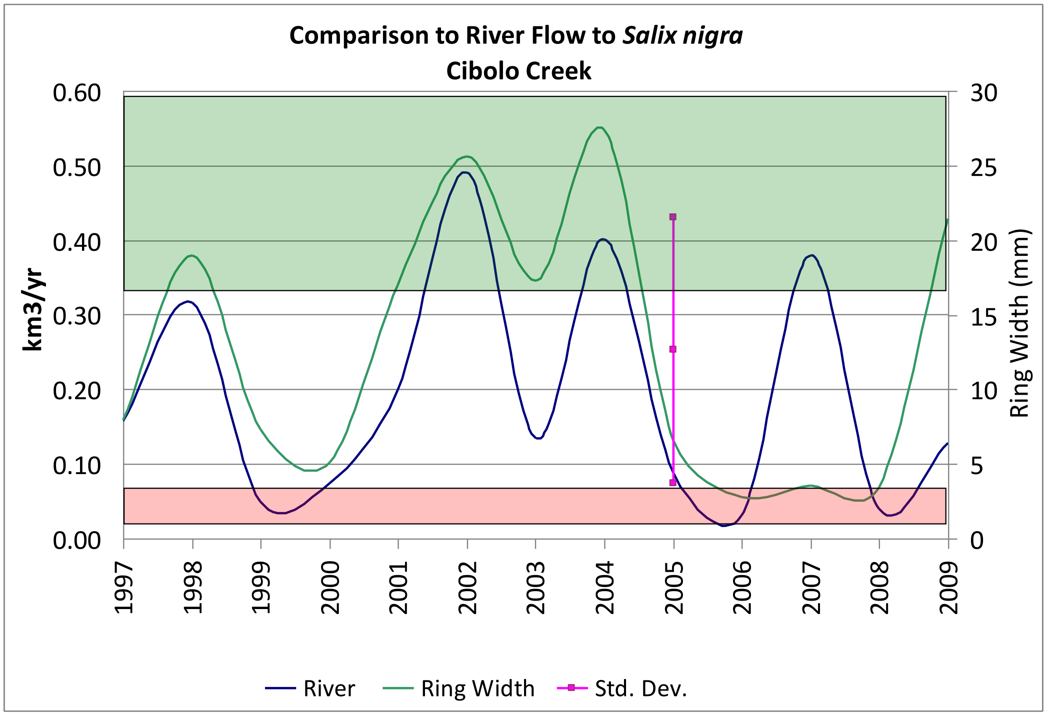


**Figure 41c:** Annual River Flow vs *S. nigra* Productivity

*S. nigra* was suppressed when flows dropped below 0.08 $km^3$/y and grew best with flow above 0.32 $km^3$/y (Fig. 41c).

## Goliad

Figures 42a-d illustrate the data for key indicator species (*A. negundo, F. pennsylvanica, S. nigra,* and *C. laevigata*) summarized in Table 10. Each graph is a comparison of total annual river discharge for that site's gauging station (refer to Table 2) vs. basal growth for that same year. The green masking corresponds to discharge that resulted in highest productivity, while the red masking corresponds to discharge associated with reduced and/or inversely proportional tree growth. The pink line indicates one standard deviation of ring width (with the center dot showing medium ring width) for which 76% of all that specie's BI falls within, and was used to examine significantly high and low productivity years.

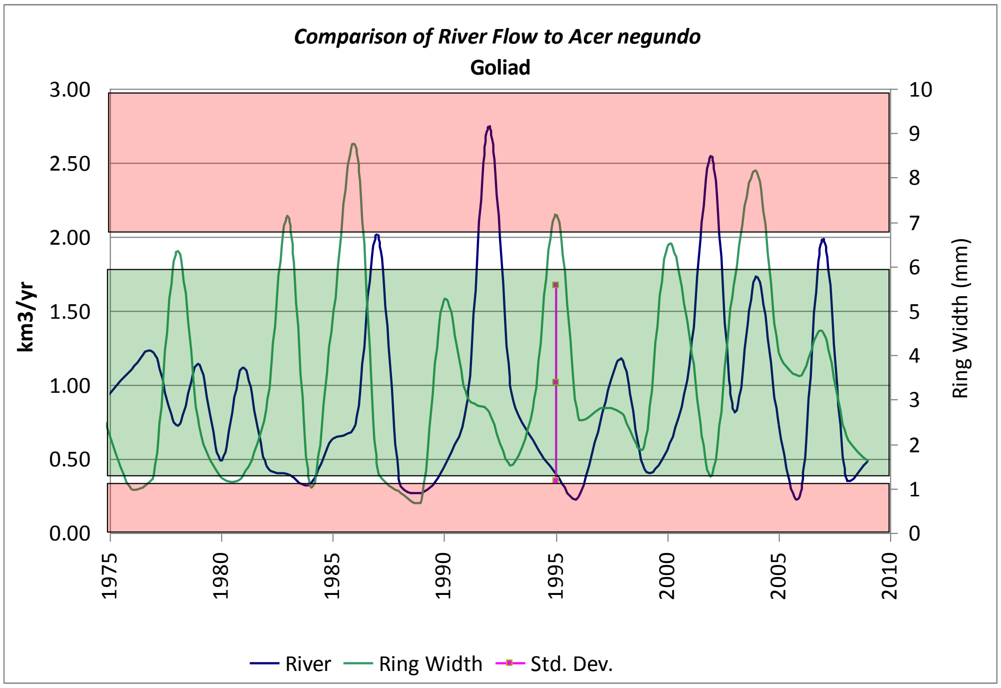


**Figure 42a:** Annual River Flow vs *A. negundo* Productivity

Flows below 0.4 and above 2.0 km$^3$/y tended to suppress growth in *A. negundo* (Fig. 42a). The specie showed best growth from 0.4 – 1.8 km$^3$/y.

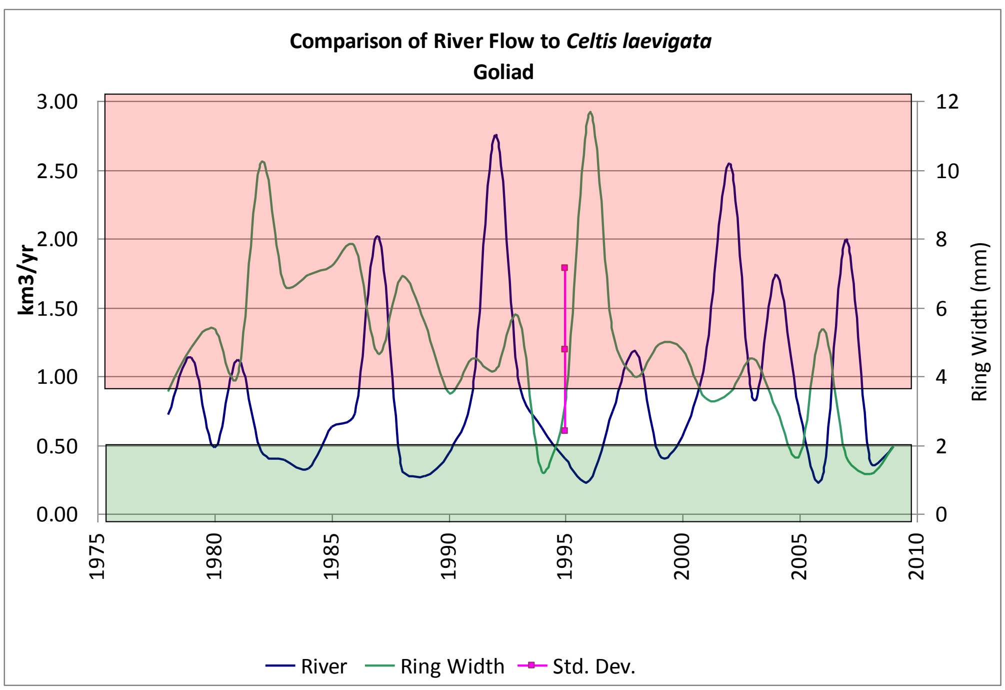


**Figure 42b:** Annual River Flow vs *C. laevigata* Productivity

*C. laevigata* also had a generally inverse relationship with excessive river flows. It was suppressed by flows above 1.0 and grew best with flows below 0.50 km$^3$/y (Fig. 42b).

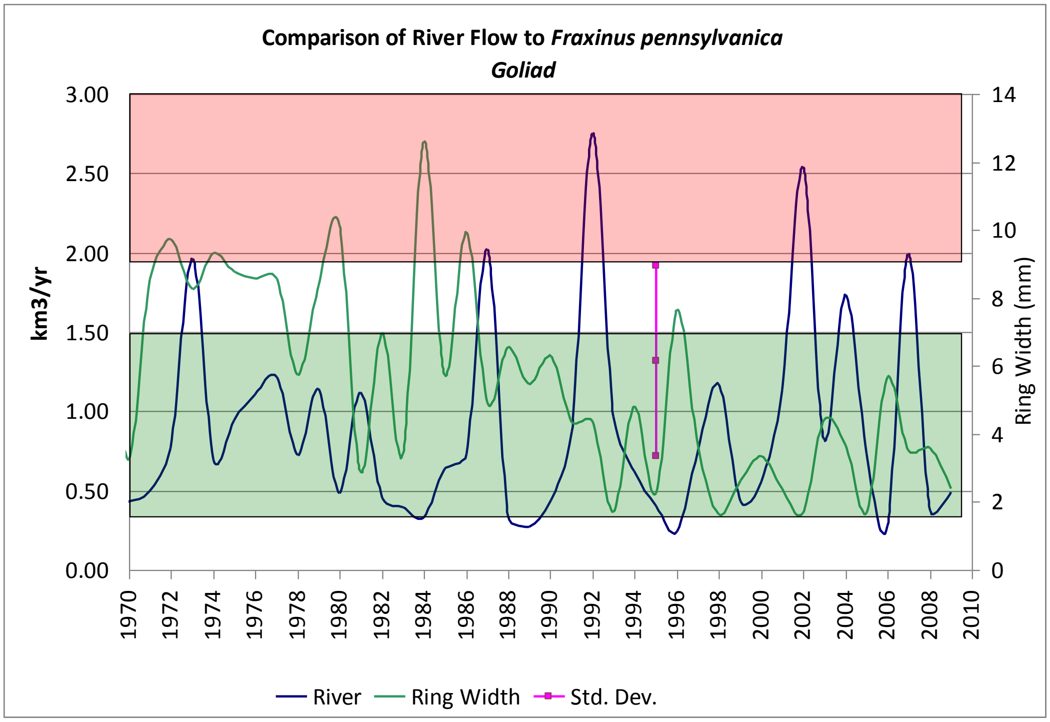


**Figure 42c:** Annual River Flow vs *F. pennsylvanica* Productivity

*F. pennsylvanica* too had a generally inverse relationship with excessive river flows. It was suppressed by flows above 2.0 and grew best with flows below 1.5 km$^3$/y (Fig. 42c).

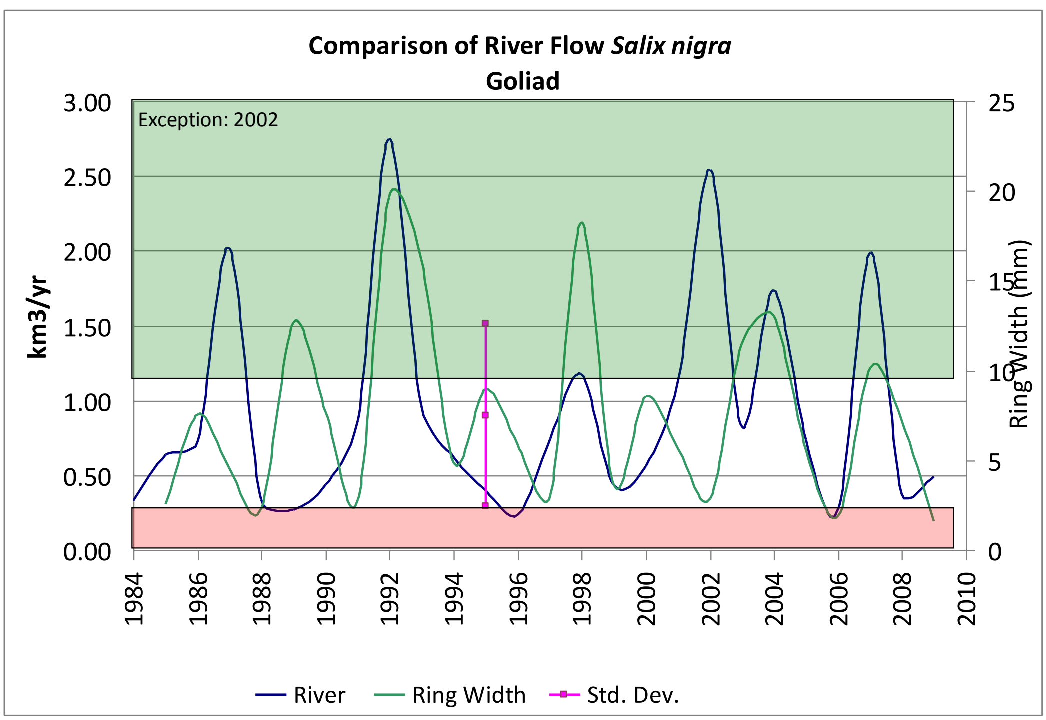


**Figure 42d:** Annual River Flow vs *S. nigra* Productivity

*S. nigra* was the only specie in the community with a direct relationship to river discharge (Fig. 42d). It was suppressed by flows below 0.30 km$^3$/y but had optimal growth with flows in excess of 1.1 km$^3$/y. *U. crassifolia* was not graphed. Trees showed age complacency and were excluded from analysis.

**Hwy 77**

Figures 43a-c illustrate the data for key indicator species (*A. negundo, F. pennsylvanica*, and *S. nigra*) summarized in Table 10. Each graph is a comparison of total annual river discharge for that site's gauging station (refer to Table 2) vs. basal growth for that same year. The green masking corresponds to discharge that resulted in highest productivity, while the red masking corresponds to discharge associated with reduced and/or inversely proportional tree growth. The pink line indicates one standard deviation of ring width (with the center dot showing medium ring width) for which 76% of all that specie's BI falls within, and was used to examine significantly high and low productivity years.

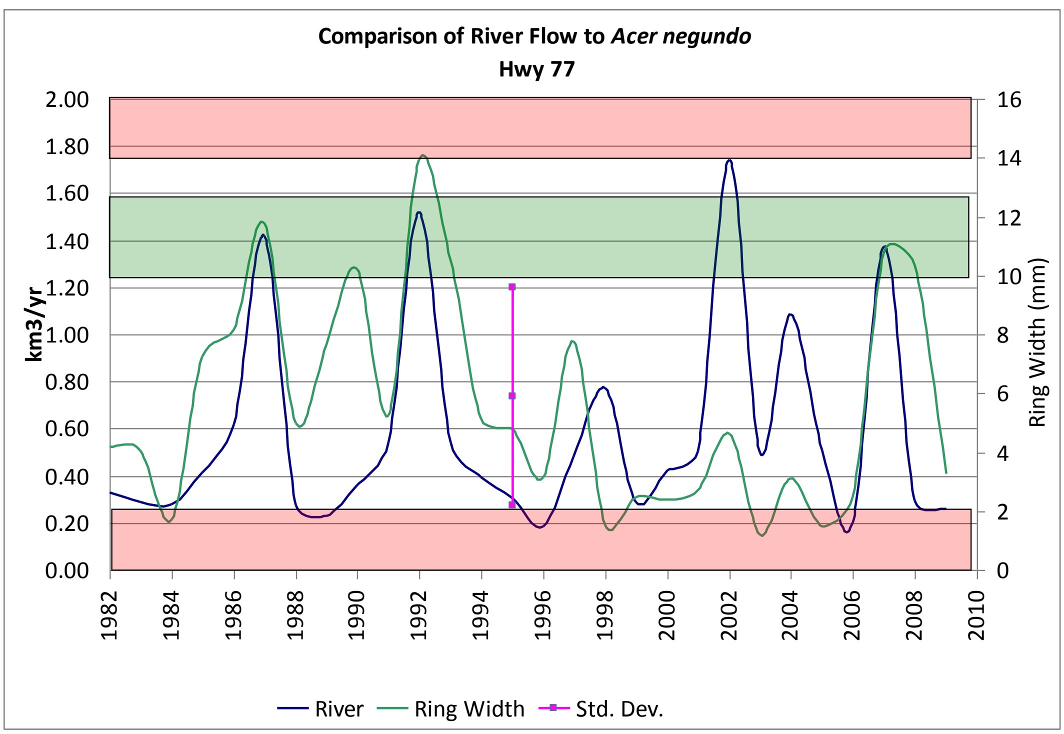


**Figure 43a:** Annual River Flow vs *A. negundo* Productivity

Flows below 0.22 and above 1.8 km$^3$/y tended to suppress growth in *A. negundo* (Fig. 43a). The specie showed best growth in a small range from 1.2 – 1.6 km$^3$/y.

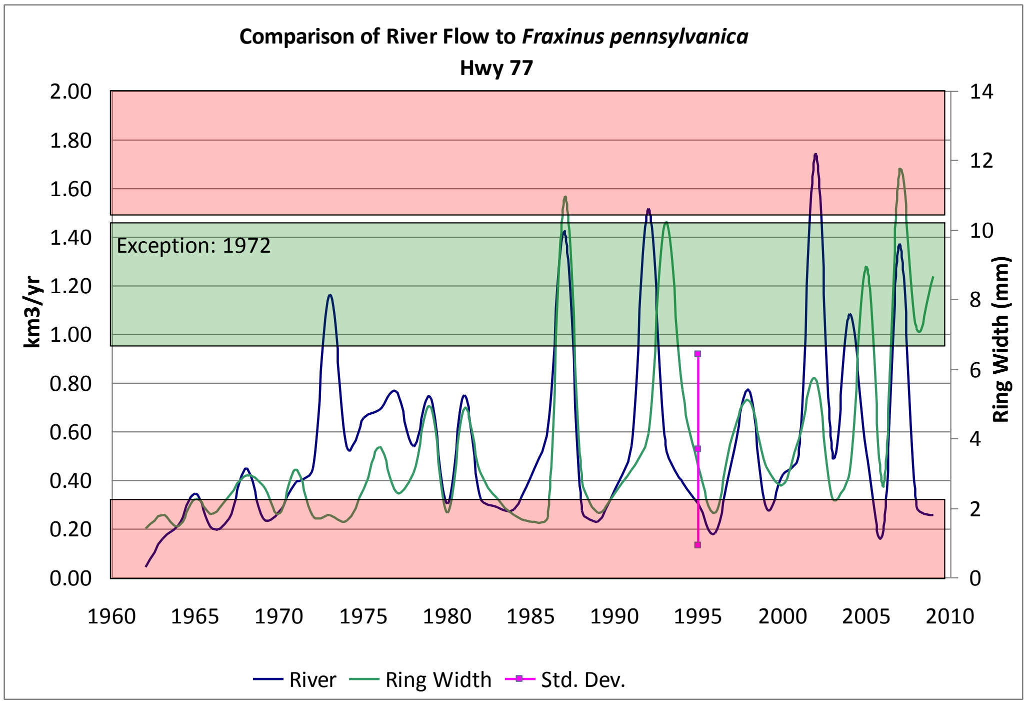


**Figure 43b:** Annual River Flow vs *F. pennsylvanica* Productivity

Flows below 0.3 and above 1.5 km$^3$/y tended to suppress growth in *F. pennsylvanica* (Fig. 43b). The specie showed best growth from 0.9 – 1.5 km$^3$/y.

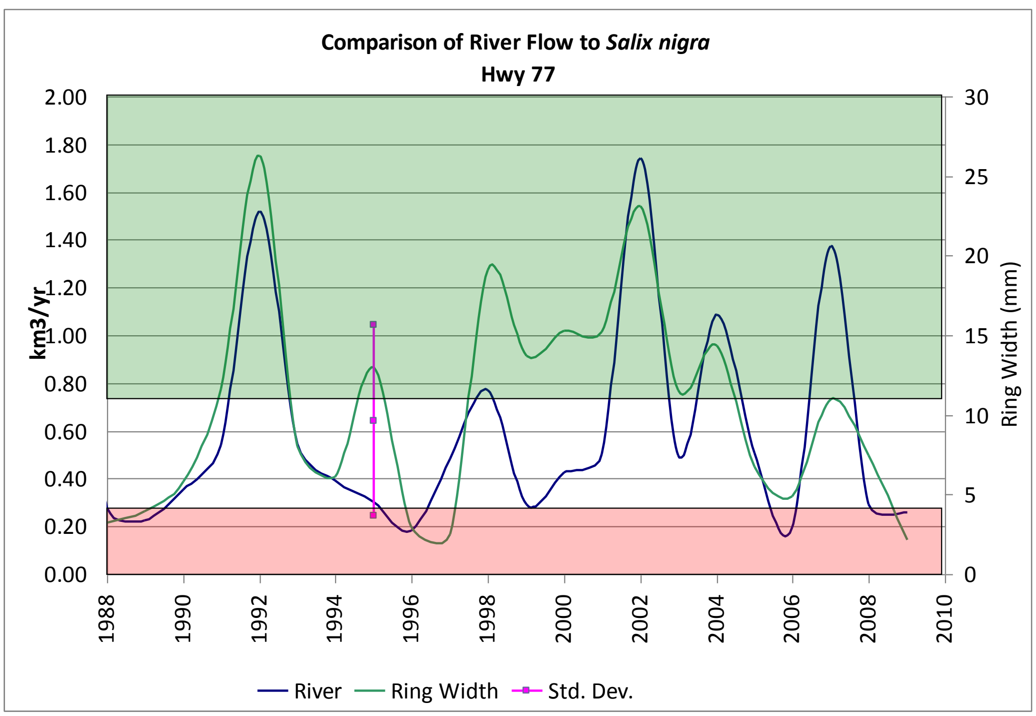


**Figure 43c:** Annual River Flow vs *S. nigra* Productivity

Similar to the Goliad Site, *S. nigra* was the only specie in the Hwy 77community with a direct relationship to river discharge (Fig. 43c). It was suppressed by flows below 0.22 $km^3/y$ but had optimal growth with flows in excess of 0.8 $km^3/y$.

**Flood Frequency and Timing**

Because several trees showed marked negative responses to excessive flows, (and the mid 80's appeared repeatedly as a tipping point) graphs were created to compare select flows for each of the three river gauges in the 25 years leading up to 1985 as well as the 25 years post-1985. Based on general information about average channel heights in the study areas, USGS reported flood stages, and relationships between flood stage and discharge in cubic feet per second (cfs_ (see Table 3 and Fig.'s 11, 14 and 17) the following flows were chosen as a representative flood for each gauging station:
#08186000 at Cibolo Creek near Falls City = 650 cfs
# 08188500 at Goliad, TX = 1000 cfs
#08181800 near Elmendorf = 1000 cfs

Figure 47 shows that in the spring and fall months, flow in Cibolo Creek has decreased since 1985. However in summer (June and July) and early winter (November and December, flows have increased, causing a shift of flood timing along Cibolo Creek.

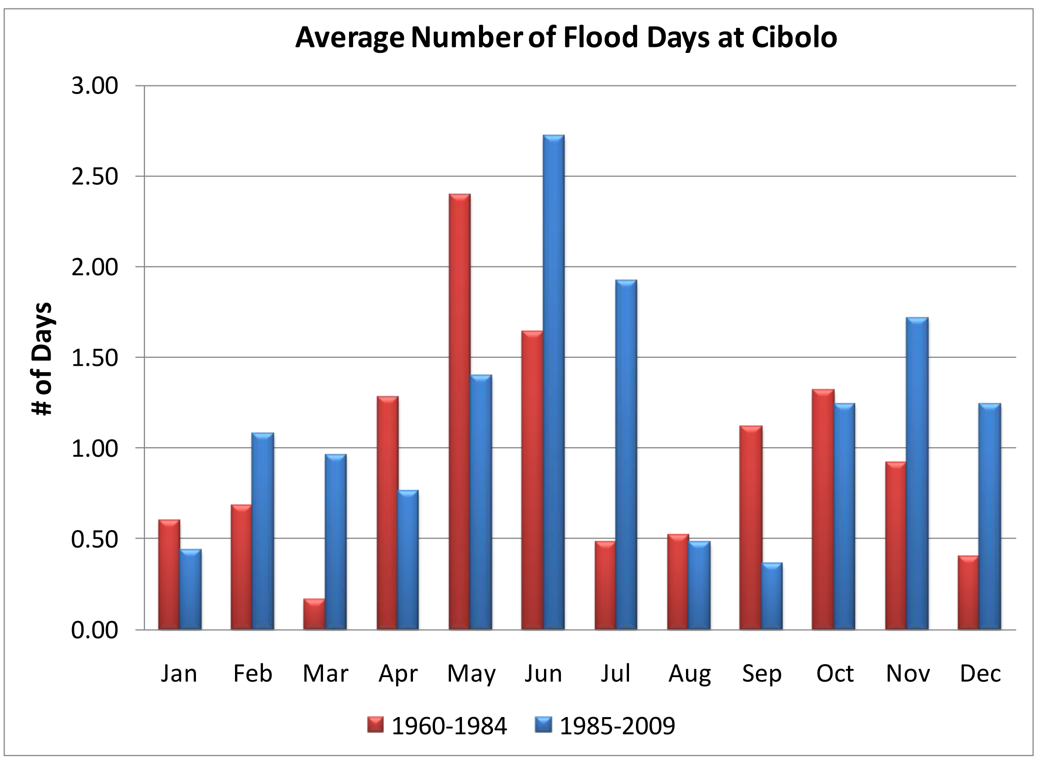


**Figure 47:** Comparison of pre and post-1985 # of days in which flow exceeded 650 cfs (recorded as flood days) at USGS gage #08186000 at Cibolo Creek near Falls City

Flow along the San Antonio River at Goliad, TX (USGS gage # 08188500) has seen a reduction in the number of days in which flows exceed 1000 cfs in May (and slightly in February and October), but all other months exhibit increases (Fig. 48).

In particular winter months of November to January as well as mid-summer July have seen considerable increases.

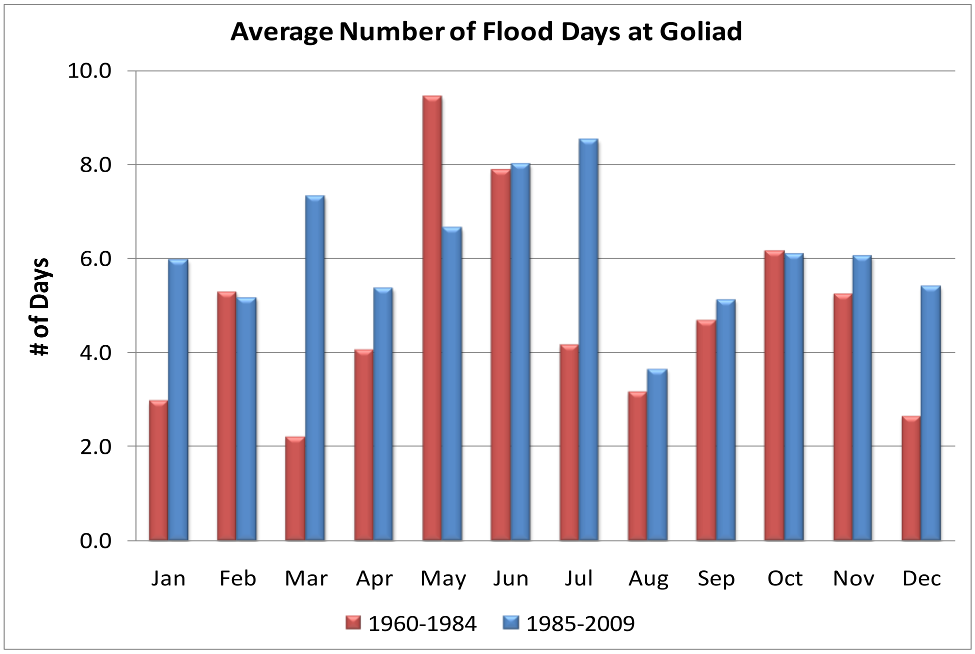


**Figure 48:** Comparison of pre and post-1985 number of days in which flow exceeded 1000 cfs (recorded as flood days) at USGS gage 08188500 at Goliad, TX

According to Figure 49 flow along the San Antonio River (USGS gage #08181800) near Elmendorf, TX has seen an overall increase in flow exceeding 1000 cfs for all months except February which remained relatively unchanged, and May which has seen a reduction. June and July had the greatest increases in post-1985 years.

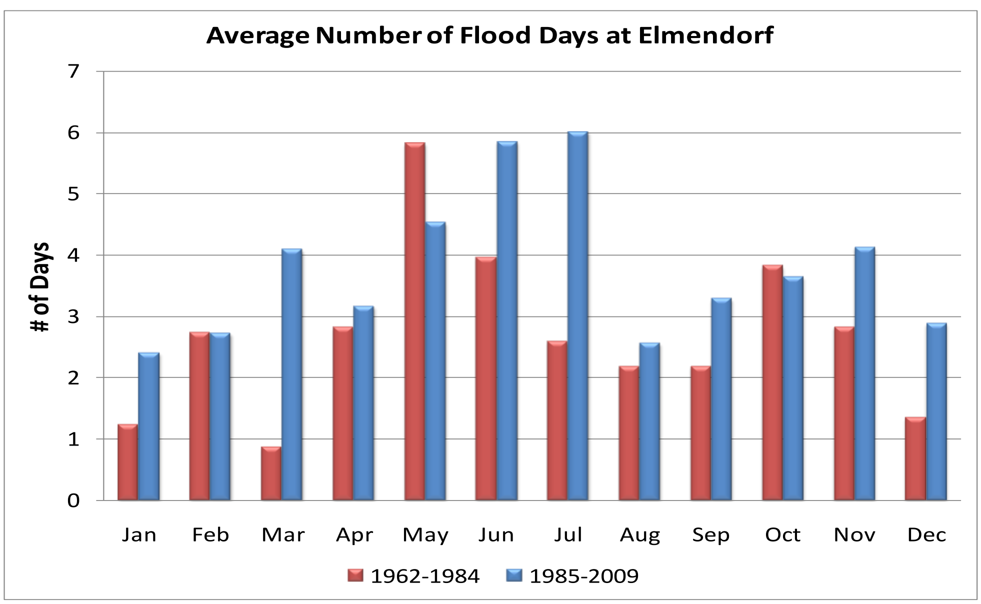


**Figure 49:** Comparison of pre and post-1985 # of days in which flow exceeded 100 cfs (recorded as flood days) at USGS gage #08181800 near Elmendorf

Seen in all gauged sites (Figs. 47-49) is evidence that flows for May are considerably reduced, but are increased in the driest parts of summer - June and July, as well as an increase of discharge in winter months. Most important to the trees should be the alteration to summer months, which often pose much more hardship for trees as they struggle for water to maintain productivity throughout the hot, dry Texas heat. However, closer inspection of select floods and their effect on that's year's BI indicate otherwise. Four flood events whose flows were large enough to be seen at the monthly as well as the yearly scale can be seen in the recent record: in 1992 a flood in February was responsible for the majority of that year's flow. 2002 and 2007 both had floods in July that account for the majority of their annual flow and 2004 experienced a flood in November that accounted for the majority of that year's flow. Individual tree responses dictate that the 2002 and 2007 floods were often indicated as suppressing events for those trees that were limited in productivity in too high flows. 2004 (the December flood) tended to have little effect on productivity and 1992, the February event, had mixed results. Some trees benefited from the early season flood, but more showed a suppression of growth that year. Note: these are excessively high floods, outside of normal high flow; however clearly changes in timing of flood pulses have the potential to influence annual BI for that year's growth.

## SAN ANTONIO RIVER CONCLUSIONS

Results show that the San Antonio River is a highly incised stream. With the exception of point bars, channel slopes were steep and showed evidence of frequent slumping. Floodplains ranged from 5-8m above baseflow. Obvious breaks existed between gently-sloped, rather horizontal floodplains and the active incised river channel; though Cibolo Creek sites were less incised but still steep. Often lower-tiered sand bars could be found where upper bank soils had accumulated near the low-water's edge.

When considered as a continuum community along the river, the combined results of water table measurements indicate that *S. nigra* was the only species that was consistently limited to regions where the water table was more shallow than 3m (though *A. negundo* and *F. pennsylvanica* did too, with varying results). What cannot be separated from these results would be the wetting potential of higher stream flows. Because of the shallow roots of trees such as *S. nigra, A. negundo* and *F. pennsylvanica*, their distribution could also be highly influenced by stream bank wetting when soil water tables were receding and/or out of root reach. A limitation to the water table depth study was the broad spatial scale between transects (even given the 5m distance addition), as well as depth limitations to hand auguring, which limit conclusions about water table and tree distribution.

Clearly, flows along the San Antonio River have increased over the past several decades. Particularly, the past 25 years have seen exceptional increases in discharge along all analyzed reaches in this study for this river. To better predict future flow regime necessary to protect riparian zones along the San Antonio River, we first had to analyze both historical productivity as well as examine the effects of those known changes on that productivity over time.

The use of multiple dominant species to individually analyze river flow to productivity, rather than relying on general wetland riparian groupings was very revealing. The variability between species' locations, seed dispersal, and productivity for species typically grouped together demonstrates a limitation to the traditional method of using general riparian classes for determining riparian functionality and health. A better approach may be to determine one or two key indicator species for use in determining long-term past maintenance as a way to predict future maintenance. The best example of this limitation is the difference in responses between *S. nigra* and *F. pennsylvanica*. Both are often considered FACW and/or OBL, depending on sources, both grow in very similar habitats, yet an examination of their response to long-term river flow showed that while excessively high flows often result in suppression of BI for mature *P. pennsylvanica, S. nigra* thrives at those same flows. Had they been clumped together the distinctly unique responses would have been obscured.

The question is which of these species be a better indicator? Actually, the use of *both* would be more beneficial. Because they both represent species indicative of a healthy riparian zone, the combined information of both responses provides a richer picture for predicting future flows. Additionally, this study recommends that one or two species be utilized as key indicator species for predicting riparian zones in decline (undergoing invasion of upland species to the detriment of riparian-healthy species), indicating the true riparian zone is either being reduced or overtaken because of altered flow/water availability. A key species for this indicator appears to be *C. laevigata*. Other than the Calaveras Site, where trees of this specie were uniquely outside of the river's direct influence, mature *C. Laevigata* trees' productivity appears to be limited by excessively high flows, even more so than *F. pennsylvanica* in most cases – indicating a potential cap to this species' ability to completely invade habitat of riparian-healthy species over time. But given past studies on its prevalence (Bush and Van Auken, 1984; and Bush *et. al,* 2006) it does appear to be gaining in dominance over the past 25 years.

In summary, data from this study indicate that if both *S. nigra* and *F. pennsylvanica* are taken into consideration then total annual flows for gaging site #08188500 at Goliad, TX are best kept under 2.0 $km^3/y$ (also encompassing most other community species' needs) and above 0.25 $km^3/y$. If *F. pennsylvanica* is excluded, then no cap appears necessary, however, the argument for a cap would be a) 2.0 $km^3/y$ also aligns with most other community species' productivity needs and b) while having/maintaining for only one riparian-healthy species isn't necessarily indicative of unstable river community (Prichard *et. al,* 1998) the very fact of both their historical presences would support maintenance of both for this river. Total annual flows for gauging site #08186000 at Cibolo Creek near Falls City are best kept under 0.40 $km^3/y$ and above 0.08 $km^3/y$. Total annual flows for gauging site #08181800 near Elmendorf, TX are best kept under 0.8 $km^3/y$ and above 0.22 $km^3/y$.

All gauged sites show considerably reduced discharge for May, but increases in the driest parts of summer, June and July, as well as some winter months. Analysis of select floods and their effect on that's year's tree BI indicate four flood events - whose flows were large enough to be seen at the monthly as well as the yearly scale - can be found in the recent record: in 1992 a flood in February was responsible for the majority of that year's flow. 2002 and 2007 both had floods in

July that account for the majority of their annual flow, and 2004 experienced a flood in November that accounted for the majority of that year's flow. Aside from *S. nigra*, individual tree responses) show that the 2002 and 2007 floods were often indicated as suppressing events for those trees that were limited in productivity in excessively high flows (including *F. pennsylvanica*). 2004 (the year of the December flood) tended to have little effect on productivity for most species, and 1992, the February event, had mixed results. Some trees benefited from the early-season flooding, but more showed a suppression of growth that year. Clearly changes in timing of flood pulses have the potential to influence annual BI for that year's growth, and rather than benefit mature trees, excessively high flow events may have negative effects so strongly recorded that the tree rings themselves reflect that event. General maintenance of the above recommended flows with annual/semi-annual floods into the riparian zone in spring and early fall should provide a stable riparian zone that is healthy enough to maintain and/or recover from natural episodic events.

Several species showed lower counts for trees in the 10-15 yr age classes. Given the very large flood event in early 1993 (16 years previous), and the known reduction of productivity shown in so many trees in the community, the low counts may be indicative of a larger community response to that flood. When stressed by such a large disturbance not only might a tree suffer reduced productivity but as a defense mechanism that same tree will either reduce fruit production and/or drop seeds maturely in order to survive (Myers, 1989). Therefore recruitment would be lower following an episodic event and may explain the lower numbers of trees in this age group.

*S. nigra* drops seeds usually from April to July in its southern range. Though also wind dispersed, adequate flows during these months must be maintained to allow for water dispersal. *S. nigra* saplings have been shown to fair best when wetted frequently (daily to weekly) but also allowed a period of several dry days in between to allow for soil draining. (Li *et. al.,* 2004).

Because adult *S. nigra* grow along the channel slopes and very near water's edge, adequate flows would include those events that overbank at least partially the channel slope to allow for water dispersal. As mentioned earlier, such events typically occur every year or two (Leopold, 1994). *F. pennsylvanica* seeds drop in late fall and winter, but do not germinate until the next spring. Wind dispersal can usually carry their samara a few hundred feet. Water dispersal would require adequate flow (bankfull and inundation into the floodplain) during winter/fall months. Currently along the San Antonio River, seed dispersal appears to be adequately maintained for all species, with the small exception of lower-channel slope *F. pennsylvanica* seedlings. However, the presence of both mature and saplings in those areas indicate this anomaly doesn't appear to a historical issue (and may be related to delayed germination or some other current-year factor). Unless river conditions drastically reduce in the future, seed dispersal does not appear to be a limiting consideration to a future healthy riparian zone.

Therefore general flow regimes should take into consideration seasonal flows that inundate both in spring and fall to adequately provide for seedling dispersal and sapling survival at least on a semi-annual basis. To predict a *specific* inundation, discharge and key indicator species' ranges from this study need to be coupled with studies using hydrological modeling of discharge to site spatial inundation, and from that the number of flood days for those periods estimated.

Considering the San Antonio River's flow is increasing rather than decreasing, plant invasions into the active channel do not appear to be an issue for this river. Though *C. laevigata* are expanding in the study sites they don't appear to be competitively excluding either of the indicator species, *S. nigra* or *F. pennsylvanica*, they don't appear to be establishing inside the bank channel, and their mature stands appear to exhibit limited productivity to higher stream flows, indicating they are not likely to be an issue in the future if flows are maintained at comparable levels.

*S. nigra* age distributions indicate that very few trees reach half their expected lifespan. Given their close proximity to the water's edge, loss of trees to high water flows probably explains their short life spans. This is likely the case for *A. negundo* as well. Because recruitment is strong, *S. nigra* appears to be relatively stable, though not expanding as there are low numbers of trees of early replacement age (5-15 years). Overall, the majority of trees (excepting *P. deltoides* and *C. illinoinensis*) appear stable enough to maintain themselves and/or recover future episodic flooding or drought events, but do not appear to be invading a channel whose high rate of erosion appears to provide frequent scouring of channel-dwelling plants.

# CHAPTER 3
# BRAZOS RIVER

## RIVER FLOW

Table 11 shows the USGS gauging stations used for comparison to tree ring growth, and the sites to which each gauge correlated. The length of recorded discharge and elevation data are indicated for each site.

**Brazos River**

| USGS # | Location | Discharge Data | Gage Height | Correlates to Site(s) |
|---|---|---|---|---|
| 8096500 | Waco / McLennan Co. | 1899-2009 | 1998-2009 | Marlin |
| 8098290 | Highbank / Falls Co. | 1966-2009 | 1986-2009 | Hearne, Snook |
| 8111500 | Hempstead / Washington Co. | 1939-2009 | 1998-2009 | Brazos Bend |

**Table 11:** USGS Gauging Stations for the Brazos River

The annual discharge for all three gauges, in Figure 50, shows that all are comparable in their flow patterns.

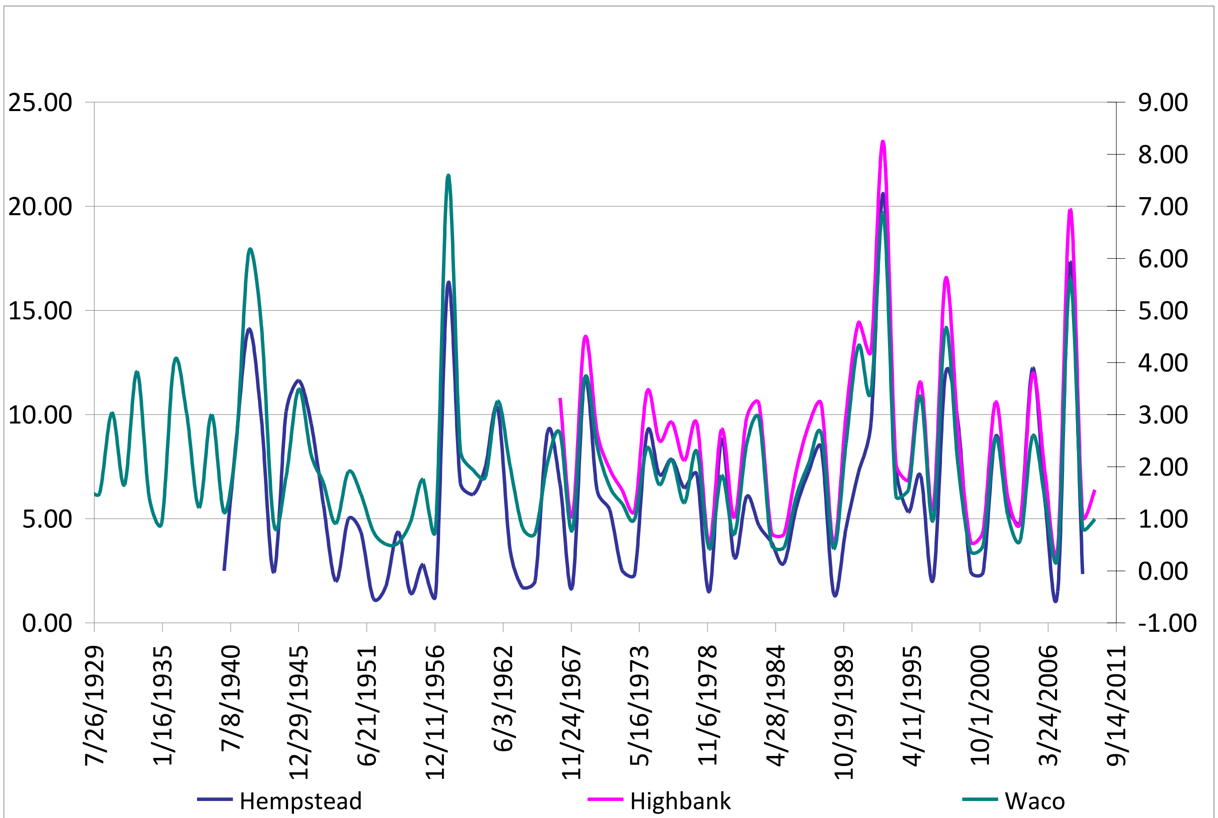


**Figure 50:** Gauge information for all three river gauges. Y-axes units are flow in $km^3$yr.

USGS Gage #08096500 at Waco, TX from 1900 to 2009 is shown in Figure 51. Generally, flows fall between 0.5 to 4.0 $km^3$/y, with years occurring in excess of that ~10% of the time. Latitude for this station is 31°32'09", longitude is 97°04'23", and the gage datum is 106.5m above sea level. It is located in McLennan County, TX and has a drainage area of 51,782 km$^2$.

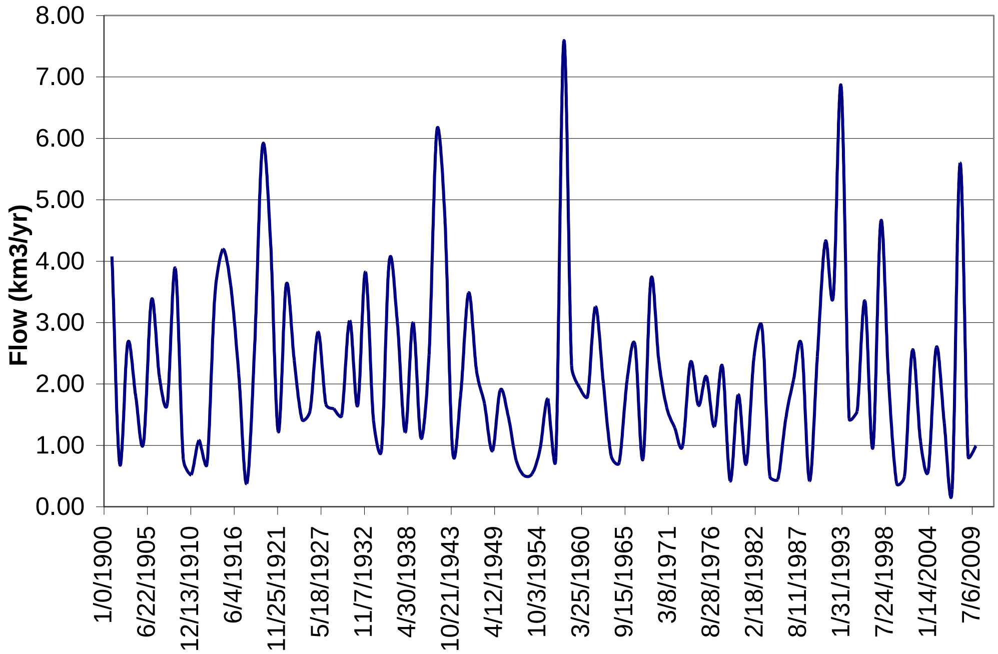


**Figure 51:** Total Annual Flow for the Brazos River at Waco, TX

USGS Gage #08028290 at Highbank, TX from 1966 to 2009 is shown in Figure 52. Generally flows fall between 0.5 to 4.0 km$^3$/y, with five years exceeding that amount over the~35 years of recorded data. Latitude for this station is 31°08'02", longitude is 96°49'29", and the gage datum is 85.1m above sea level. It is located in Falls County, TX and has a drainage area of 54,053 km$^2$.

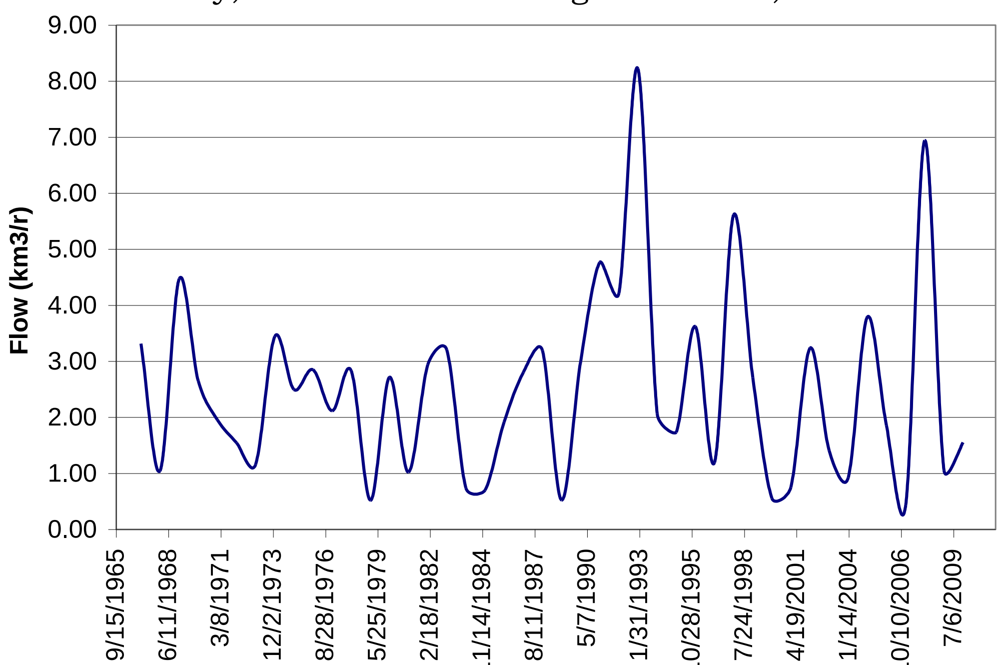


**Figure 52:** Total Annual Flow for the Brazos River at Highbank, TX

USGS Gage #08111500 at Hempstead, TX from 1939 to 2009 is shown in Figure 53. Generally flows fall between 1.0 and 10.0 $km^3/y$, with years exceeding that amount a total of nine times during the recorded period. Latitude for this station is 30°07'44", longitude is 96°11'15", and the gage datum is 32.89m above sea level. It is located in Washington County, TX and has a drainage area of 88,873 $km^2$.

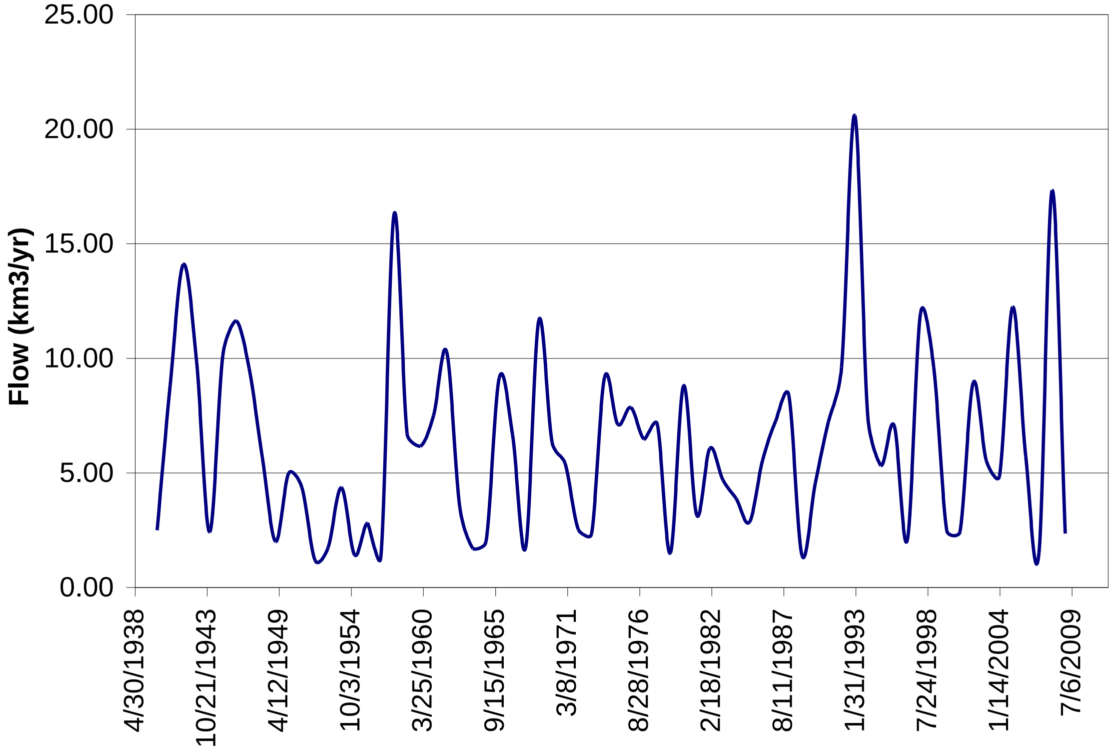


**Figure 53:** Total Annual Flow for the Brazos River at Hempstead, TX

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Shown in Table 12 are the four sampled sites, their sample dates, and river discharge and USGS gage elevation for the sample date (refer to Table 11 for corresponding USGS gages). The bank-bank distance for each transect represents the top of the channel bank, determined as where slope sharply leveled off. The channel height indicates the vertical distance to the top of the channel. Most sites, though steeply sloped, had understory coverage along the channel slope. Hearne Transect 02 and Snook Transects 01 and 02 represent point bars with extended sand bars and more gently sloping channel banks (with large cut banks on the opposite bank).

Channel height for the point bars ranged from 4-8m, and between 6 and 13m for other transects. Brazos Bend, the downstream-most site, had very steep banks, all exceeding 13m vertical distance.

| **Site Name** | **Trans #** | **Bank-Bank Dist (m)** | **Channel Ht (m)** | **Dominant Understory Along Channel Slope** | **Sample Date** | **Gauge Elev (m)** | **Dischg CFS** |
|---|---|---|---|---|---|---|---|
| Marlin | | | | | | | |
| | 1 | 85 | 6.5 | *Ambrosia trifida* | 7/22/10 | 2.5 | 526 |
| | 2 | 140 | 9.0 | *Ambrosia trifida* | 7/22/10 | 2.5 | 526 |
| | 3 | 95 | 7.0 | *Ambrosia trifida* | 7/21/10 | 2.8 | 657 |
| Hearne | | | | | | | |
| | 1 | 120 | 6 | *Ampelopsis arborea* | 7//26/10 | 3.1 | 972.0 |
| | 2 | 160 | 4.5 | *Toxicodendron radicans* | 8/4/10 | 2.9 | 782.0 |
| | 3 | 65 | 6 | *Salix nigra* saplings | 8/4/10 | 2.9 | 782.0 |
| Snook | | | | | | | |
| | 1 | 90 | 8 | *Ambrosia trifida* | 7/29/10 | 3.3 | 1220.0 |
| | 2 | 110 | 4 | *None - bare sand* | 7/29/10 | 3.3 | 1220.0 |
| | 3 | 55 | 13 | None - bare sand | 7/27/10 | 3.8 | 1910.0 |
| Brazos Bend | | | | | | | |
| | 1 | 70 | 12.8 | *Equisetum spp.* | 7/28/10 | 12 | 1830 |
| | 2 | 85 | 11.6 | *Toxicodendron radicans* | 7/28/10 | 12 | 1830 |
| | 3 | 65 | 12.2 | *Vitis mustangensis* | 7/28/10 | 12 | 1830 |

Table 12: Brazos River Sites and their general characteristics

## Percent Composition

The percent composition for all seedlings are shown in Table 13. *C. laevigata* was the dominant seedling for Brazos and for all sites combined, and second most common for Marlin and Snook. *Salix nigra* was most dominant at Snook and Hearne and second most common at all sites combined. Most dominant at Marlin was *U. fulva*. Other dominant species included *C. drummondii* found at all sites and second most dominant at Hearne; and P. deltoides which was common at Brazos but absent at all other sites.

**Seedlings**

| Site | Brazos | | Marlin | | Snook | | Hearne | | All Sites | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Count | % | Count | % | Count | % | Count | % | Count | % |
| *Acer negundo* | 53 | 8.6 | 8 | 1.4 | 1 | 1.2 | 4 | 1.5 | 66 | 4.3 |
| *Carya illinoiensis* | 3 | 0.5 | 33 | 5.9 | | 0.0 | | 0.0 | 36 | 2.4 |
| *Celtis laevigata* | 342 | 55.7 | 142 | 25.4 | 19 | 22.6 | 34 | 12.6 | 537 | 35.2 |
| *Cornus drummondii* | 71 | 11.6 | 106 | 19.0 | 5 | 6.0 | 99 | 36.7 | 281 | 18.4 |
| *Foresteria pubescens* | 1 | 0.2 | | 0.0 | | 0.0 | | 0.0 | 1 | 0.1 |
| *Fraxinus pennsylvanica* | | 0.0 | 2 | 0.4 | | 0.0 | | 0.0 | 2 | 0.1 |
| *Fraxinus texana* | 10 | 1.6 | 3 | 0.5 | | 0.0 | 12 | 4.4 | 25 | 1.6 |
| *Ilex decidua* | 3 | 0.5 | | 0.0 | | 0.0 | | 0.0 | 3 | 0.2 |
| *Juglans nigra* | 1 | 0.2 | | 0.0 | | 0.0 | | 0.0 | 1 | 0.1 |
| *Morus rubra* | | 0.0 | 2 | 0.4 | | 0.0 | | 0.0 | 2 | 0.1 |
| *Platanus occidentalis* | 11 | 1.8 | | 0.0 | 5 | 6.0 | | 0.0 | 16 | 1.0 |
| *Populus deltoides* | 103 | 16.8 | | 0.0 | | 0.0 | | 0.0 | 103 | 6.7 |
| *Salix nigra* | | 0.0 | 51 | 9.1 | 49 | 58.3 | 113 | 41.9 | 213 | 13.9 |
| *Sapium sebiferum* | 8 | 1.3 | | 0.0 | | 0.0 | | 0.0 | 8 | 0.5 |
| *Ulmus crassifolia* | 8 | 1.3 | 4 | 0.7 | 4 | 4.8 | 5 | 1.9 | 21 | 1.4 |
| *Ulmus fulva* | | 0.0 | 208 | 37.2 | 1 | 1.2 | 3 | 1.1 | 212 | 13.9 |
| **Total** | **614** | | **559** | | **84** | | **270** | | **1527** | |

Table 13: Percent Composition for Seedlings at each site and all sites combined.

The percent composition for all saplings are shown in Table 14. *C. drummondii* was most dominant at Brazos, followed by *P. occidentalis*. *C. laevigata* was most common at Marlin, followed by *C. illinoinensis*. With a percent composition of 65.5% *S. nigra* was overwhelmingly most dominant at Snook, followed by *C. laevigata*. *C. drummondii* and *S. nigra* were the two most dominant species at Hearne. Taken together, *C. drummondii* represented the most dominant saplings encountered, representing a percent composition of 26.6% and found in all sites. *S. nigra*, also found at all sites, was the second most dominant saplings for all sites combined. Though present at most sites *A. negundo* seedlings and saplings each had percent compositions less than 4, indicating they are present along the river continuum but in low numbers. *C. laevigata* was the third most dominant sapling for all sites combined. No *P. deltoides* saplings were sampled at any of the sites.

**Saplings**

| **Site** | **Brazos** | | **Marlin** | | **Snook** | | **Hearne** | | **All Sites** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Count | % | Count | % | Count | % | Count | % | Count | % |
| *Acer negundo* | 5 | 2.9 | 2 | 0.9 | | 0.0 | 8 | 2.6 | 15 | 2.1 |
| *Bumelia lycioides* | | 0.0 | 1 | 0.5 | | 0.0 | 2 | 0.6 | 3 | 0.4 |
| *Carya illinoiensis* | 13 | 7.6 | 31 | 14.6 | | 0.0 | 6 | 1.9 | 50 | 6.9 |
| *Celtis laevigata* | 11 | 6.4 | 37 | 17.5 | 5 | 17.2 | 21 | 6.8 | 74 | 10.2 |
| *Cornus drummondii* | 66 | 38.4 | 18 | 8.5 | 1 | 3.4 | 107 | 34.5 | 192 | 26.6 |
| *Forestiera angustifolia* | 1 | 0.6 | | 0.0 | | 0.0 | | 0.0 | 1 | 0.1 |
| *Fraxinus americana* | | 0.0 | | 0.0 | | 0.0 | 2 | 0.6 | 2 | 0.3 |
| *Fraxinus pennsylvanica* | | 0.0 | 26 | 12.3 | | 0.0 | | 0.0 | 26 | 3.6 |
| *Fraxinus texana* | 7 | 4.1 | 1 | 0.5 | | 0.0 | 7 | 2.3 | 15 | 2.1 |
| *Ilex decidua* | 11 | 6.4 | | 0.0 | | 0.0 | | 0.0 | 11 | 1.5 |
| *Melia azedaraxh* | 2 | 1.2 | | 0.0 | | 0.0 | | 0.0 | 2 | 0.3 |
| *Morus alba* | | 0.0 | 2 | 0.9 | | 0.0 | | 0.0 | 2 | 0.3 |
| *Morus rubra* | | 0.0 | 18 | 8.5 | | 0.0 | | 0.0 | 18 | 2.5 |
| *Platanus occidentalis* | 31 | 18.0 | | 0.0 | 3 | 10.3 | | 0.0 | 34 | 4.7 |
| *Quercus macrocarpa* | 1 | 0.6 | | 0.0 | | 0.0 | | 0.0 | 1 | 0.1 |
| *Salix nigra* | 8 | 4.7 | 25 | 11.8 | 19 | 65.5 | 111 | 35.8 | 163 | 22.5 |
| *Sapium sebiferum* | 9 | 5.2 | | 0.0 | | 0.0 | | 0.0 | 9 | 1.2 |
| *Ungnadia speciosa* | 1 | 0.6 | | 0.0 | | 0.0 | | 0.0 | 1 | 0.1 |
| *Ulmus crassifolia* | 6 | 3.5 | 46 | 21.7 | | 0.0 | 9 | 2.9 | 61 | 8.4 |
| *Ulmus fulva* | | 0.0 | 5 | 2.4 | 1 | 3.4 | 37 | 11.9 | 43 | 5.9 |
| **Total** | **172** | | **212** | | **29** | | **310** | | **723** | |

Table 14: Percent Composition for Saplings at each site and all sites combined.

The Importance Values for all mature trees are shown in Table 15. *C. laevigata* and *P. occidentalis* were most dominant at Brazos. *S. nigra* and *C. laevigata* dominated both Marlin and Snook, though *P. deltoides* was also in the mix as the second-most dominant at Snook. Hearne saw *C. laevigata* and *U. fulva* as its two most dominant mature trees. Taken together, *S. nigra* were most dominant, followed *C. laevigata* and *U. fulva* respectively. Adult *P. deltoides* were sampled at all sites, though their overall importance value ranked them as the 6$^{th}$ most dominant species, behind even *A. negundo* and *P. occidentalis*.

**Mature**

| Site | Brazos | | Marlin | | Snook | | Hearne | | All Sites | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Count | % | Count | % | Count | % | Count | % | Count | % |
| *Acer negundo* | 16 | 11.7 | 8 | 5.6 | | 0.0 | 12 | 14.3 | 36 | 8.2 |
| *Carya illinoiensis* | 5 | 3.6 | 7 | 4.9 | | 0.0 | | 0.0 | 12 | 2.7 |
| *Celtis laevigata* | 37 | 27.0 | 24 | 16.8 | 4 | 5.3 | 17 | 20.2 | 82 | 18.6 |
| *Cornus drummondii* | 13 | 9.5 | | 0.0 | 2 | 2.6 | 5 | 6.0 | 20 | 4.5 |
| *Fraxinus pennsylvanica* | 1 | 0.7 | 4 | 2.8 | | 0.0 | 5 | 6.0 | 10 | 2.3 |
| *Fraxinus texana* | 11 | 8.0 | | 0.0 | | 0.0 | 2 | 2.4 | 13 | 3.0 |
| *Ilex decidua* | 1 | 0.7 | | 0.0 | | 0.0 | | 0.0 | 1 | 0.2 |
| *Melia azedaraxh* | 3 | 2.2 | | 0.0 | | 0.0 | | 0.0 | 3 | 0.7 |
| *Morus rubra* | | 0.0 | 13 | 9.1 | | 0.0 | | 0.0 | 13 | 3.0 |
| *Platanus occidentalis* | 34 | 24.8 | | 0.0 | | 0.0 | 1 | 1.2 | 35 | 8.0 |
| *Populus deltoides* | 2 | 1.5 | 3 | 2.1 | 7 | 9.2 | 10 | 11.9 | 22 | 5.0 |
| *Salix nigra* | 6 | 4.4 | 34 | 23.8 | 62 | 81.6 | 11 | 13.1 | 113 | 25.7 |
| *Sapium sebiferum* | 3 | 2.2 | | 0.0 | | 0.0 | | 0.0 | 3 | 0.7 |
| *Ulmus americana* | 1 | 0.7 | | 0.0 | | 0.0 | | 0.0 | 1 | 0.2 |
| *Ulmus crassifolia* | 4 | 2.9 | 2 | 1.4 | 1 | 1.3 | 8 | 9.5 | 15 | 3.4 |
| *Ulmus fulva* | | 0.0 | 48 | 33.6 | | 0.0 | 13 | 15.5 | 61 | 13.9 |
| **Total** | **137** | | **143** | | **76** | | **84** | | **440** | |

Table 15: Percent Composition for Mature Trees at each site and all sites combined

## Species' Ranges

Figure 54 shows the range of seedlings at Brazos Bend. No *S. nigra* seedlings were found in any of the transects. Nor were any saplings (Fig. 55) even though adults for this specie were located in the area (Fig. 56). *A. negundo* was found from water's edge to the full extent of the 50m transects and as high as 11m above water's edge. *P. deltoides* was found from 6 to 19m distance and 2 to 5m elevation. *C. laevigata* was found from outer channel edge to the full extent sampled. *C. illinoinensis* and *U. crassifolia* were found only in the furthest ~15m of the forest sample and highest elevations.

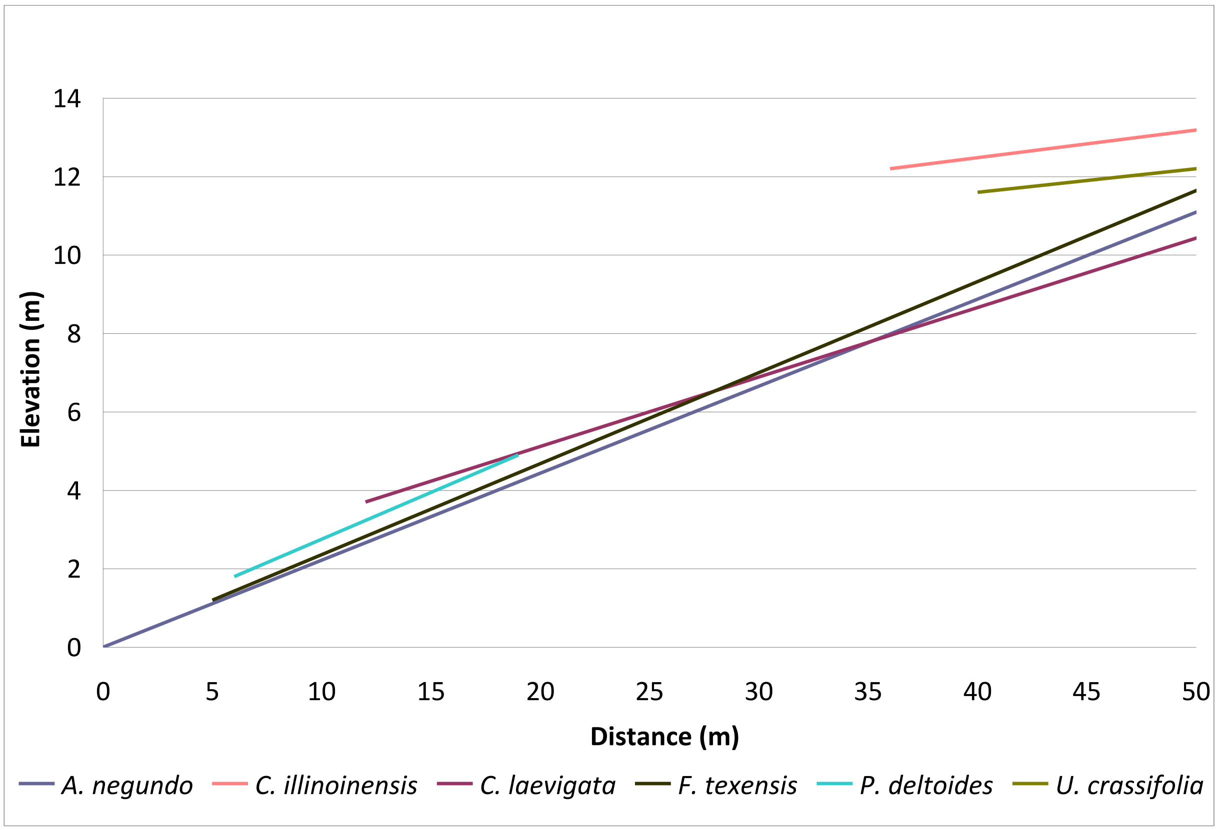


**Figure 54:** Brazos Bend Seedling Ranges

Sapling distribution for Brazos Bend trees shows that fewer trees were found (only four species) and both *A. negundo* and *C. laevigata* showed markedly less spatial coverage (Fig. 55).

Adult *S. nigra* were located from near water's edge to 12m distance and 6m height (Fig. 56). *P. deltoides* trees ranged from 20 to 35m and 5.5 to 11.5m above the stream. Clearly seedling distribution does not coincide with adult spatial coverage in this site. Coupled with a total lack of saplings, this pattern may be indicative of recent water needs for both dispersal and survivability of young being inadequate. When comparing *A. negundo* saplings to adults, a similar pattern emerges (young are located closer to water than mature) though not as strongly, as there is some overlap (and seedlings were dispersed throughout, but also were found located much closer to the stream than adults).

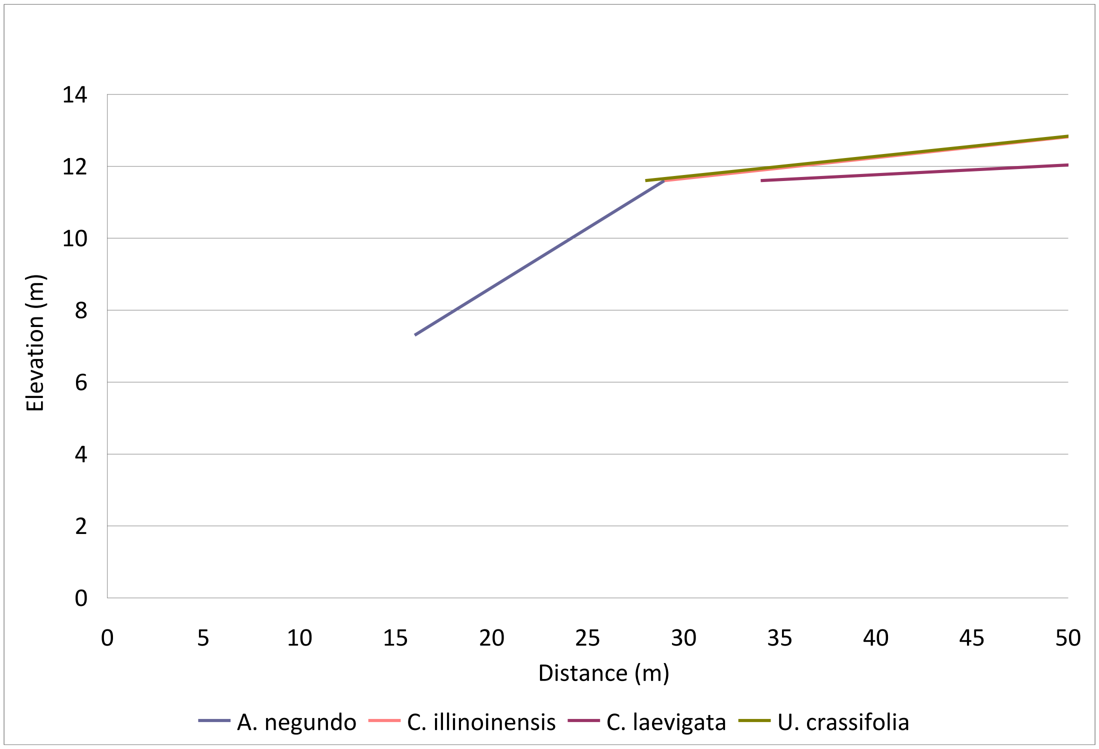


**Figure 55:** Brazos Bend Sapling Ranges

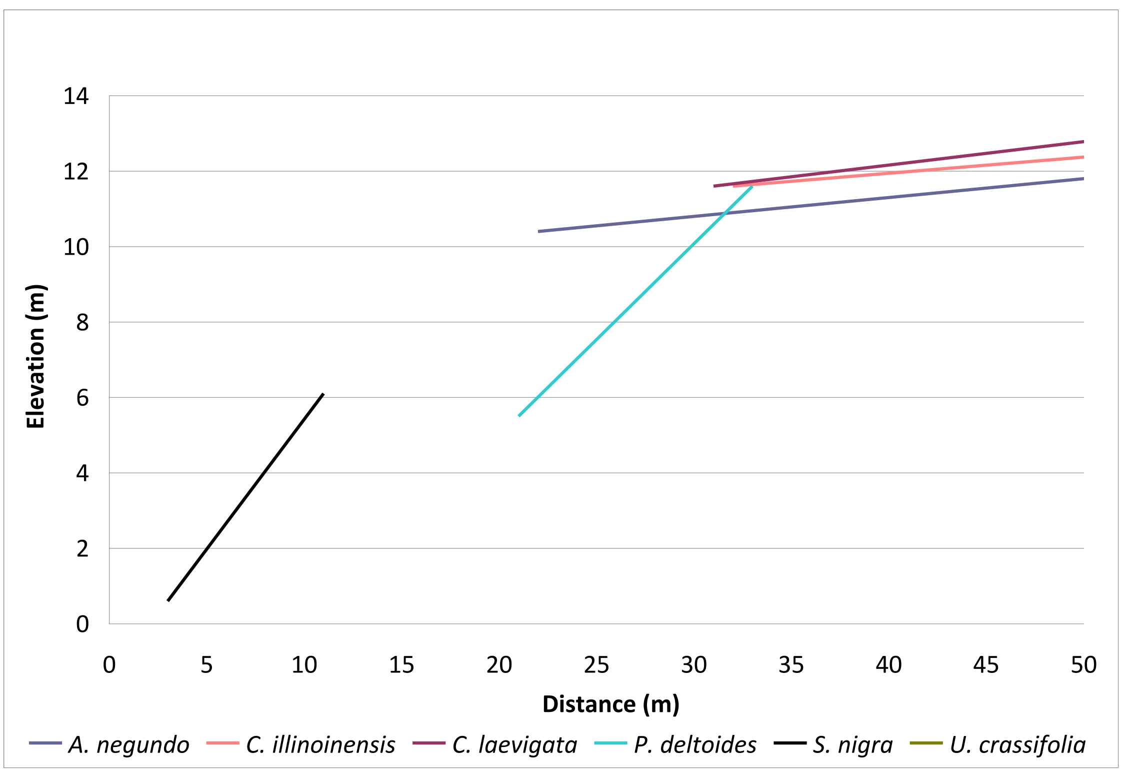


**Figure 56:** Brazos Bend Mature Tree Ranges

The Hearne Site biodiversity ranges are shown in Figures 57-59. Because some age classes for the indicator specie *S. nigra* were still being sampled at 50m, transects for the Hearne site were extended to 80m to ensure that full spatial coverage of this specie was mapped. This large coverage is likely due, in large part, to Transect 02 being located on a point bar, where channel slope was gentler and led into gradually rolling landscape. Figure 57 shows *S. nigra* seedlings widely dispersed from water's edge to 55m distance and 4.5m elevation. *A. negundo* seedlings were located between 35 and 60m distance and 1.5 and 4.5m elevation. *U. fulva* seedlings were isolated at about 45m distance to the stream. Both *C. laevigata* and *U. crassifolia* were common after 25m distance to the stream and above 5m.

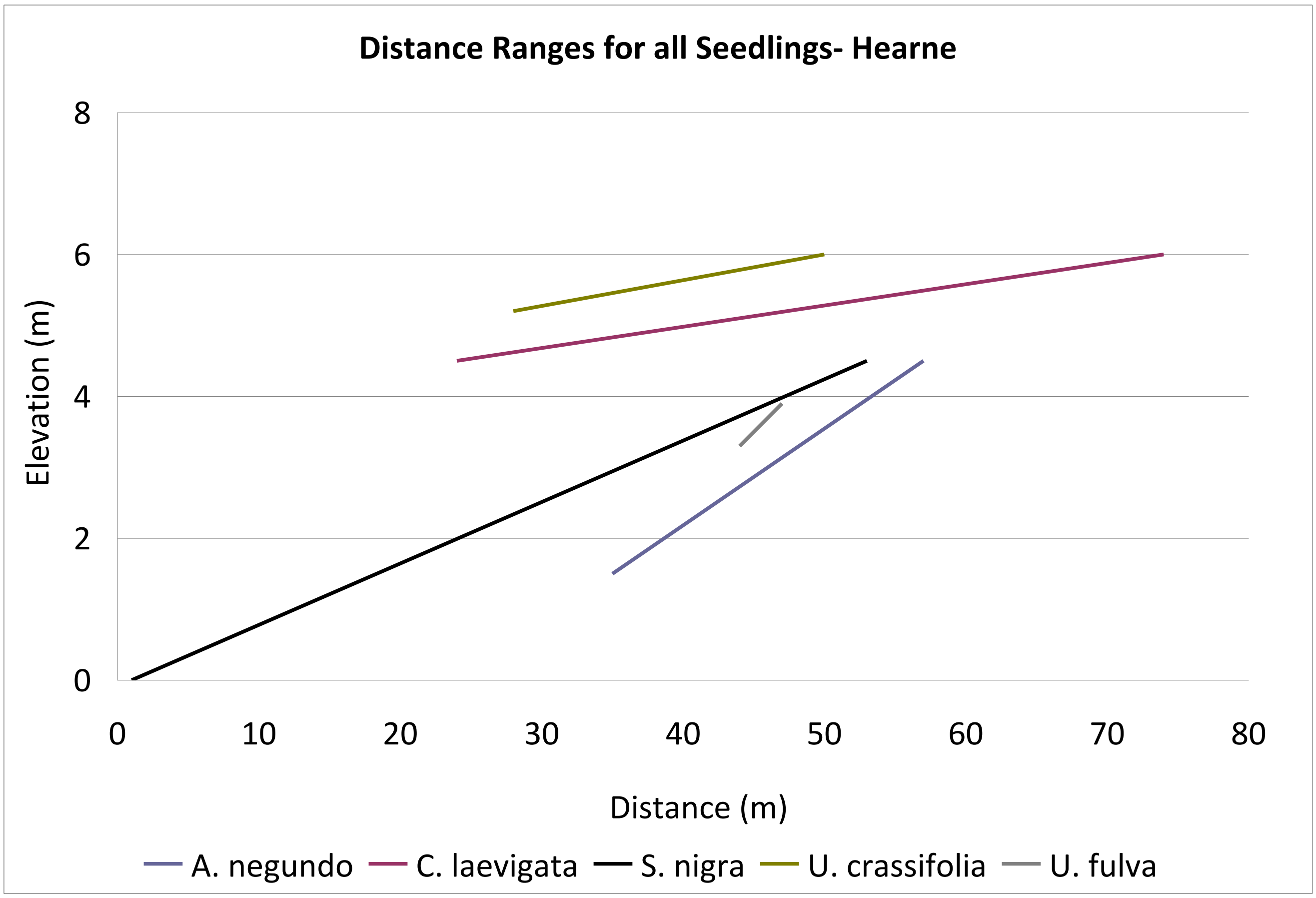


**Figure 57:** Hearne Seedling Ranges

Saplings for *S. nigra* were broadly located from 5m to 55m distance to the stream (Fig 58). *A. negundo* were 12m to 60m but were all located at ~4m elevation. *C. laevigata* and *C. illinoinensis* were as close as 10m and as far away as 50+m. *U. fulva* were found 18m distance and 3m elevation up to 65m distance and 4.5m elevation.

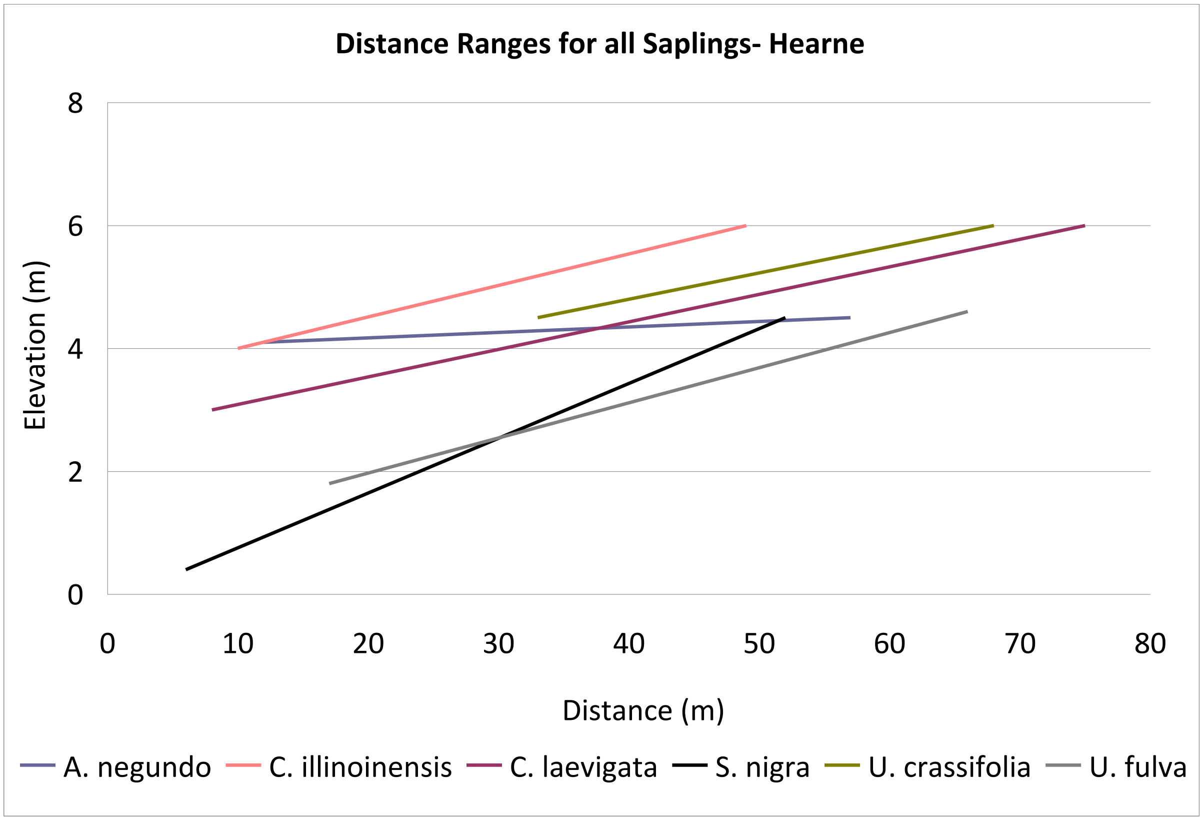


**Figure 58:** Hearne Sapling Ranges

While its seedlings and saplings were found at water's edge, mature individuals of *S. nigra* were located 10m distance and 1.5m elevation from water's edge and ranged as far as 65m distance (Fig. 59). Probably what contributes to their wide spatial distance is the Hearne 02 transect, which was located on a point bar and had a gentle channel slope that gradually changed to rolling landscape. This may explain the spatial distribution of *A. negundo* as well. However, the spatial difference between seedlings/saplings and mature individuals for *S. nigra* indicates this species may be expanding toward/into the channel in the future. *A. negundo* saplings fell in line with mature, but seedling distribution actually began more distant to the channel than mature locations would suggest it should be. Mature *P. deltoides* were located between 40 and 65m distance and 2.5 and 4.5m elevation to water's edge. No recruitment or replacement appears to be occurring for this species as there was a total lack of seedlings and saplings along this stretch of the Brazos.

Other mature species dominant in the community included, *F. pennsylvanica* (which also had no recruitment/replacement classes), *C. laevigata, U. crassifolia,* and *U. fulva* with a fairly broad distribution of 15 to 40m.

Similar to the Hearne Site, Marlin Site transects were also sampled up to 85m; though it was not located on a point bar as was one of the Hearne transects it had *S. nigra* in excess of 50m. Figure 60 shows no seedlings were found for none of the riparian-healthy indicator species (*S. nigra, A. negundo, P. deltoides, F. pennsylvanica*). The only seedlings in this area were found in excess of 18m distance and 1m elevation, and consisted of *C. illinoinensis, C. laevigata, F. texensis,* and *U. fulva.*

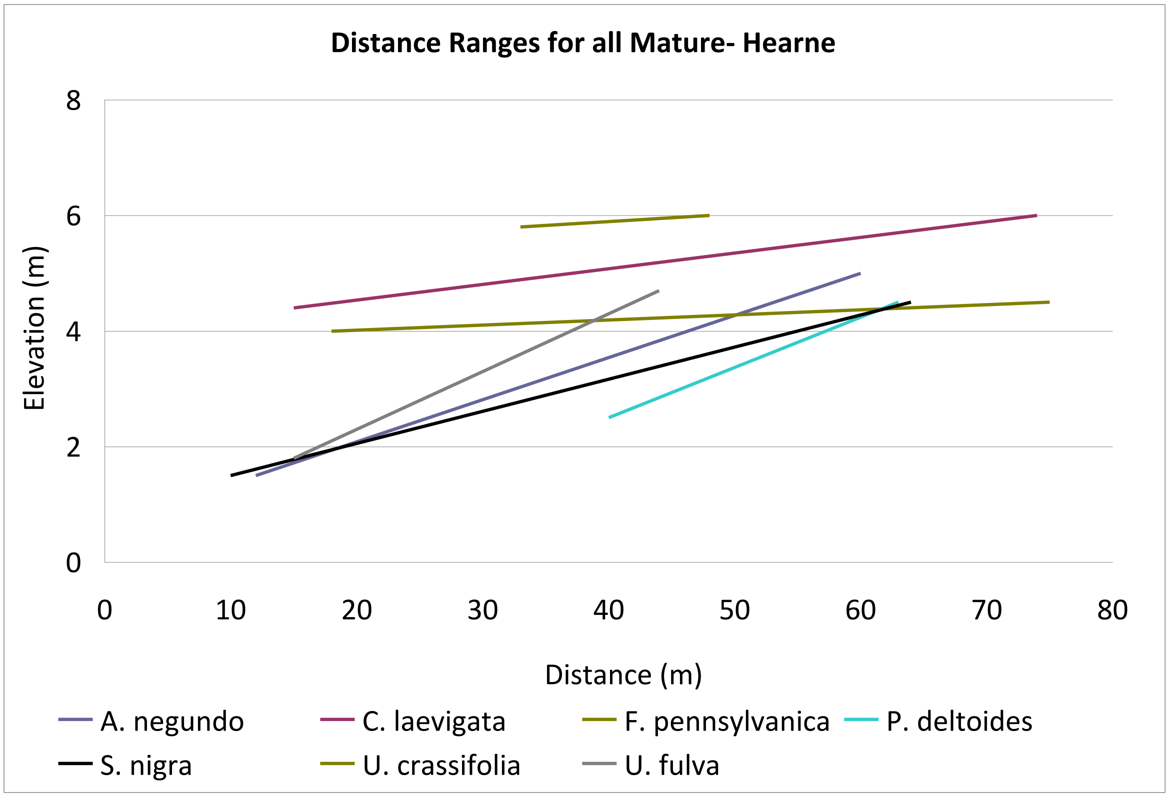


**Figure 59:** Hearne Mature Tree Ranges

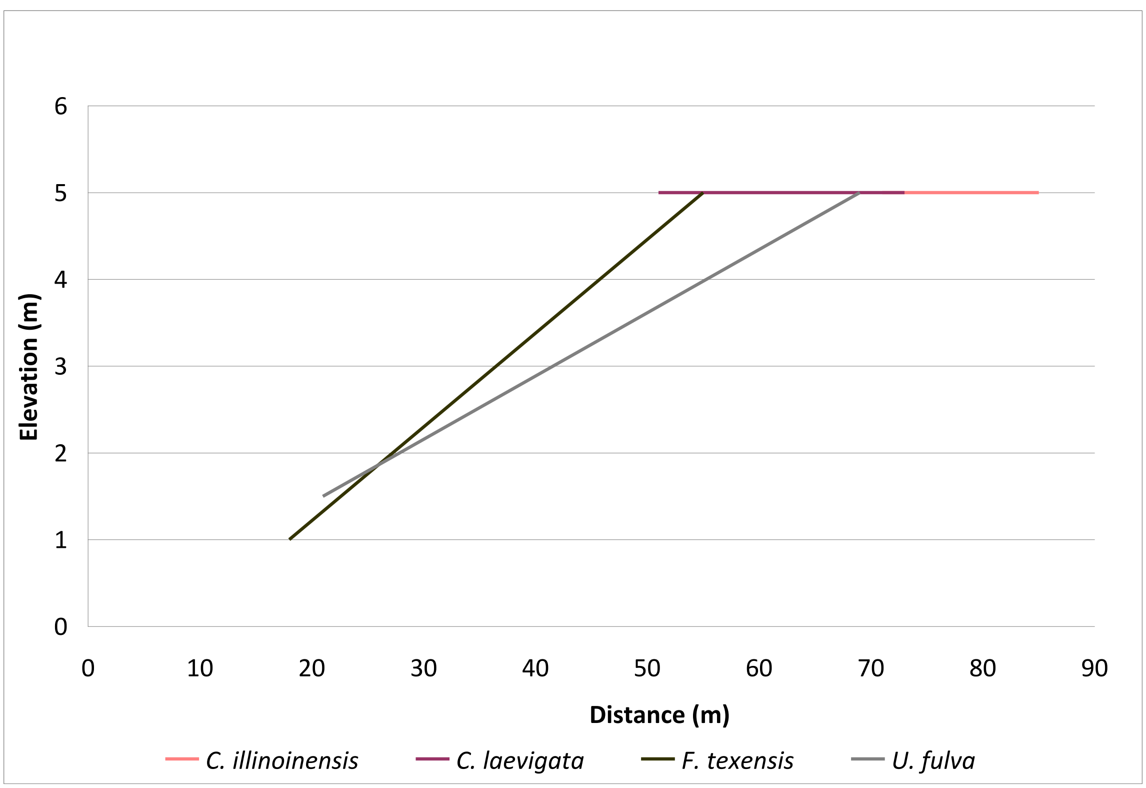


**Figure 60:** Marlin Seedling Ranges

Saplings for *S. nigra* were found in the Marlin Site (Fig. 61) and were located between 5 and 10m distance and 0 to 1m elevation from the water's edge. *A. negundo* also were found from 13 to 50m distance and 2.5 to 5m elevation. Other species' saplings included *C. illinoinensis, C. laevigata, U. crassifolia* and *U. fulva*.

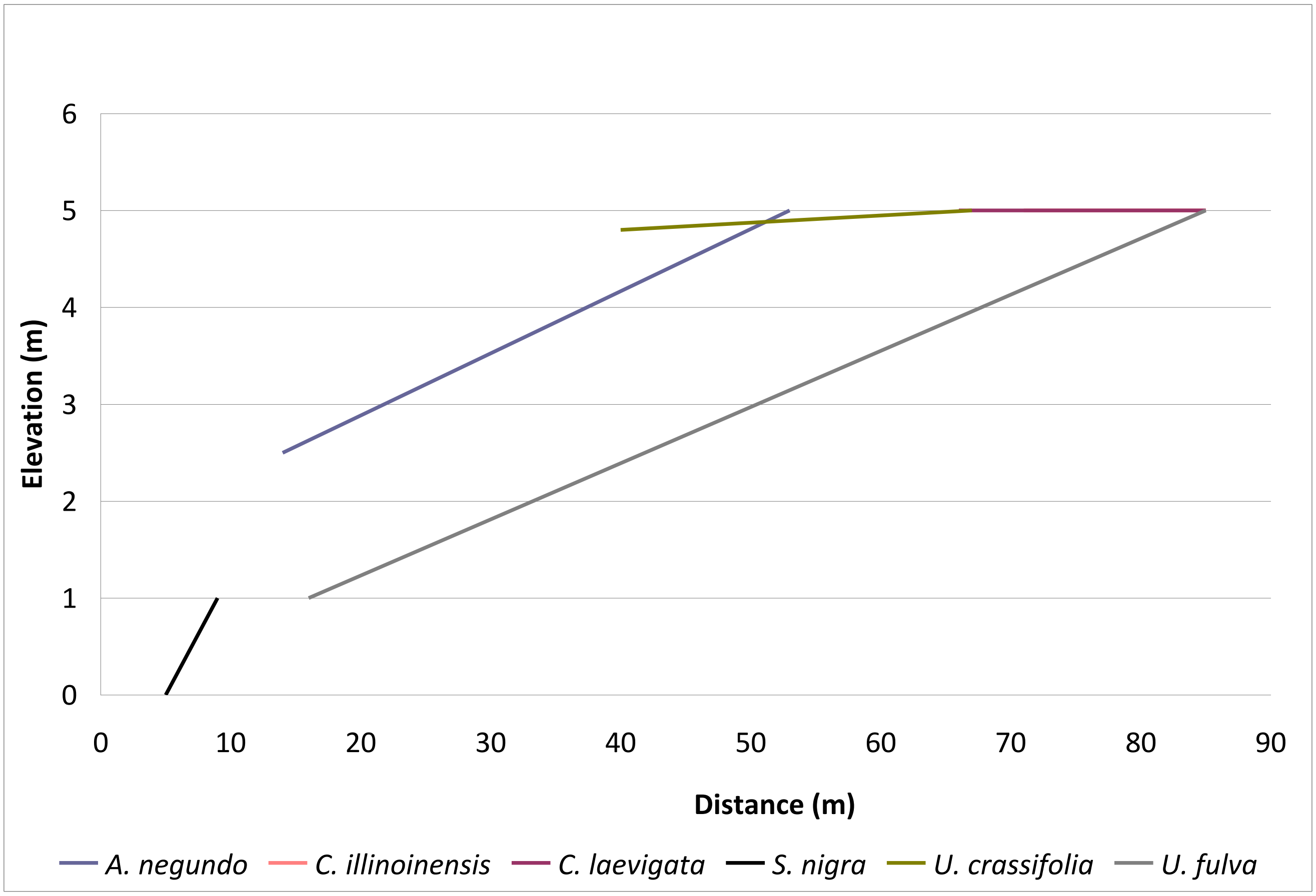


**Figure 61:** Marlin Sapling Ranges

Figure 62 shows the mature classes for Marlin, which included *C. laevigata, P. deltoides, S. nigra* and *U. fulva. S. nigra* adult trees ranged from 10 to 45m distance and 1 to 5m elevation, further distant than the saplings found in this site. *P. deltoides* was found in one very small location 60m distant and 5m elevation above water's edge.

Snook transects, which included two points, were extended up to 100m to ensure that all riparian-healthy species' ranges were mapped. Biodiversity ranges are shown in Figures 63-65. Seedlings for *S. nigra* were located from water's edge to 15m distance and up to 4.5m height (Fig. 63). *C. laevigata* seedlings didn't appear until 42m distance and *U. crassifolia*, the only other dominant specie with seedlings was located from 25 to 85m.

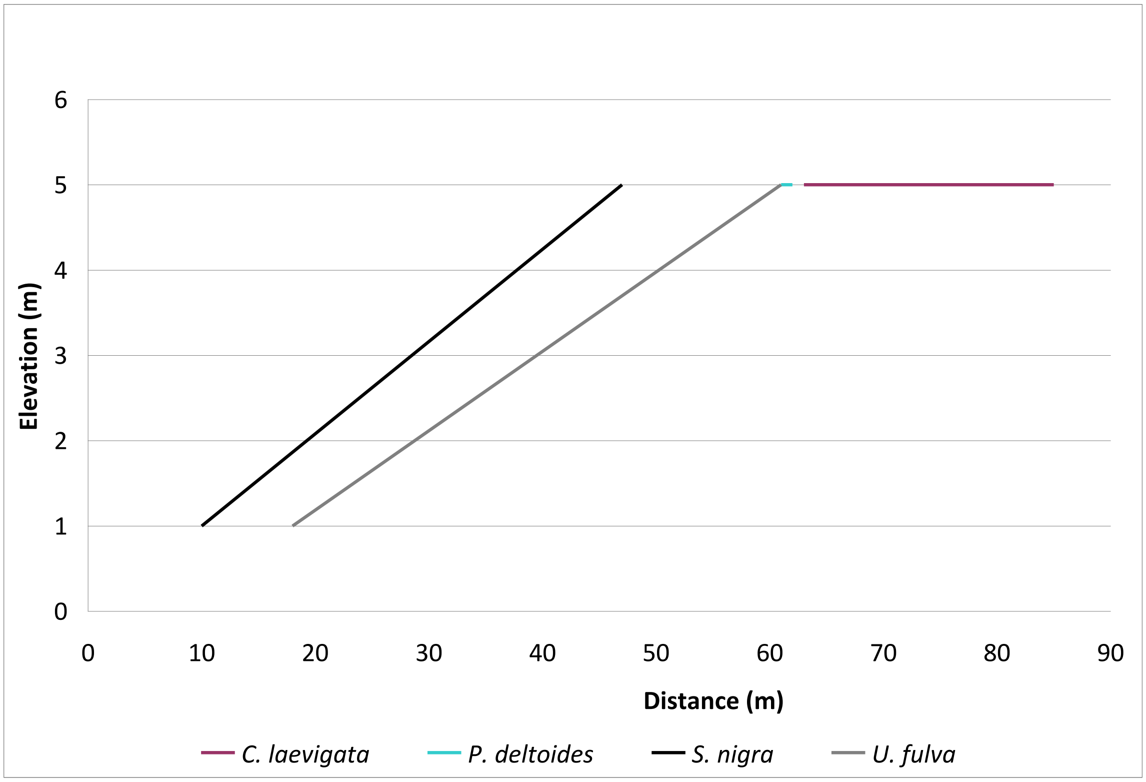


**Figure 62:** Marlin Mature Tree Ranges

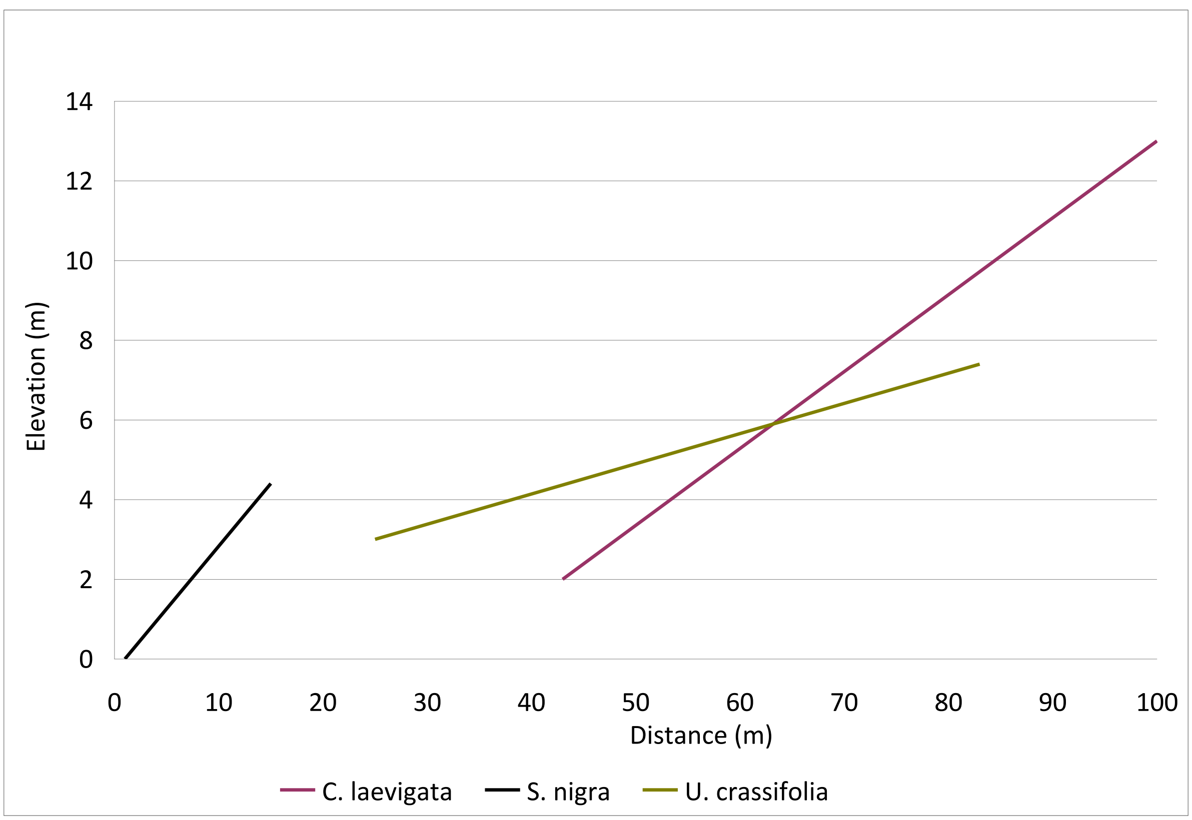


**Figure 63:** Snook Seedling Ranges

*S. nigra* saplings' distribution were from water's edge to 25m distance and 7m elevation (Fig. 64). *C. laevigata* sapling ranged from 35 to 48m distance.

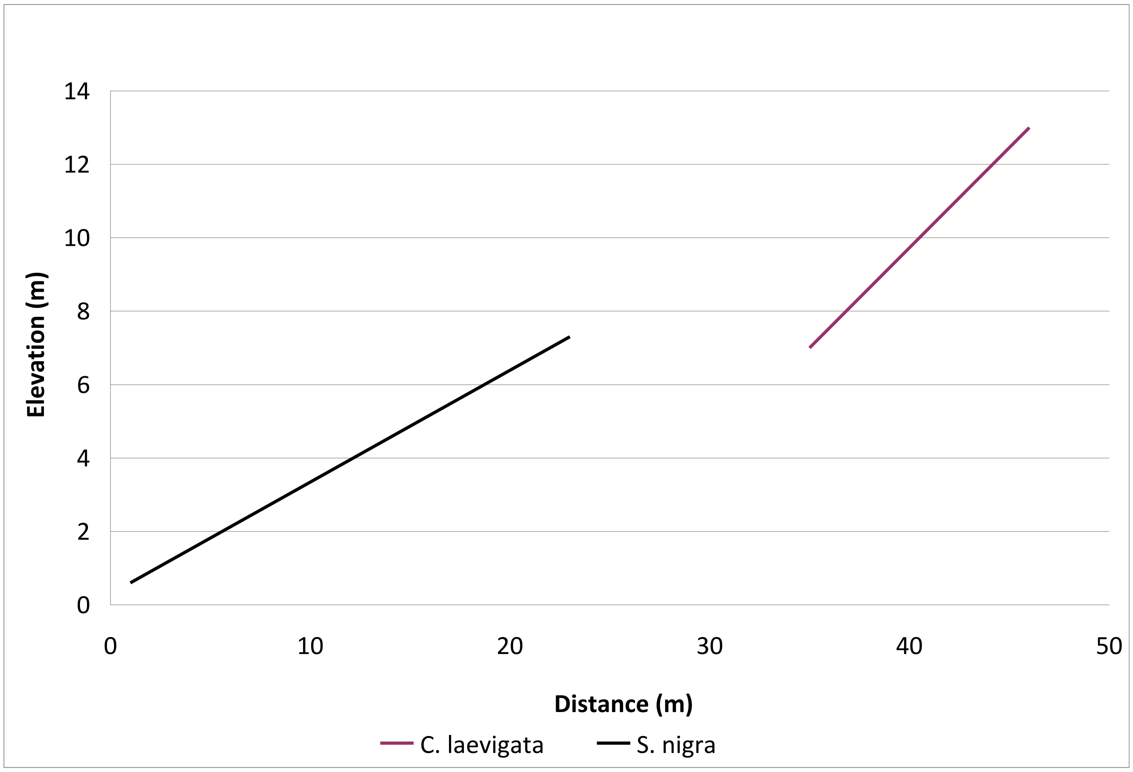


**Figure 64:** Snook Sapling Ranges

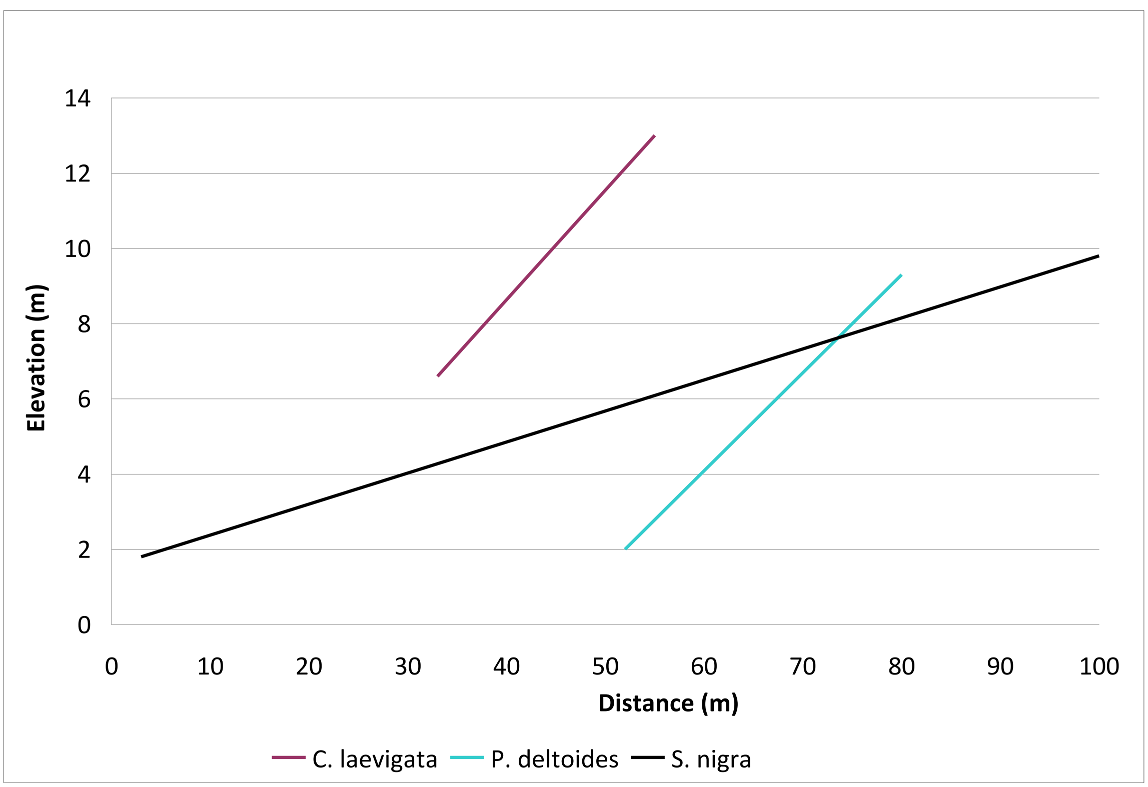


**Figure 65:** Snook Mature Tree Ranges

Figure 65 shows *S. nigra* adults ranged from 3m to 100m distance and from 2m to 10 elevation, a much broader ranger than either its seedlings or saplings. *P. deltoides* ranged from 50m to 80m distance and 2 to 9m elevation, though it had a lack of recruitment or replacement classes (Figs. 63 and 64). *C. laevigata*, with a spatial distance between 30 and 55m fell in the range of its seedlings and saplings, though seedlings extended much further distances than either of the other two age classes.

Seedlings, Saplings and Mature Trees for all Brazos River sites combined are shown in Figures 66 through 68. Figure 66 shows that while biodiversity varied between individual sites, when combined, seedlings for several species can be found along the river's continuum. *S. nigra* and *A. negundo* seedlings grow both along the channel slopes as well as outside those banks, though *S. nigra* never sprouted above 4.5m while *A. negundo* seedlings could be found as high as 12m elevations above water's edge. All other species' seedlings grow from bank edge to varying distances outward. *C. laevigata* was most broadly dispersed among all seedlings, occupying distances from 10m to the full 100m extent sampled by any transects, and at elevations from 2m to 13m.

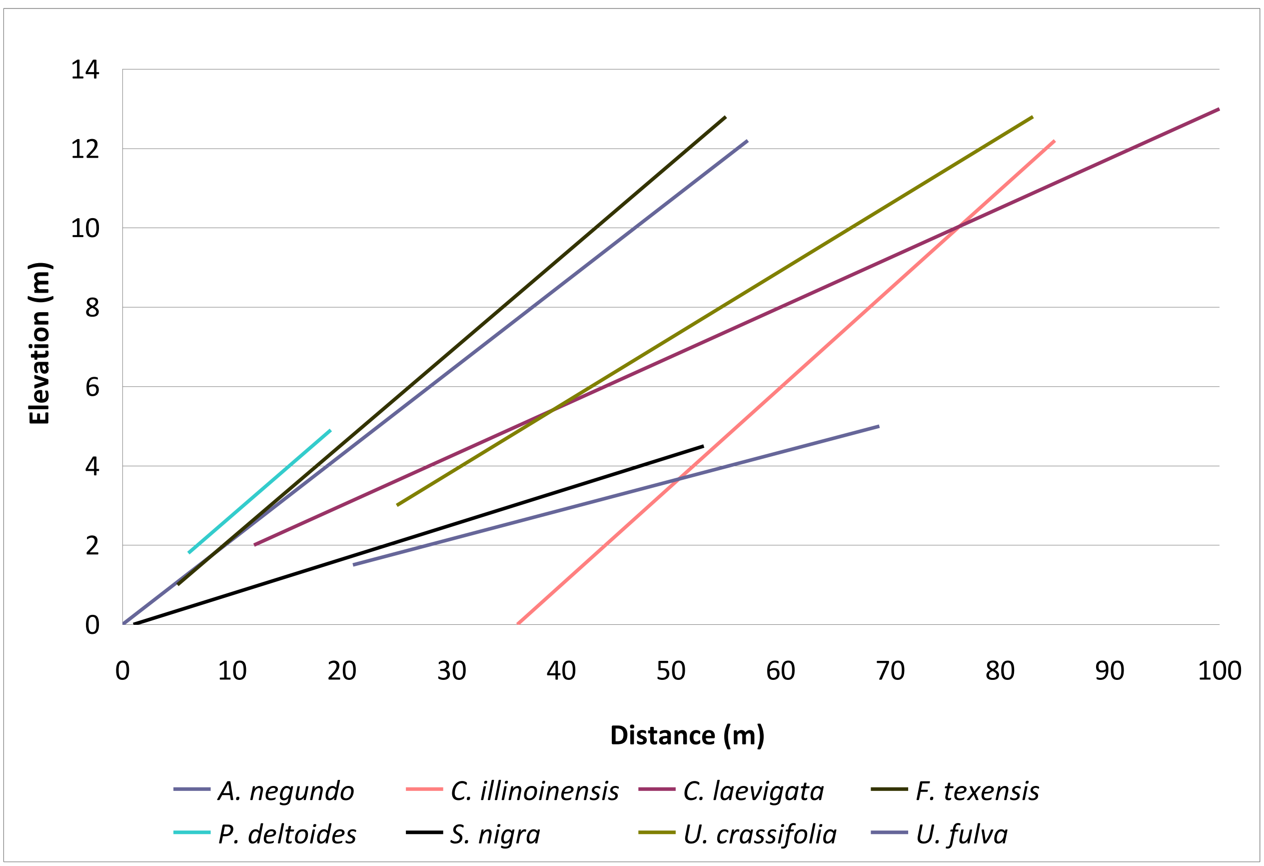


***Figure 66:*** *Brazos River All Sites Combined Seedling Ranges*

Figure 67 shows the spatial distribution of the most common saplings. *S. nigra* shows coverage from water's edge to 52m distance and 7m elevation. All other saplings were limited to outside the channel slope. *A. negundo* saplings ranged from 15m distance and 1m elevation to 85m distance and 5m elevation. As with its seedling distribution, *C. laevigata* showed a very broad coverage of from bank edge to outer sampling limits.

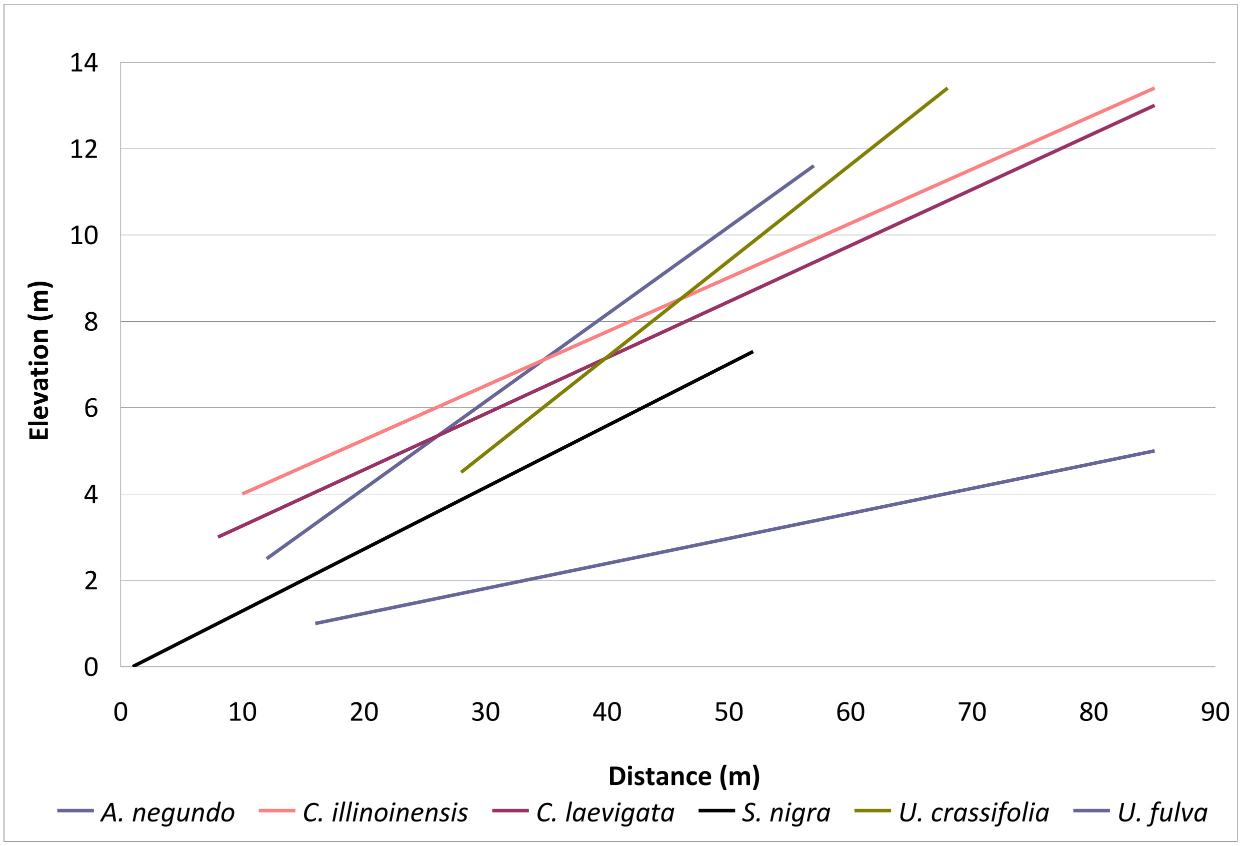


**Figure 67:** Brazos River All Sites Combined Sapling Ranges

Adult trees of *S. nigra* ranged from near water's edge to the full 100m sampled by any sites, and up to 10m elevation (Figure 68). *P. deltoides* adults ranged from 20m distance and 2m elevation to 80m distance and 10m elevation. However the far-reaching coverage is primarily because of the point bars at Transects 01 and 02 at the Snook Site. *A. negundo* adults grew from 15m distance to 62m, and between 1 and 5m elevation. *C. laevigata* adults ranged from 15 to 85m, indicating recruitment for this specie is extending further away from the stream than mature trees have historically been located.

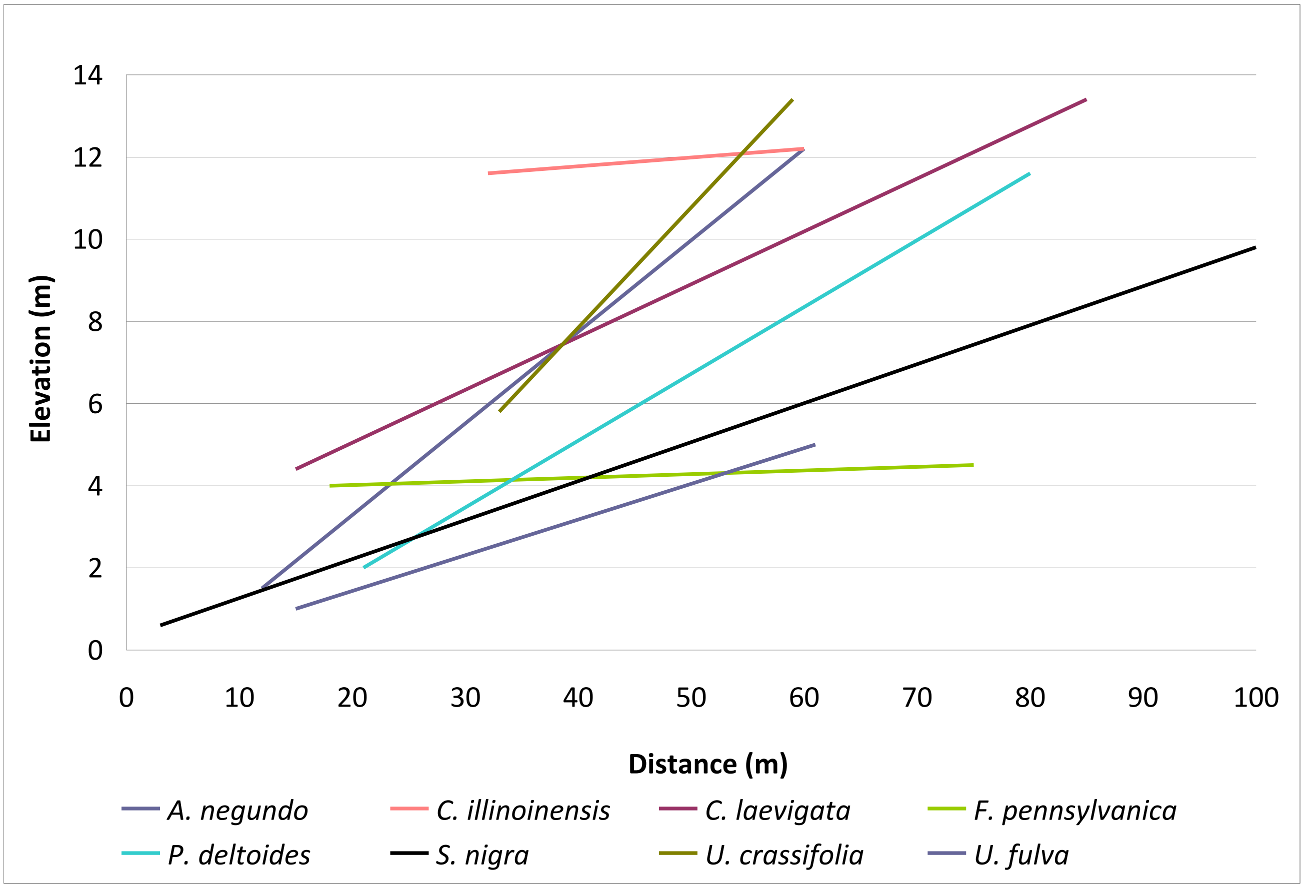


**Figure 68:** Brazos River All Sites Combined Mature Tree Ranges

**Mature Tree Stand Age Distribution**

Age classes for dominant species along the Brazos River, based on the multiplication factor of Table 8 are shown in Figure 69. For trees that were sampled at both the San Antonio and Brazos Rivers, abundances were fewer (sometimes far fewer) along the Brazos, except for *C. laevigata* which had much higher counts than along the San Antonio River.

*A. negundo* had no representatives older than 30 years of age, less than 40 mature trees along the entire river sampling sites, and only 15 saplings. Given that seedling counts were high and the specie was seen at most sites, it still has the potential for longterm success along the Brazos. *C. illinoinensis* had gaps in its age distribution and only one tree in its ideal reproductive age. However, the past 15 years have seen an increase in tree counts, reaching a high of 50 saplings, but reduced seedling count. Its longterm success will depend on those young saplings and mature trees' survival to reproductive maturity.

*C. laevigata* appears to be rapidly expanding, both in count and in spatial coverage (see Figs. 66-68), and in the past 15 years has become a dominating tree in the riparian zone.

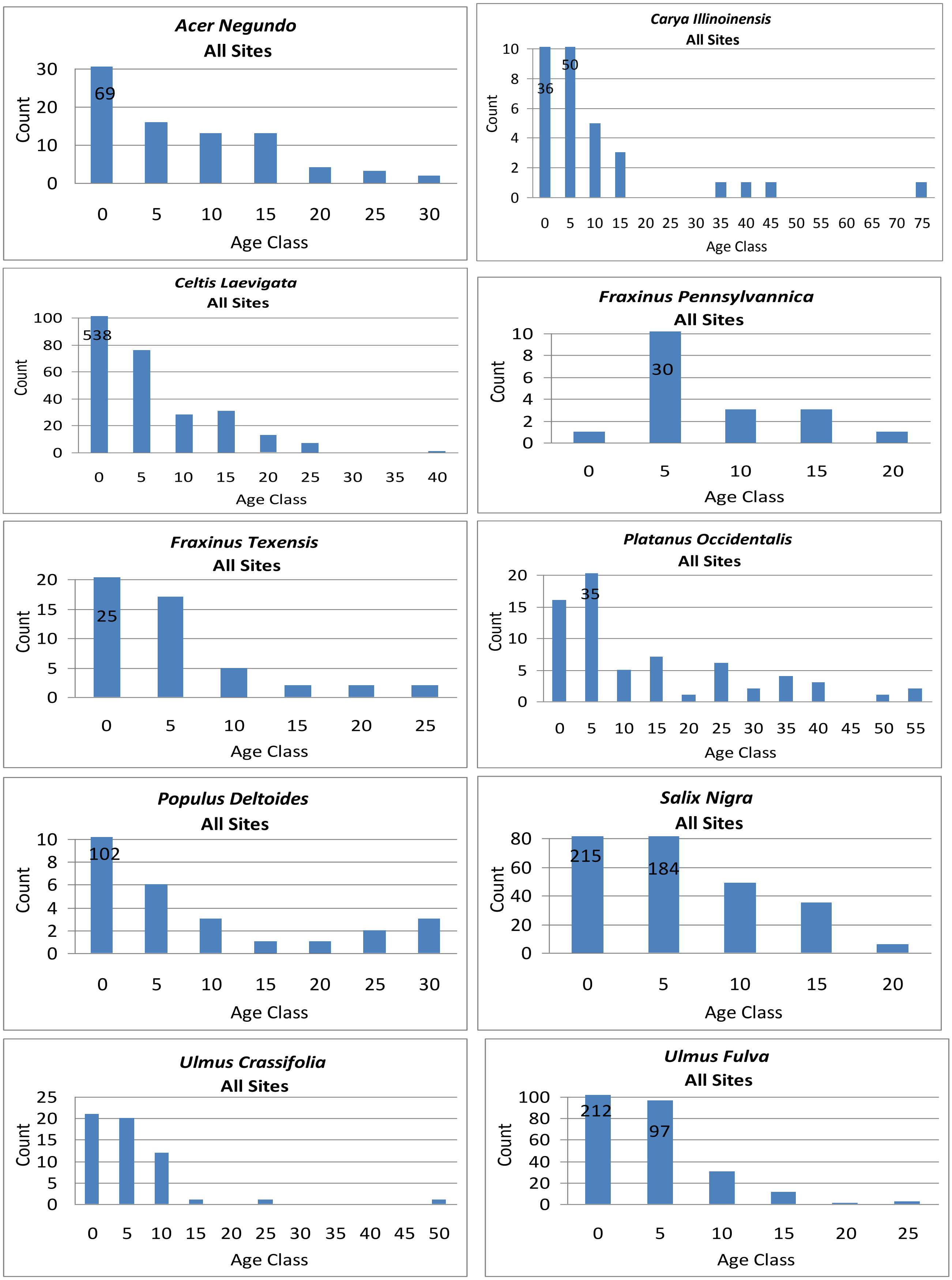


**Figure 69:** Age Classes for Several Dominant Species Along the Brazos River

*F. pennsylvanica* had low counts of mature trees, low spatial distribution among sites, and a very low seedling count (one) along the entire river continuum. Clearly persistence of this tree could be jeopardized if an episodic event were to remove too many adult trees. However, another member of the *Fraxinus* genus, *F. texensis* with its pyramid-shaped age distribution does appear to be expanding in the riparian zone. *P. occidentalis* has representation at several age classes and though seedling counts were low, sapling counts are high for this specie. *P. deltoides* has adults ranging from 5-30 years. The optimum reproductive age for this specie is 35 years (see Table 7), indicating that though several trees have reached reproductive maturity (10 years), it is currently not functioning at its optimal potential. Only one tree each was found in the 10 and 15 years classes combined and sapling distribution was low, but seedling distribution was high; though highly constrained spatially along channel slopes (see Fig. 66) in comparison to adult distribution (Fig. 69). For *S. nigra* only one tree older than 15 years was sampled; but sapling/seedling counts indicate healthy expansion of this specie. Both *Ulmus* species show very young stands at less than 15 years, but vigorous recruitment, especially by *U. fulva* which is far outpacing *U. crassifolia* along this river.

SOIL HYDRIC CONDITIONS

**Water Table Depth**

Figures 70 through 73 show the depth to water table for augured transects within the four sites; and a summary of sites, soil classes and observed soil characteristics is given in Table 16. A 'star' in Figures 70-73 indicates water table was reached for that depth.

Figure 70 indicates that at 5m distance to the stream water table depth was 2.1m, and beyond that was below 4m in the Brazos Bend Site. Sampling distance only extended to 30m at which large gravel and rubble were encountered and further depths could not be reached. When compared to Figure 56 (mature tree ranges) it appears that persistence of the shallowest water table corresponds with *S. nigra*, as it grows only where the water table was shallower than 4m. *P. deltoides* coverage between 20 and 35m and 6-12m elevations would indicate these trees have likely formed the deeper-penetrating taproot typical of this species. Other species' spatial distribution appears to be independent of a shallow water table, and no mature *A. negundo* adults were sampled in this site's biodiversity plots.

Figure 71 and Table 16 indicate that at 5m distance to the stream water table depth was 1.8m, at 15m it was 3.5m deep, 30m was 3.7m and 45m distance had a water table depth of 3.9m in the Hearne Site. When compared to Figure 59 (mature tree ranges) it appears that persistence of the shallowest water table allows for much of the expansion seen in *S. nigra*, *P. deltoides* and *A. negundo* further to the stream. In fact, their spatial coverage shows all are well under 6m elevation to stream and where water table is within 4m from ground surface.

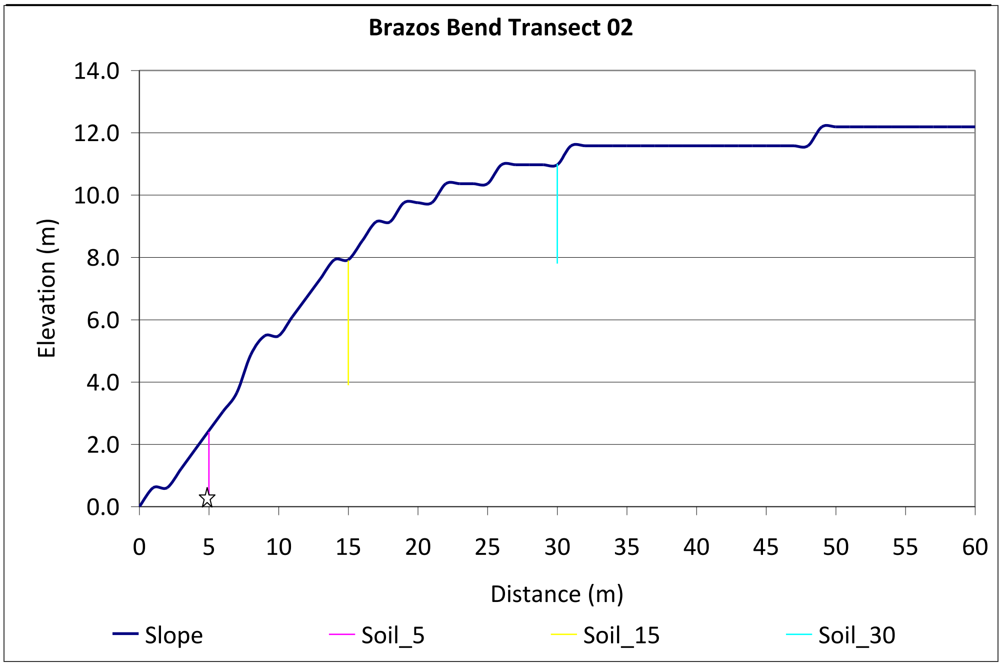


**Figure 70:** Augured Soil Depths for Transect 02 in the Brazos Bend Site

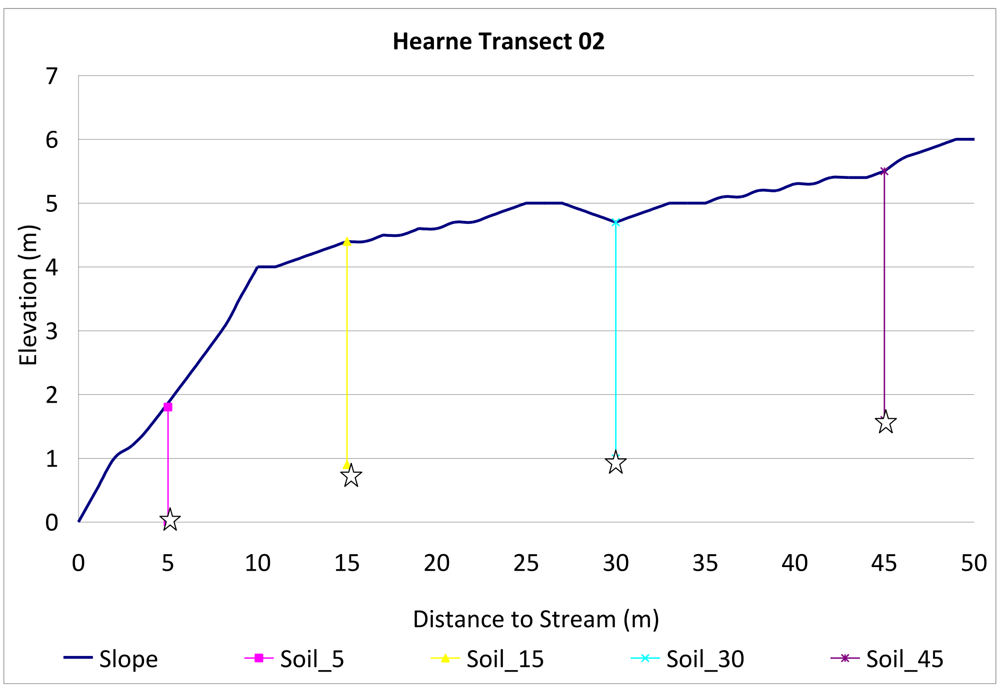


**Figure 71:** Augured Soil Depths for Transect 02 in the Hearne Site

Figure 72 and Table 16 indicate that at 5m distance to the stream water table depth was 1.8m, at 15m it was 3.5m deep, 15m was 3.7m and 45m distance had a water table depth of 3.9m in the Marlin Site. When compared to Figure 62 (mature tree ranges) it appears that *S. nigra* again appears to line up with a water table less than 4m, as its distribution extends to almost 40m and 5m elevation. The only *P. deltoides* sampled was at 60m distance, clearly outside the range of shallow water table. No *A. negundo* adults were sampled in this site's biodiversity plots. Other species' spatial distribution appears to be independent of a shallow water table.

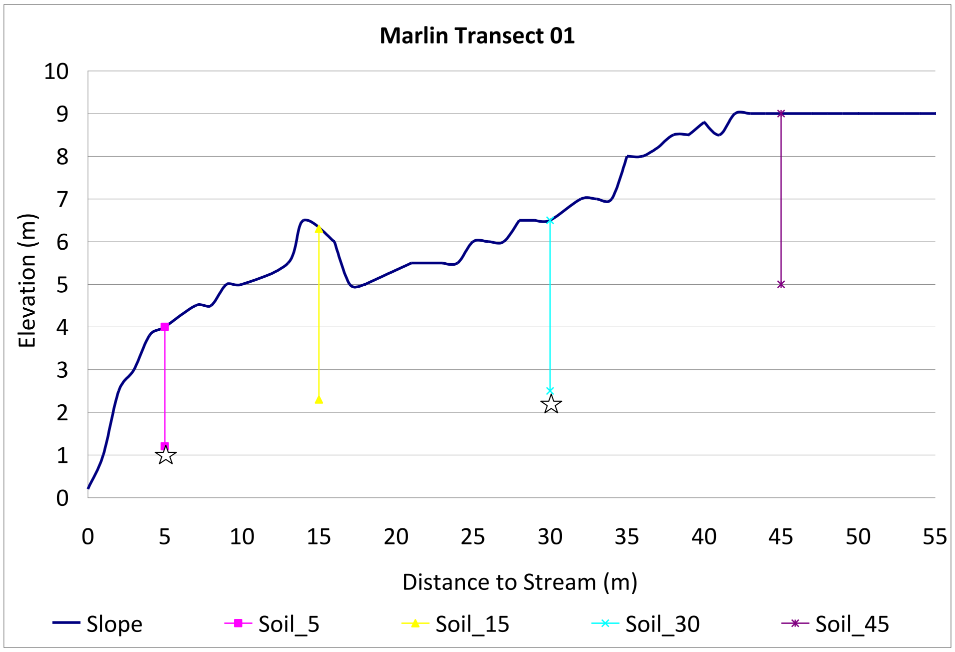


**Figure 72:** Augured Soil Depths for Transect 01 in the Marlin Site

Figure 73 and Table 16 indicate that at 5m distance to the stream water table depth was 0.9m, at 15m it was 2.7m deep, 30m was inconclusive (sandy soil cave-ins prevented further auguring than 3m, and 45m distance had a water table depth lower than 4m in the Snook Site. When compared to Figure 65 (mature tree ranges) it appears that *S. nigra* distribution is independent of water table depth. However, two factors may draw this conclusion into doubt. One factor was that Transect 01 was used for soil auguring, but Transect 02 further upstream was along a much further-extending point bar that may have been raising the groundwater levels for those trees. Additionally, approximately 200m distance to the stream was a pond. Conversations with the property owner indicated that this pond was a remnant of the past stream channel which had re-routed itself around the small knoll in between to deposit the new point bar.

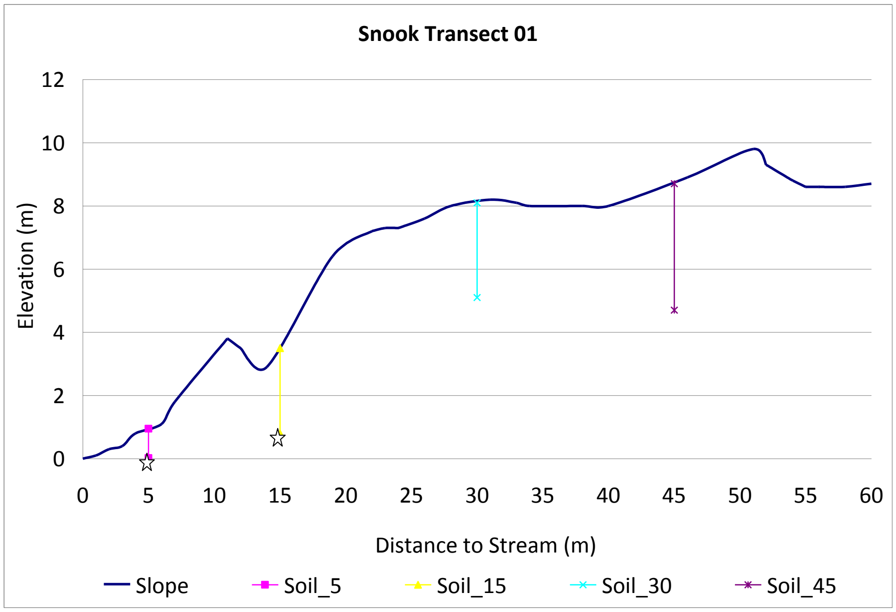


**Figure 73:** Augured Soil Depths for Transect 01 in the Snook Site

Close proximities of two shallow water bodies – pond and stream base flow - may be allowing lateral hyporheic connectivity in fissures between the two that could possibly be supplementing root uptake of species in this area. Observational evidence indicates that a number of *S. nigra, P. occidentalis, P. deltoides* and *C. laevigata* tended to form parallel bands at various distances to the stream that could be indicative of underground ribbons of these shallow water tables.

| Site Descriptions | Distance 5m | 15m | 30m | 45m |
|---|---|---|---|---|
| **Brazos Bend** | | | | |
| *SSURGO Soil Classes* | Fine Sandy Loam | Fine Sandy Loam | Fine Sandy Loam | Fine Sandy Loam |
| *Observed Soil Characteristics* | Sand/Cla | Up - Sand/Clay Low - Clay | Up - Clay Low - Clay/Rubble | N/A |
| *Depth (m) / Water* | 2.1 / Y | 4 / N | 3.2 / N | N/A |
| **Hearne** | | | | |
| *SSURGO Soil Classes* | Loamy Fine Sand | Loamy Fine Sand | Loamy Fine Sand | Loamy Fine Sand |
| *Observed Soil Characteristics* | Sandy | Up - Fine Sand Low - clay/gravel | Up - Sand Low - clay/gravel | Up - Sand/clay Low - clay/gravel |
| *Depth (m) / Water* | 1.8 / Y | 3.5 / Y | 3.7 / Y | 3.9 / Y |
| **Marlin** | | | | |
| *SSURGO Soil Classes* | Loamy Fine Sand | Loamy Fine Sand | Loamy Fine Sand | Loamy Fine Sand |
| *Observed Soil Characteristics* | Fine Sand | Up - Fine Sand Low - Sand/clay | Up - Sand Low - clay | Up - Sand/clay Low - clay/gravel |
| *Depth (m) / Water* | 2.8 / Y | 4 / N | 4 / Y | 4 / N |
| **Snook** | | | | |
| *SSURGO Soil Classes* | Very Fine Sandy Loam | Very Fine Sandy Loam | Very Fine Sandy Loam | Very Fine Sandy Loam |
| *Observed Soil Characteristics* | Fine Sand/Silt | Collapsing Fine Sand | Collapsing Fine Sand | Sand//Clay |
| *Depth (m) / Water* | 0.9 / Y | 2.7 / Y | 3 / N | 4 / N |

**Table 16:** Summary of Soil Auguring

### Relationship of Species Range to Soil Water Depth

Excepting the unique pattern at Snook, *S. nigra* tended to be limited to areas where groundwater was shallow, as did *A. negundo* when it was encountered. While some dependence on shallow groundwater was seen for *P. deltoides*, several trees exhibited shallow-water independence, likely due to taproot formation. In comparison to Brazos Bend, the pattern of further distribution but lower elevation limits may be an indication that distance-to-stream may be further with a shallow groundwater table, but elevation is reduced – indicating a possible inverse relationship between distance and elevation to stream that may be a factor of both groundwater and stream pulsing. Future studies could provide further investigation of this relationship. All other species' spatial distributions appear to be independent of a shallow water table.

## RIVER FLOW AND TREE PRODUCTIVITY

Table 17 is a summary of all dominant, cored trees and their relationships (both individually and as a community) to total annual river flows of their corresponding river gauges. All flows are represented as discharge in cubic kilometers per year ($km^3/y$). Two responses are given: flows at which growth was suppressed, and flows at which trees showed exceptional growth. A discussion of each specie in each site will follow below.

When taken as a community, trees along the Brazos River had broad ranges for both exceptional and suppressed growth, again demonstrating a limitation to the method of using general riparian classes for determining riparian functionality and health as was seen along the San Antonio River (see Table 17, Community Ranges for each site). Therefore determination of one or two key indicator species was used to analyze longterm past maintenance as a way to predict future maintenance. That said, there are some useful observations that can be made from within the community. Trees that generally indicate a healthy riparian forest (*A. negundo, F. pennsylvanica*) exhibit similar responses: suppression with too high or too low flows, while *S. nigra* showed suppression for too-low flows but optimal growth increased always with increasing flow. Trees that would be indicators of upland expansion/invasion into the riparian zone show varied responses at different sites and under different conditions. Another potential indicator, *P. occidentalis* was found at two sites. Along one site it exhibited suppression only with excessively low flows, but at the other site it exhibited suppression with both excessively high and low flows. This limited dataset and varied response make *P. occidentalis* a less reliable indicator. *P. deltoides*' response was also interesting as it tended to vary with location (at 2 sites it had a direct relationship to increasing flow, one site it showed suppression when flows were too high and at one site it exhibited complete lack of dependence on stream flow). All of these likely speak to its ability to form a taproot upon maturity. Based on this information, *S. nigra* and *A. negundo* appear to be key indicators for productivity and functionality of this zone. *F. pennsylvanica*, too would be a suitable indicator, however its absence in several sites limits its usefulness.

The Brazos Bend Site community had broad ranges for both exceptional and suppressed growth. Trees experienced growth suppression to flows ranging from less than 2.5 $km^3/y$ and in excess of 12.2 $km^3/y$. *S. nigra* and *P. deltoides* are the only two species that showed both direct relationship with streamflow and no suppression with excessively high discharge years.

Taken as a community, trees from the Hearne Site showed productivity was highest with flows between 3.1 and 3.6 $km^3/y$, but generally showed suppression when discharge was outside that range. While *A. negundo* and *P. deltoides* were each suppressed by both too-low and too-high flows, *S. nigra* growth showed its greatest potential with the highest flows.

The Marlin community showed suppression of growth below 3.1 and above 3.5, with optimal growth in between – with the exception of *S. nigra* which showed no adverse effects to high flows. *A. negundo* was suppressed by too-high flows, but *S. nigra* and *P. deltoides* showed their greatest BI with highest flows (with the exception of the 1992 flood on *S. nigra* productivity).

The community response to river flow at the Snook Site showed optimum growth of trees between 2.5 and 7.3 $km^3/y$, with suppression of flows generally outside that range, though species' responses varied considerably. *A. negundo* and *P. occidentalis* exhibited suppression with too-high and too-high flows. *P. deltoides* showed independence of growth to stream levels and *S. nigra* showed no suppression with increased flow along the river.

| Species, Relationship to River Flow | Brazos Bend (in km3/yr) | Hearne (in km3/yr) | Marlin (in km3/yr) | Snook (in km3/yr) |
|---|---|---|---|---|
| *Acer negundo* | | | | |
| Growth suppressed | >20 | <0.6 and >6.1 | >4.4 | <1.8 and >6.7 |
| Exceptional Growth | 4.9 - 18.3 | 3.1 - 3.8 | 0.6 - 3.1 | 3.1 - 5.5 |
| *Carya illinoinensis* | | | | |
| Growth suppressed | >12.2 | N/A | N/A | <1.2 |
| Exceptional Growth | 2.5 - 9.8 | N/A | N/A | >4.3 |
| *Celtis laevigata* | | | | |
| Growth suppressed | >15.9 | >3.6 | <1.2 | <0.5 |
| Exceptional Growth | 2.5 - 12.2 | <3.6 | >4.3 | >4.3 |
| *Fraxinus pennsylvanica* | | | | |
| Growth suppressed | N/A | <1.2 and >3.6 | N/A | N/A |
| Exceptional Growth | N/A | 3.1 - 3.6 | N/A | N/A |
| *Populus deltoides* | | | | |
| Growth suppressed | <2.5 | <1.2 and >3.6 | <1.2 | N/D* |
| Exceptional Growth | >12.2 | 3.1 - 5.5 | >2.4 | N/D* |
| *Salix nigra* | | | | |
| Growth suppressed | <2.5 | <1.8 | <0.6 | <1.8 |
| Exceptional Growth | >7.3 | >3.1 | >3.1 | >3.6 |
| *Ulmus crassifolia* | | | | |
| Growth suppressed | N/A | N/D* | >3.5~ | N/A |
| Exceptional Growth | N/A | N/D* | <1.2 | N/A |
| *Platanus occidentalis* | | | | |
| Growth suppressed | <1.8 | N/A | N/A | <1.0 and >8.0 |
| Exceptional Growth | >11.6 | N/A | N/A | 2.5 - 6.8 |
| **Community Ranges** | | | | |
| Growth suppressed | <2.5 and >12.2 | <1.8 and >3.6 | <3.1 and >3.5 | <2.5 and>7.3 |
| Exceptional Growth | 2.5 - 12.2 | 3.1 - 3.6 | Varies | 3.1 - 6.8 |

*No relationship detected - inconclusive results (appear to have opposite relationship)
~*Ulmus fulva*

**Table 17:** Summary of Tree Response to River Flow Along the Brazos River

Below are data and a discussion of the response by specie, grouped by site.

## Brazos Bend

Figures 74a-c illustrate the data summarized in Table 17. Only key indicator species were shown graphically. Each graph is a comparison of total annual river discharge for that site's gauging station (refer to Table 12) vs. basal growth for that same year. The green masking corresponds to discharge that resulted in highest productivity, while the red masking corresponds to discharge associated with reduced and/or inversely proportional tree growth. The pink line indicates one standard deviation of ring width (with the center dot showing medium ring width) for which 76% of all that specie's BI falls within, and was used to examine significantly high and low productivity years.

Figure 74a shows that while *A. negundo* experiences its best growth between 4.9 - 18.3 km$^3$/y, and doesn't appear to be affected by low flows, flows in excess of 20 km$^3$/y cause a reduction in BI.

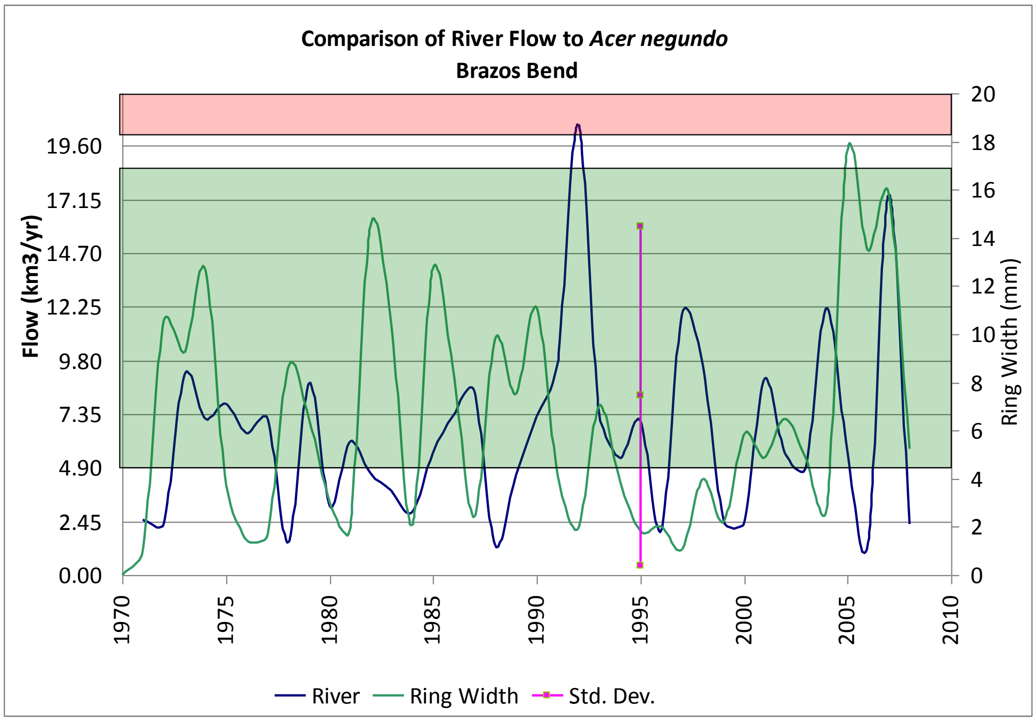


**Figure 74a:** Annual River Flow vs *A. negundo* Productivity

Figure 74b shows that *C. laevigata* doesn't appear to be limited by low flows and experiences its best growth between 2.5 and 12.2 km$^3$/y, but flows in excess of 15.9 km$^3$/y cause a reduction in BI.

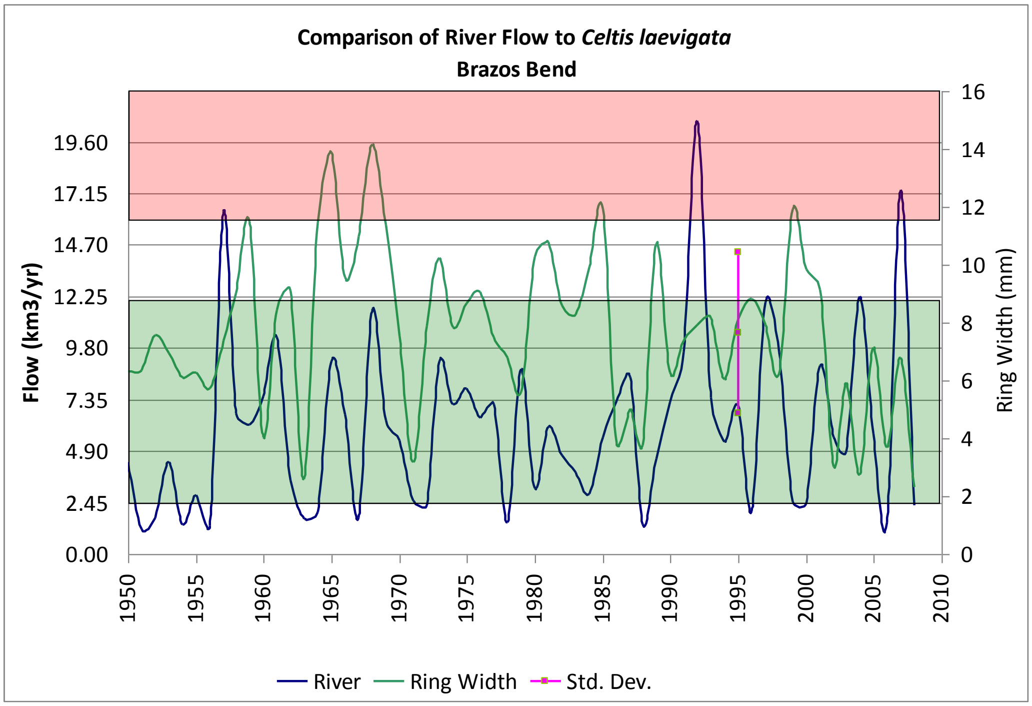


**Figure 74b:** Annual River Flow vs *C. laevigata* Productivity

Because of the very young age of *S. nigra* adults in Brazos Bend, while a positive relationship to increased flows was seen, making longterm conclusions was difficult and no masking was applied (Fig. 74c).

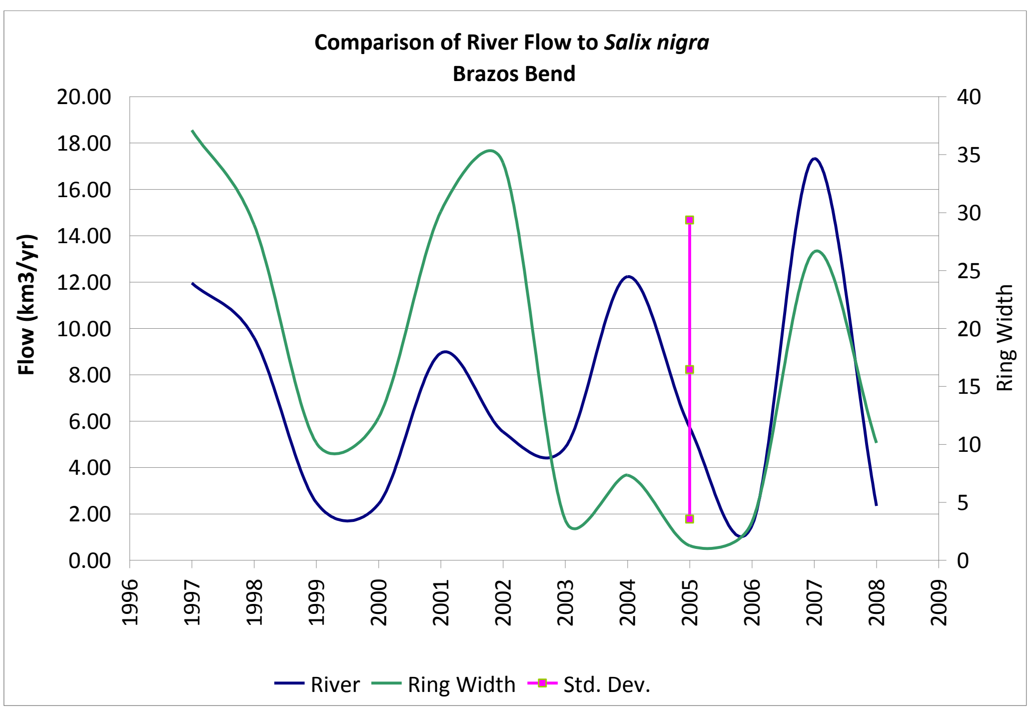


**Figure 74c:** Annual River Flow vs *S. nigra* Productivity

## Hearne

Figures 75a-c illustrate the data summarized in Table 17. Each graph is a comparison of total annual river discharge for that site's gauging station (refer to Table 12) vs. basal growth for that same year. The green masking corresponds to discharge that resulted in highest productivity, while the red masking corresponds to discharge associated with reduced and/or inversely proportional tree growth. The pink line indicates one standard deviation of ring width (with the center dot showing medium ring width) for which 76% of all that specie's BI falls within, and was used to examine significantly high and low productivity years.

Flows below 0.6 and above 6.1 km$^3$/y tended to suppress growth in *A. negundo* (Fig. 75a). The specie showed best growth from 3.1 – 3.8 km$^3$/y.

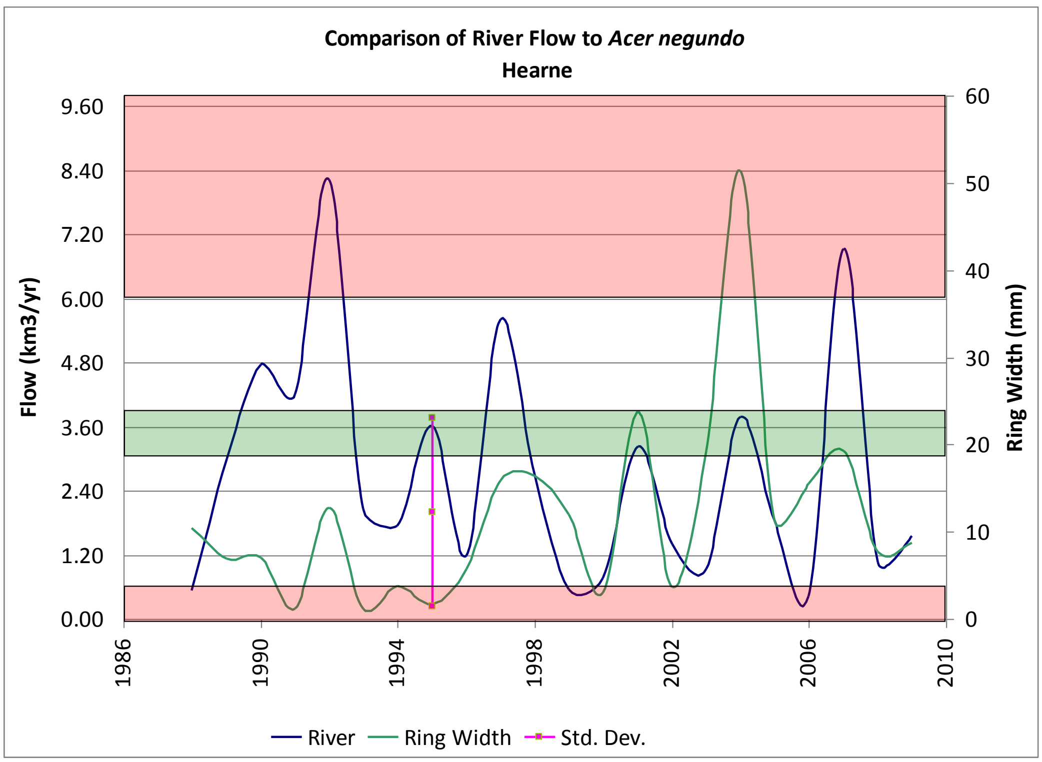


**Figure 755a:** Annual River Flow vs *A. negundo* Productivity

Figure 75b shows that while *C. laevigata* experiences its best growth below 3.6 km$^3$/y, and doesn't appear to be affected by low flows, but quickly shows a reduction in BI with flows in excess of 3.6 km$^3$/y annually.

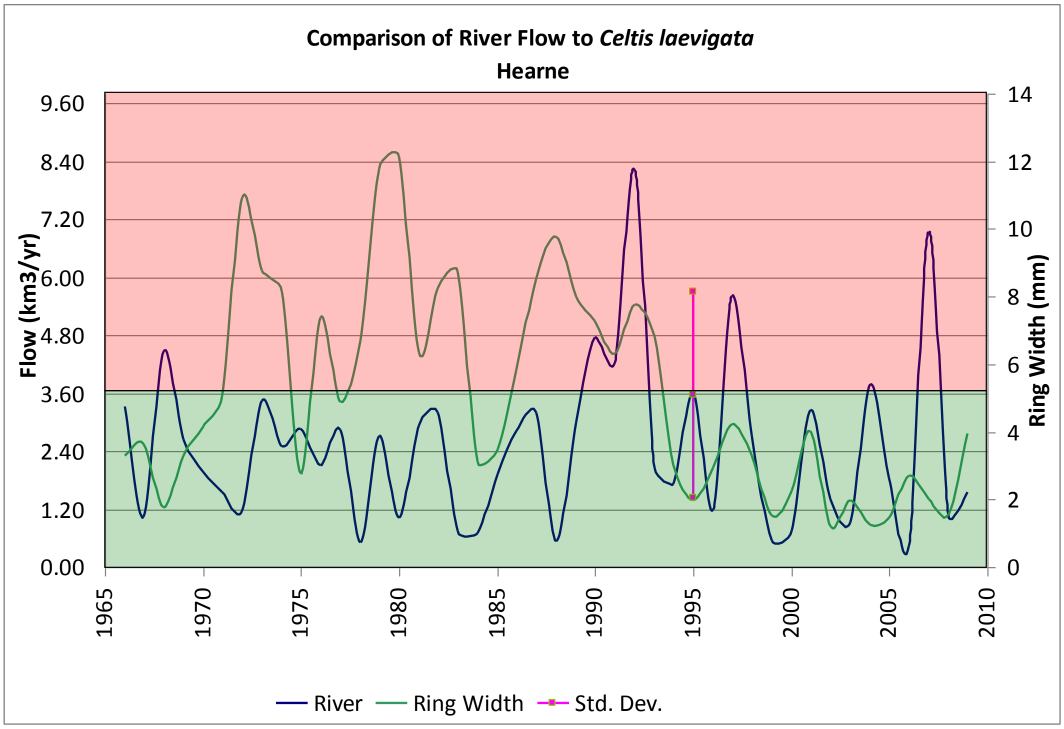


**Figure 75b:** Annual River Flow vs *C. laevigata* Productivity

*S. nigra* was the only specie in the community with a direct relationship to river discharge (Fig. 75c). It was suppressed by flows below 1.8 $km^3/y$ but had optimal growth with flows in excess of 3.1 $km^3/y$.

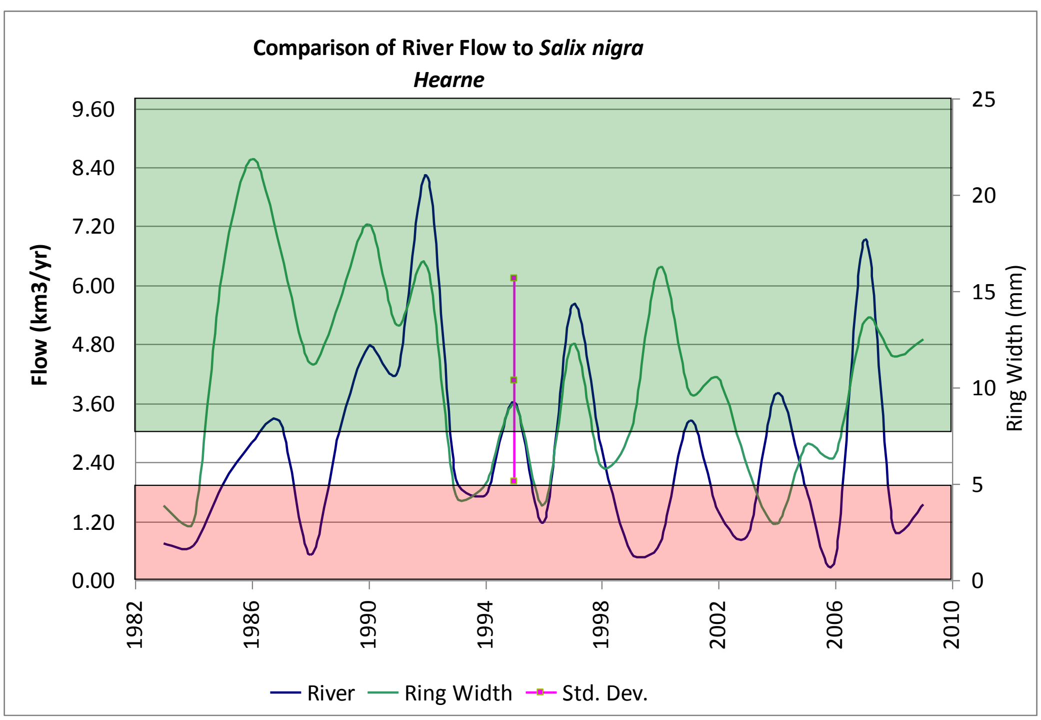


**Figure 75c:** Annual River Flow vs *S. nigra* Productivity

## Marlin

Figures 76a-b illustrate the data summarized in Table 17. Each graph is a comparison of total annual river discharge for that site's gauging station (refer to Table 12) vs. basal growth for that same year. The green masking corresponds to discharge that resulted in highest productivity, while the red masking corresponds to discharge associated with reduced and/or inversely proportional tree growth. The pink line indicates one standard deviation of ring width (with the center dot showing medium ring width) for which 76% of all that specie's BI falls within, and was used to examine significantly high and low productivity years.

Figure 76a shows that *A. negundo* experiences its best growth between 0.6 and 3.1 $km^3/y$, and doesn't appear to be affected by low flows, but flows in excess of 4.4 $km^3/y$ cause a reduction in BI.

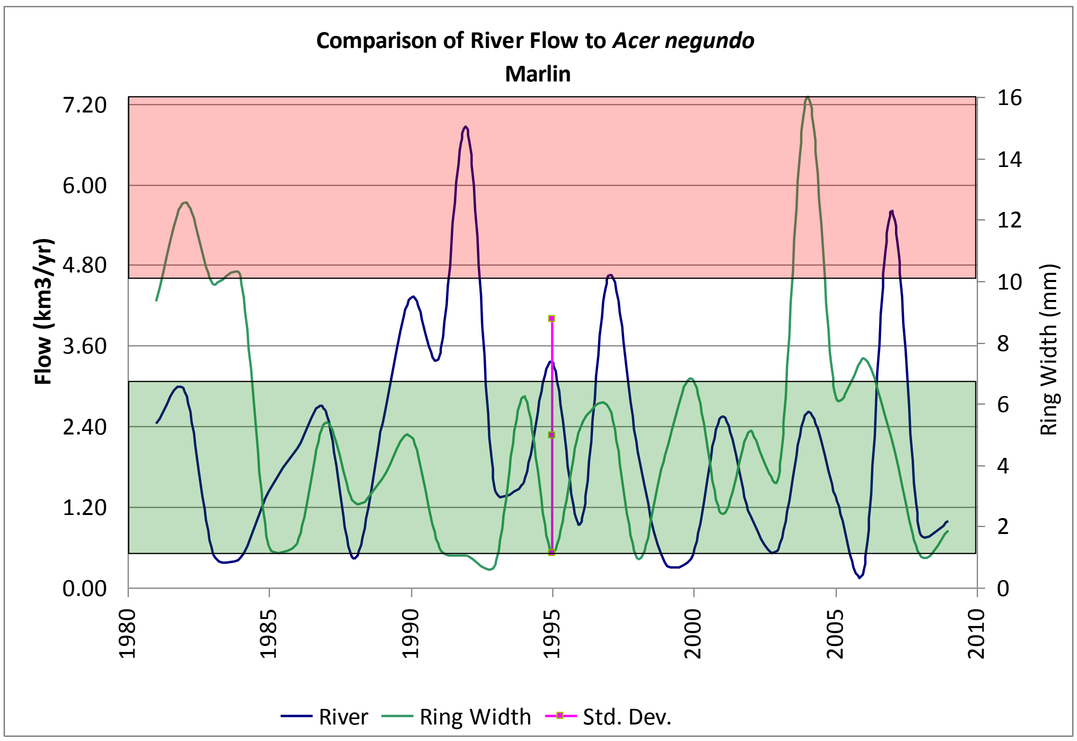


**Figure 76a:** Annual River Flow vs *A. negundo* Productivity

*S. nigra* also exhibited a direct relationship to river discharge (Fig. 76b). It was suppressed by flows below 0.6 $km^3/y$ and had optimal growth with flows in excess of 4.3 $km^3/y$. One exception to that was the major flood in 1992: that year and the year following *S. nigra* productivity declined considerably.

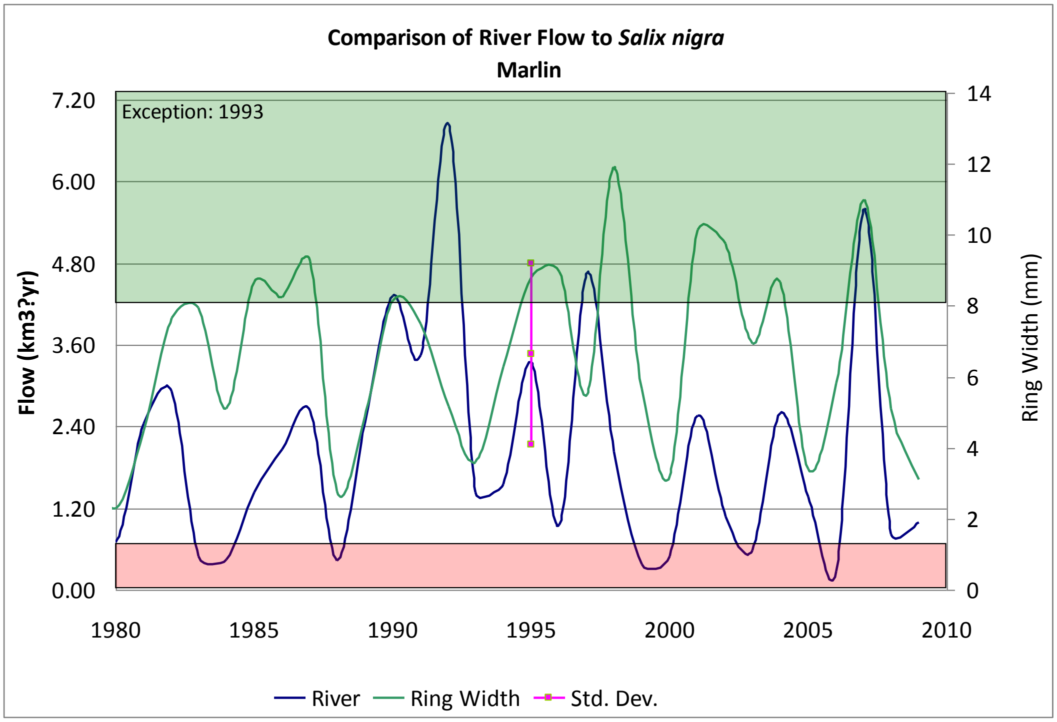


**Figure 76b:** Annual River Flow vs *S. nigra* Productivity

## Snook

Figures 77a-c illustrate the data summarized in Table 17. Each graph is a comparison of total annual river discharge for that site's gauging station (refer to Table 12) vs. basal growth for that same year. The green masking corresponds to discharge that resulted in highest productivity, while the red masking corresponds to discharge associated with reduced and/or inversely proportional tree growth. The pink line indicates one standard deviation of ring width (with the center dot showing medium ring width) for which 76% of all that specie's BI falls within, and was used to examine significantly high and low productivity years.

Flows below 1.8 and above 6.7 $km^3/y$ tended to suppress growth in *A. negundo* (Fig. 77a). The specie showed best growth from 3.1 – 5.5 $km^3/y$.

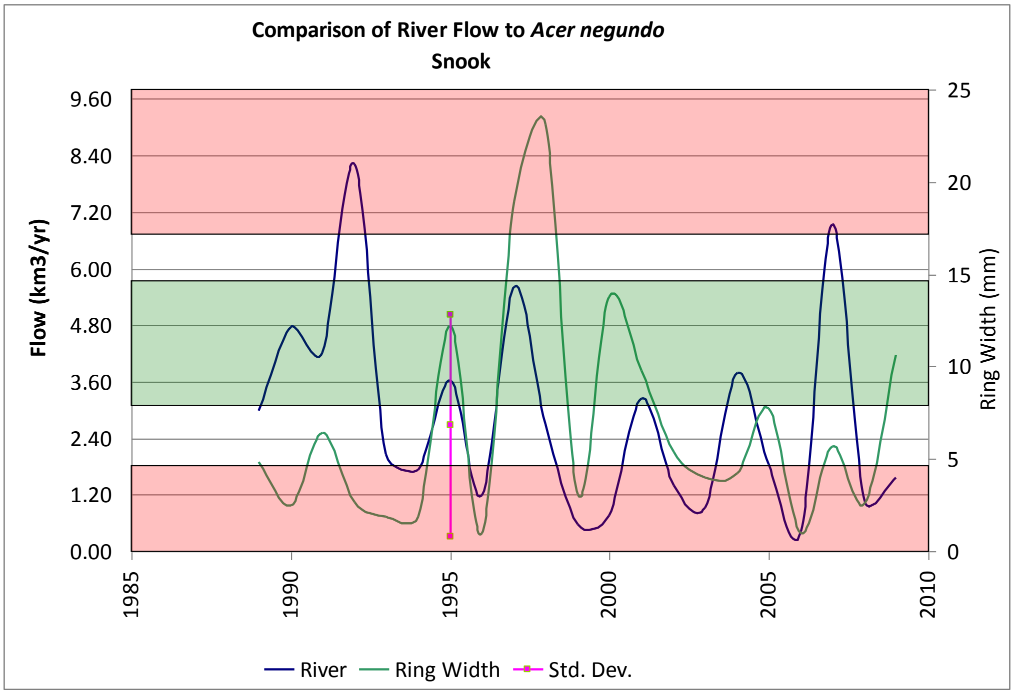


**Figure 77a:** Annual River Flow vs *A. negundo* Productivity

While *C. laevigata* showed best growth with the high flows in 2007, the short age of trees, coupled with variability in BI prevented longterm analysis of this specie's relationship to discharge (Fig. 77b).

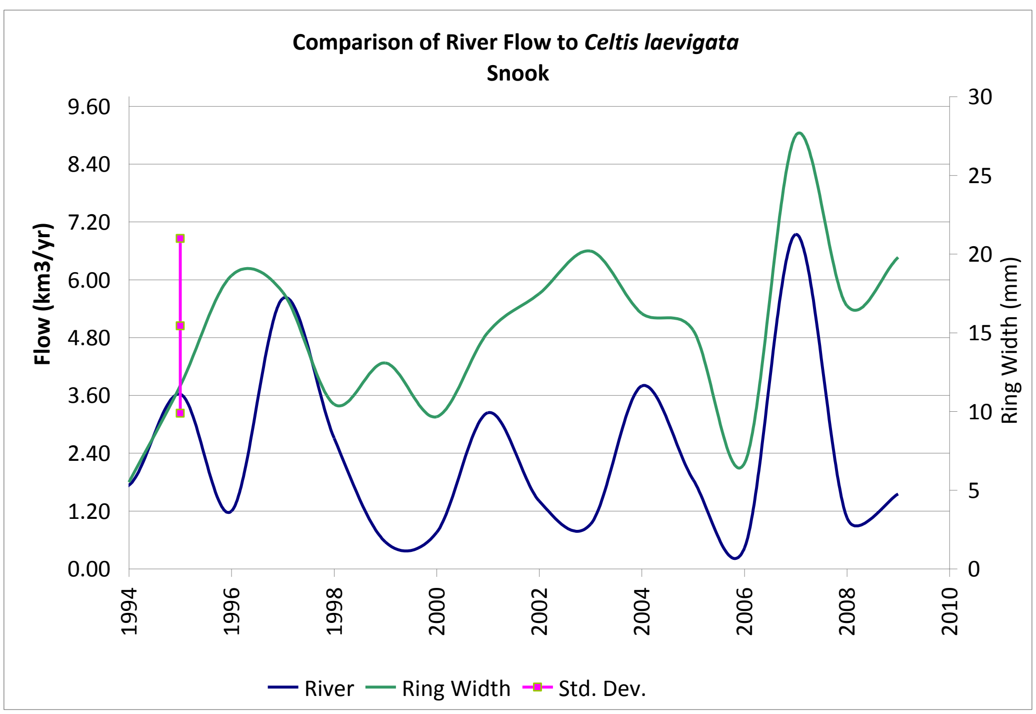


**Figure 77b:** Annual River Flow vs *C. laevigata* Productivity

*S. nigra* again exhibited its characteristic direct relationship to river discharge (Fig. 77c), this time with one exception: the 2007 flood. It was suppressed by flows below 0.8B km$^3$/y but had optimal growth with flows in excess of 1.5B km$^3$/y.

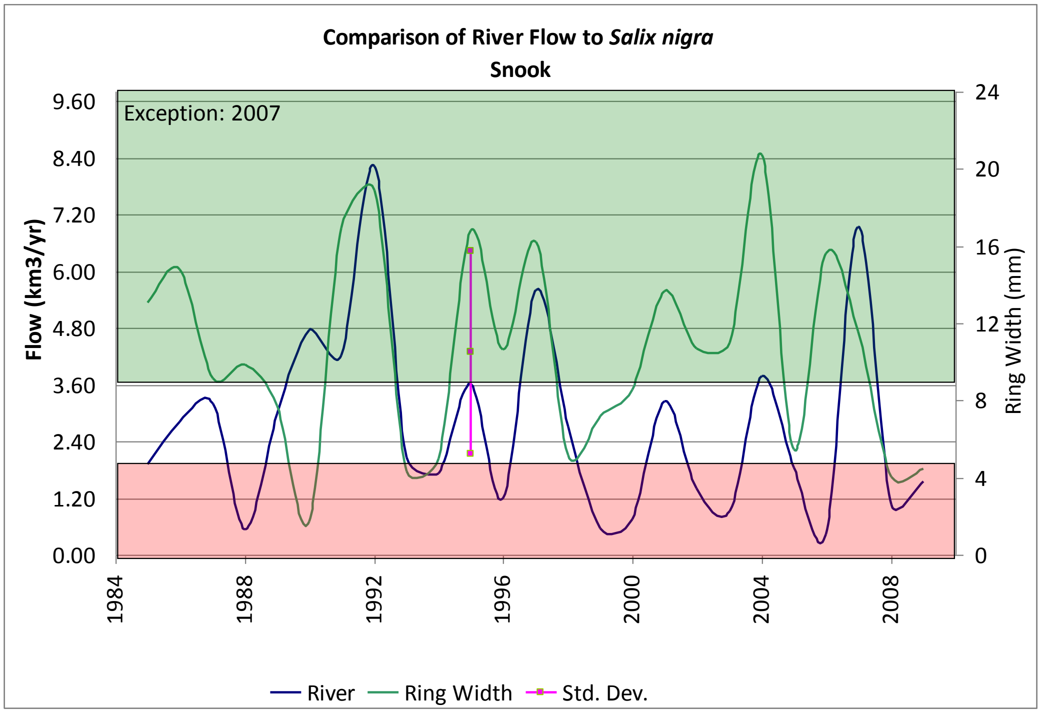


**Figure 77c:** Annual River Flow vs *S. nigra* Productivity

## Flood Frequency and Timing

Comparison of select flows for each of the three river gauges in the 25 years leading up to 1985 as well as the 25 years post-1985 are shown in Figures 78-80. Based on general information about average channel heights in the study areas (see Table 12) the following flows were chosen as a representative flood for each gauging station:

#08096500 at Waco, TX = 1,000 cfs
#08098290 at Highbank, TX = 6,000 cfs
#08111500 Hempstead, TX = 2,000 cfs

Figure 78 shows that in the spring and fall months flow at Waco, TX has increased since 1985 for the months of February to June, and in September, though the largest increases were in March and April - showing increases of 4 and 6 days, respectively. July and October show slight decreases in flow, indicating that shifts to timing of flow have been concentrated to early spring and September.

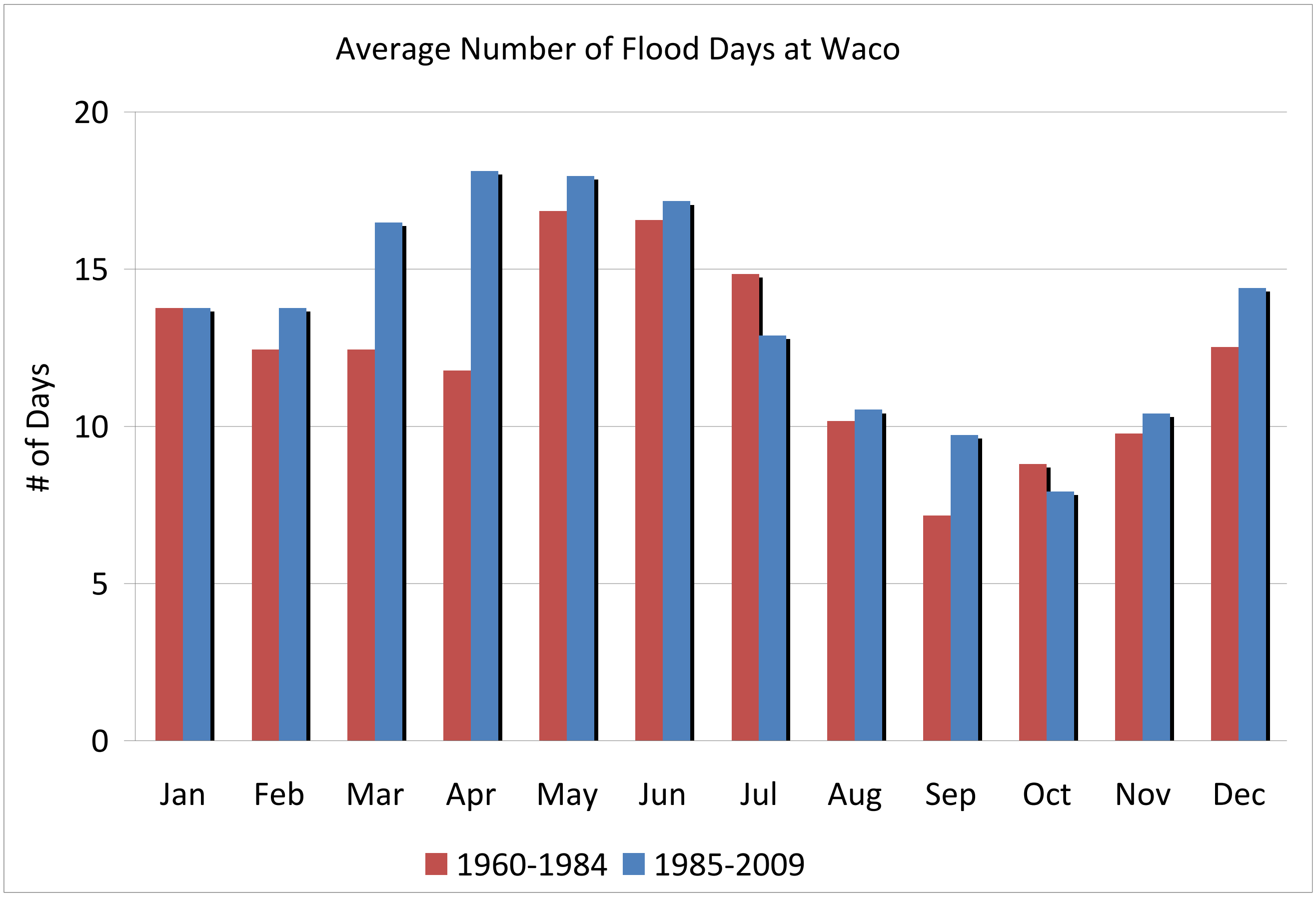


**Figure 78:** Comparison of pre and post-1985 number of days in which flow exceeded 1000 cfs (recorded as flood days) at USGS gage 08096500 at Waco, TX

Figure 79 shows that in the spring and fall months, flow at Highbank, TX has increased since 1985 in the months of January to March and again in July and August, with the largest increases were in March and June showing increases of 4 and 3.5 days, respectively. July and October show slight decreases in flow, indicating that shifts to timing of flow have been concentrated to early spring and September.

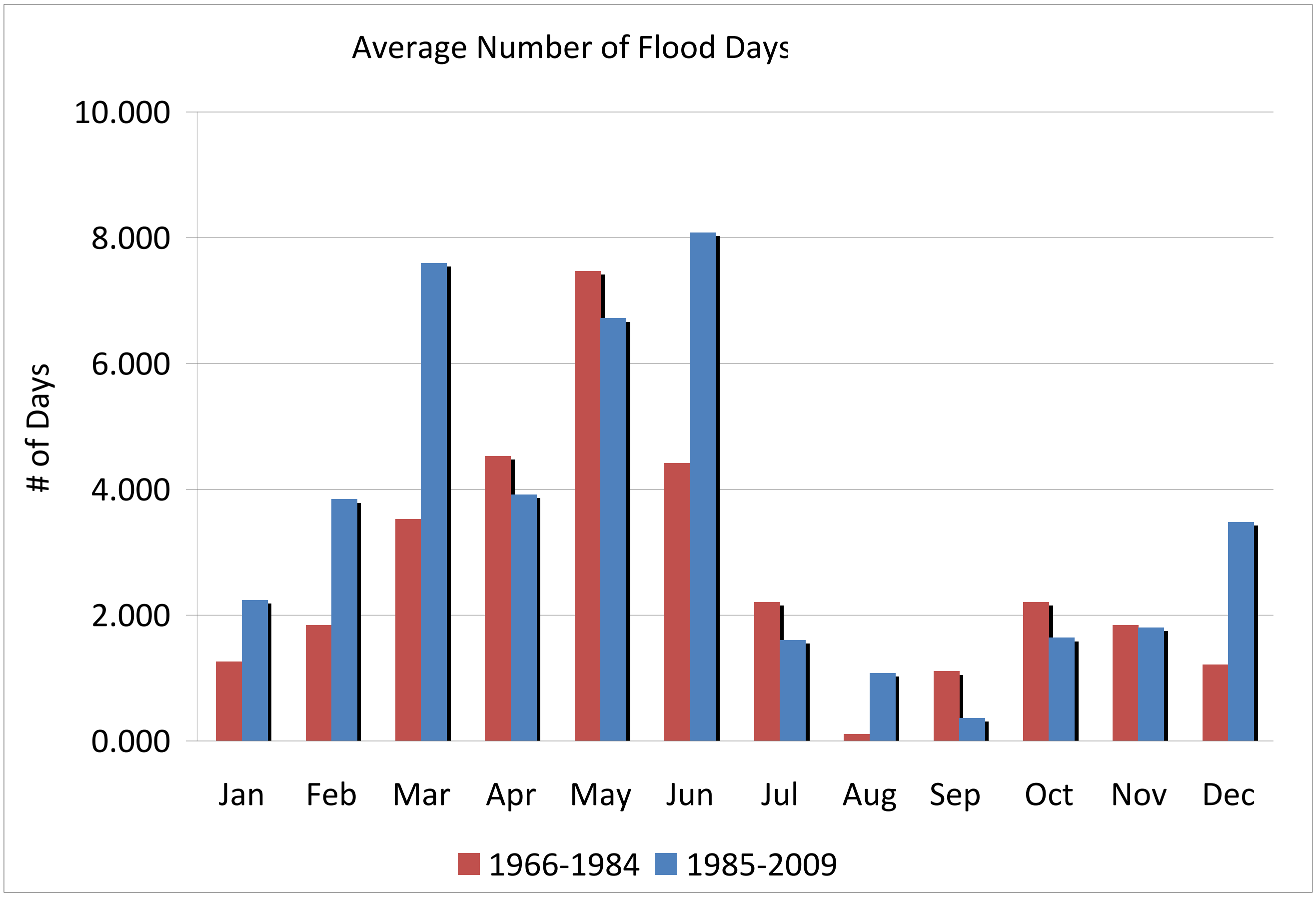


**Figure 79:** Comparison of pre and post-1985 number of days in which flow exceeded 6000 cfs (recorded as flood days) at USGS gage 08098290 at Highbank, TX

Figure 80 shows that in the spring and fall months, the number of days at which flow was 2000 cfs or more at Hempstead, TX has increased since 1985 slightly during the months of March and April by four and three days, respectively.

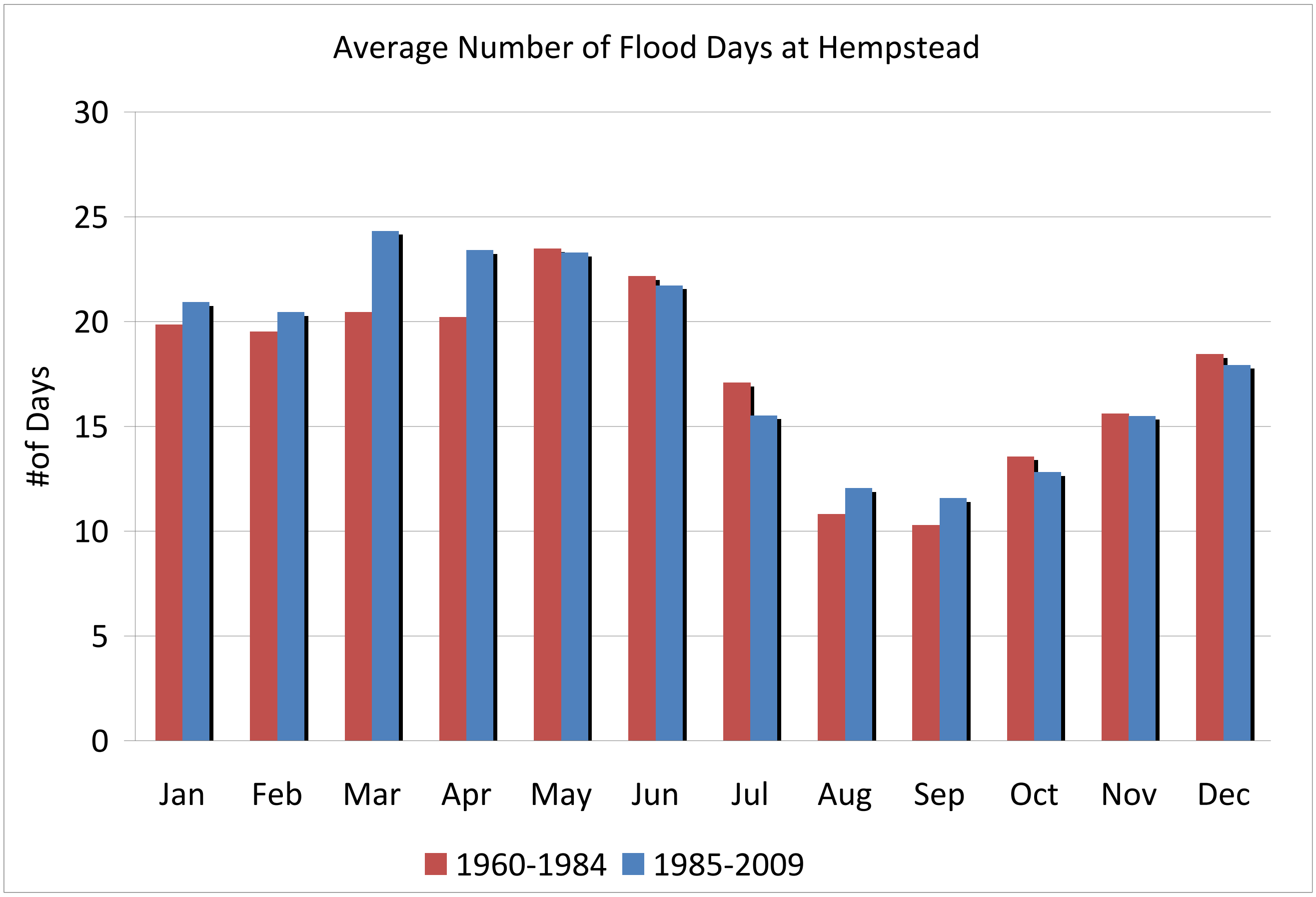


**Figure 80:** Comparison of pre and post-1985 number of days in which flow exceeded 2000 cfs (recorded as flood days) at USGS gage 08111500 at Hempstead, TX

GROUNDWATER MONITORING

A side investigation of groundwater depth was conducted to monitor fluctuations of groundwater in relation to stream water. This study was set up to test if/and by how much the groundwater table pulses, and whether those pulses are correspondent with stream levels (indicative of hyporheic connectivity), or independent of stream flows (no hyporheic connectivity). At the Hearne 02 site, a piezometer was installed ~13m distance to the stream. To access the groundwater, soil was augured to a depth of 3.7m. The piezometer was installed with a digital transducer to monitor hourly fluctuations of water level. Figure 81 shows a diagram of this installation in relation to ground surface and stream.

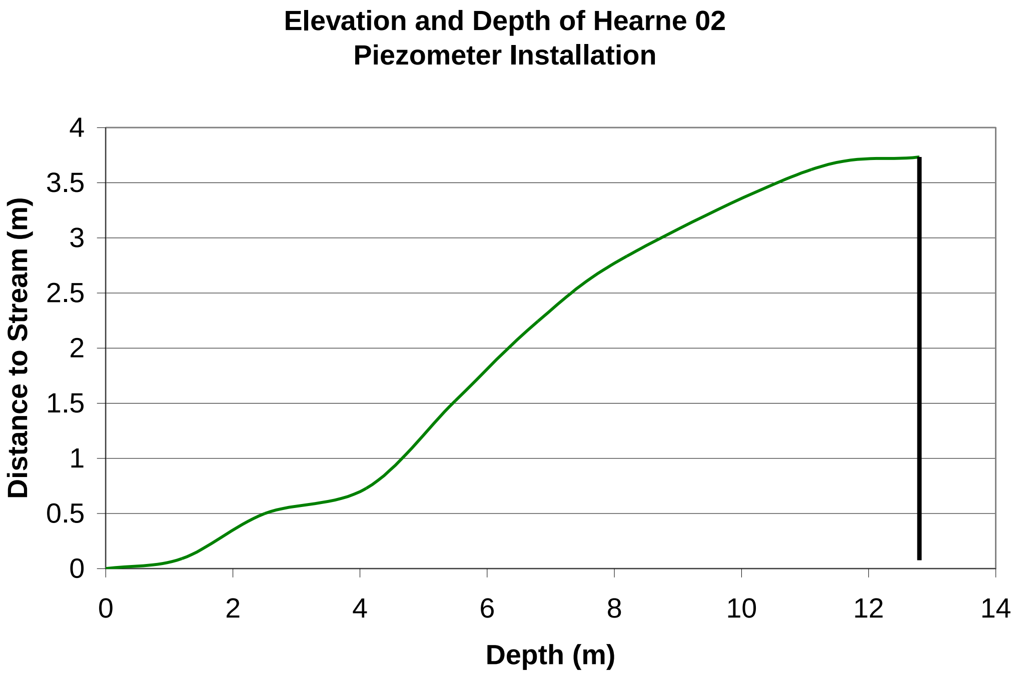


**Figure 81:** Piezometer Installation at Hearne 02

Monitoring of groundwater level was then compared to recorded gauge level heights for USGS Gage #08108700 in Bryan, TX, the closest gauge available to the site. Figure 84 shows that groundwater fluctuations very much track stream water levels, and in the period from November 4th to December 4th, 2010 it varied by almost 0.5m in the soil profile.

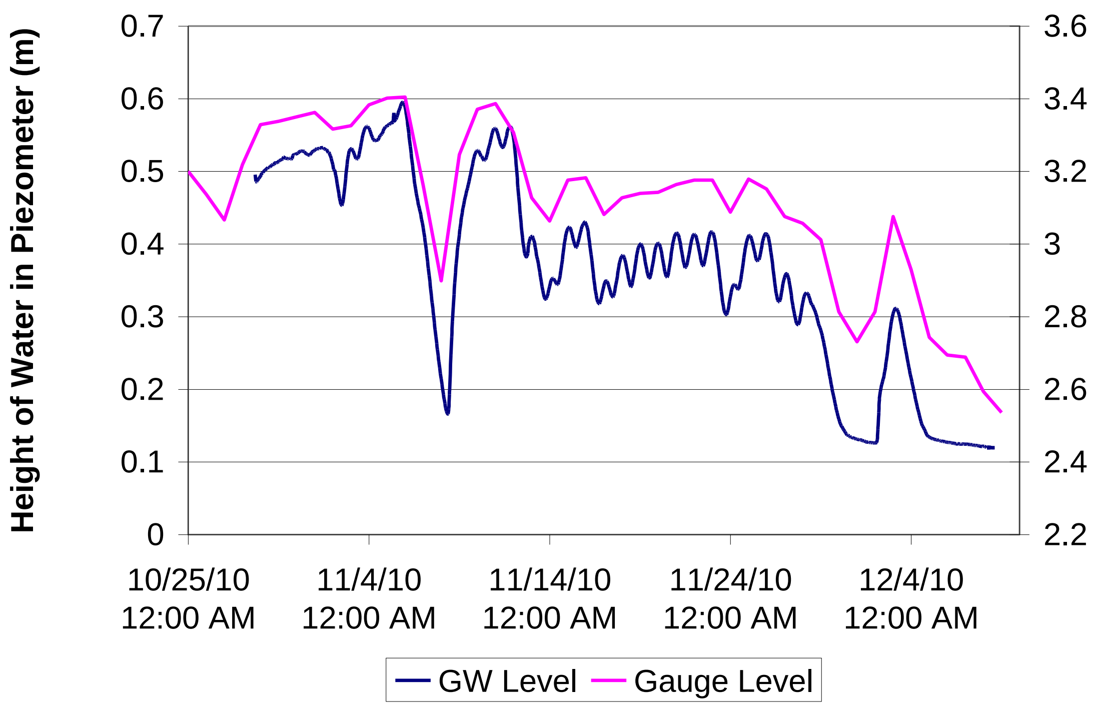


**Figure 84:** Groundwater and Stream Gauge Levels from 10/25 to 12/4/10

## BRAZOS RIVER CONCLUSIONS

Results show that the Brazos River is a highly incised stream, even more so than the San Antonio River. With the exception of point bars (one at Hearne Transect 02 and two at Snook, Transects 01 and 02) channel slopes were very steep and showed evidence of frequent slumping. Channel height for the point bars ranged from 4-8m, and between 6 and 13m for other transects. Brazos Bend the downstream-most site had very steep banks, all exceeding 13m vertical distance. Often lower-tiered sand bars could be found where upper bank soils had accumulated near the low-water's edge.

When considered as a continuum community along the river, the combined results of water table measurements indicate that *S. nigra* (except in the Snook site) appears the only species that was consistently limited to regions where the water table was more shallow than 4m (though *A. negundo* and *F. pennsylvanica* showed similar relationships in the sites where they were found). As was pointed out with the San Antonio River conclusions, because of the shallow roots of trees such as *S. nigra, A. negundo* and *F. pennsylvanica*, their distribution likely is also highly influenced by stream bank wetting when soil water tables are receding and/or out of root reach. This study verified the difficulty of separating the two.

Excepting the pattern at Snook, *S. nigra* tended to be limited to areas where groundwater was shallow, as did *A. negundo* when it was encountered. While some dependence on shallow groundwater was seen for *P. deltoides*, several trees exhibited shallow-water independence, likely due to taproot formation. Smith *et. al.*, 1989, showed that reduced stream flow had a more negative effect on *Populus* juveniles than mature trees, because water normally available to shallow-rooted juveniles was lessened, but deep-rooted mature trees remained largely unaffected.

The unique setting of the Snook 02 transect, with a nearby pond along an old stream channel, makes it an excellent site for future examination of "remnant underground streambed and their hyporheic connectivity to the current stream channel. Evidence was observed of the old stream channel's influence on several factors such as: depth to water table, independence of *S. nigra* to water table depth, altered spatial distribution of riparian-associated trees, and independence of *P. deltoides* and several other species' growth to stream flow. Because floodplain water bodies can induce lateral groundwater activity with the active channel (Hudson *et. al.*, 2006) this site presents an opportunity to test whether the floodplain lake is hydrologically separated from or connected to the main-stem channel, and what river processes are potentially being influenced.

When Snook data are compared to the most-incised site Brazos Bend, the pattern of broader spatial distribution but lower elevation limits at Snook may be an indication that further distance-to-stream is possible with a shallow groundwater table, but height above stream is also reduced – indicating a possible inverse relationship between distance and elevation to stream that may be a factor of both groundwater and periodic stream pulsing in the bank channel. Groundwater monitoring at the Hearne Site shows there is some variability in groundwater, but it appears to closely track with stream water. This supports that the nearby stream is interacting with groundwater and important to trees growing in these near-channel zones.

As with the San Antonio River study, to better predict future a flow regime necessary to protect riparian zones along the Brazos River, we first had to analyze historical productivity. The use of multiple dominant species to individually analyze river flow to productivity, rather than relying on general wetland riparian groupings was very useful and provided many insights. Based on productivity, response to streamflow and abundance of species throughout the river continuum, two species were identified as key indicators for a healthy riparian system along the Brazos River, *S. nigra* and *A. negundo*. Because they both represent species indicative of a healthy riparian zone, the combined information of both responses provides a richer picture for predicting future flows. Though used in the San Antonio River, *F. pennsylvanica* was excluded as a key indicator for this river because its overall dominance was much reduced and recruitment ages are sorely lacking. This latter point does not imply that *F. pennsylvanica* be excluded totally from analysis, as its potential loss may signal a declining health of the riparian zone, thus it warrants a watchful awareness for future studies of this river.

Additionally, this study recommends that one or two species be utilized as key indicator species for predicting riparian zones in decline (undergoing invasion of upland species to the detriment of riparian-healthy species), indicating the true riparian zone is either being reduced or overtaken because of altered flow/water availability. A key species for this indicator appears to be *C. laevigata* as in the San Antonio River.

To summarize productivity information on mature trees, using both *S. nigra* and *A. negundo* as indicators: to maintain adequate adequate/healthy productivity flows along the Brazos at Hempstead should be maintained for an annual flow of between 2.5 and 12.2 $km^3$/y. Flows along the Brazos at Highbank, TX should be maintained for an annual flow of between 1.8 and 3.6 $km^3$/y the majority of the time. Flows along the Brazos at Waco, TX should be maintained for an annual flow of between 3.1 and 3.5 $km^3$/y the majority of the time. Maintenance for this regime the majority of the time will allow for episodic flood and drought events outside those range that have historically been seen along the river to be within the tolerances of the community to withstand such events.

All three gauges showed an increase in the frequency of flood days for multiple spring months over the past 25 years. Given the two decades in the 1970's and 1980's of comparatively dry years, this trend likely reflects that pattern in pre vs post-1985 comparisons. Productivity in the trees appears to be dynamically stable with both regimes. However, there are two major flood events that are consistently implicated with suppression of flow for those trees that responded negatively to excessively high flows: the February/March flood in 1992 and the July flood in 2007. Because one was late winter – just before trees begin budding and flushing out for spring, and the other was summer, they would indicate that regardless of timing, excessive flows will reduce productivity in most trees in the zone. Therefore general maintenance of the recommended flows with flood frequencies higher in spring and early fall, as is historically seen, should provide a stable riparian zone that is healthy enough to maintain and/or recover from natural episodic events.

Interestingly, several species show lower counts for trees in the 15-20 year old age classes. Given the very large flood event in early 1992 (17 years previous), and the known reduction of productivity shown in so many trees in the community, the low counts may be indicative of a larger community response to that flood. When stressed by large disturbances not only might the tree be suffering reduced productivity but as a defense mechanism those same trees will either reduce fruit production and/or drop seeds maturely in order to survive (Stromberg and Patten, 1990). Therefore recruitment would be expected to be lower and may be the explanation for lower numbers of trees in this age group. Additionally such a major flood would act as a scouring agent of saplings along the river. Played forward, a loss of this age class may then cause a reduction of recruitment in that generation's reproductive years (i.e. less trees in one age class results in a lowering of seed production when that smaller age class reached reproductive age). Future studies of the productivity of this river should focus on addressing this population pulsing as a dynamic component of longterm recruitment and replacement patterns.

An interesting pattern with *C. laevigata* is that the stands of trees are much younger than along the San Antonio, yet their abundance is much greater. Clearly *C. laevigata* is expanding rapidly, both in numbers and in spatial coverage at further distances to the stream. Given the overall reduction of both the biodiversity of riparian-healthy species and the numbers of trees at multiple age classes within those species, along with the rapid expansion of *C. laevigata*, this may signal the riparian zone is transitioning toward less functionality. The dramatic differences in spatial coverage of healthy riparian key indicators between point bars and the more typically seen downcut banks indicates downcut banks have lower water tables, truncated ranges for indicator species, and invasion of less-than-healthy indicator species.

As mentioned earlier *S. nigra* drops seeds usually from April to July in its southern range. Adequate flows during these months must be maintained to allow for water dispersal. Because adult *S. nigra* and *A. negundo* grow along the channel slopes and up on the depositional areas of the floodplains, adequate flows would include events during both spring and fall months as well as that include both bankfull and overbanking to allow for water dispersal, germination and maintenance of the seedlings/saplings. Currently along the Brazos River, seed dispersal appears to be adequately maintained both in count and in spatial range for *S. nigra* and *A. negundo* at most sites, but not for *F. pennsylvanica*. The small number of *A. negundo* saplings is cause for concern as it may indicate flows into the zone are not adequate to maintain this species' early life stages. Flow regimes should take this into consideration, and was recommended for the San Antonio River, ensure that site inundation should mimic the 2-yr flood event to these species' spatial ranges and occur on an annual to semi-annual basis. Studies using hydrological modeling of discharge to site inundation can be overlain with this species' seedling/sapling distribution to gain a better understanding of the number of flood days (and proper discharge) necessary for *A. negundo*.

Plant invasions into the active channel do not appear to be an issue for the Brazos River. Though *C. laevigata* appears to be expanding in the study sites and represents a dominant specie in the community, it doesn't appear to be establishing *inside* the bank channel. Seed dispersal for all riparian species along the channels follows mature tree spatial distributions and does not appear to be reducing size of the channel in any way. *S. nigra* ages are even shorter than those growing along the San Antonio River and indicate that very few trees reach half their expected lifespan, barely making it to reproductive maturity. Given their close proximity to the water's edge, loss of trees to high water flows probably explains their short life spans, and is likely the case for *A. negundo* as well (a similarity to the San Antonio River). Because recruitment is strong, *S. nigra* appears to be relatively stable, though not expanding, as there are low numbers of trees of early replacement age (5-15 years). Overall, the majority of all tree species had reduced counts (compared to the San Antonio River) in all age classes. *S. nigra* still appear stable enough to maintain themselves and/or recover future episodic flooding or drought events, but do not appear to be invading a channel whose high rate of erosion appears to provide frequent scouring of channel-dwelling plants. *A. negundo* should be monitored for future survivability, and *F. pennsylvanica* appears poised for disappearance along this river given its current state.

In summary of river flow maintenance and subsequent riparian invasion: given the severe downcutting of banks along this river, rather than riparian invasion of the channel, the bigger concern is probably maintenance of those plants along the channel whose roots can provide for soil stability and protect against even further erosion of the channel.

# CHAPTER 4
# OVERALL STUDY RECOMMENDATIONS

With the exception of point bars, channel slopes on both rivers were steep and showed evidence of frequent slumping. Floodplains ranged from 5-8m above baseflow along the San Antonio and from 6-13m along the Brazos. Studies have shown channel incision to cause a lowering of water tables and drying out of stream banks to such an extent that vegetation may be converted from riparian-healthy to upland-invasive species (Micheli and Kirchner, 2002). The hydrologically disconnected stream and floodplain result in rare water inundation, and the lowered water tables potentially threaten water-dependent riparian species. To prevent loss of a healthy riparian forest, instream flow maintenance must include flood frequencies and timings to prevent such conversion.

Results of this study show that point bars represent instream flow ital sections along the river where maintenance of riparian species may be focused to ensure longterm survivability of some of the key indicator species, especially when those species' abundances are threatened along the incised stretches of the river.

Shallow groundwater is an important component of a healthy riparian ecosystem because it provides for the establishment/revegetation of such species as *Salix* and *Populus* (Stromberg, 1998) following episodic events, and is vital to providing trees the resistance to withstand major flood disturbances. Without such resiliency, large floods can have adverse ecological effects to the riparian forest (Middleton, 2002). Shallow groundwater has been shown to be the primary water source for many riparian trees ( e.g. *Salix, Populus, Platanus*) and its persistence depends on the recharging potential of flood flows (Smith *et. al.,* 1998). Additionally, the loss of shallow groundwater increases the potential for deeper-rooted invaders to persist in such areas, and an increase in upland plants is often seen as an indicator of declining water table. (Myers, 1989).

Because of the severity of incision and verticality of channel slope away from low-water's edge, depth to the water table increases rapidly in the near-bank region, often surpassing 4m, except on slopes located on the inside of a meander with considerable deposition and shallow channel slopes. Because bankfull ranges from 5-13m along these rivers, loss of connectivity appears to be a concern in the riparian zones. Further supporting this is the spatial distribution of species whose life stages depend on flooding frequency (constrained to channel slopes) vs. more upland-associated species who are either less dependent on or less tolerant of frequent soil saturation (dominated the rest of the forest). When considered as a continuum community along the river, the combined results of water table measurements indicate that *S. nigra* appears the only species that was both consistently limited to regions where the water table was more shallow than 3-4m and located abundantly along both rivers. Additional trees which exhibited spatial distributions associated with shallow groundwater/stream flushing along channel banks were *A. negundo*, *F. pennsylvanica,* and *P. deltoides* (to a limited extent). All of these species were generally limited to channel slopes and near-bank edges, unless mitigating circumstances allowed for broader distribution (point bars, etc.). All other species in this study appear water table-depth independent and made up the majority of the composition of the outer edges of the riparian forest.

The use of multiple dominant species to individually analyze river flow to productivity, rather than a reliance on general wetland riparian groupings was very useful and provided many insights. Additionally, this study recommends that one or two species be utilized as key indicator species for predicting riparian zones in decline (undergoing invasion of upland species to the detriment of riparian-healthy species), indicating the true riparian zone is either being reduced or overtaken because of altered flow/water availability. Presence of this specie would warrant future monitoring as a sentinel of potentially declining riparian functionality.

Riparian species' vigor above ground is a reflection of their below ground condition and their ability to not only sustain themselves, but also to prevent degradation of channel soils. This underscores the need for maintenance aimed at a generally healthy productive flow to ensure that species vigor is maintained, thereby increasing resiliency of those trees in weathering inevitable large floods or droughts, and ability to revegetate post-disturbance. Flow recommendations to maintain these communities are given in each river's Conclusions Section. Maintenance of suggested flows/frequencies for the majority of the time will allow for episodic flood and drought events outside those ranges to be within the tolerances of the community to withstand such events.

It is not expected that either river will kept within those flow regimes at all times. Nor would it be healthy if it *were* possible. These rivers maintain a dynamic equilibrium because they experience disturbance in the form of episodic flood and drought events. Key to sustainability of these zones is maintenance flows as often as possible at known flow regimes (discharge amount, frequency and timing) for maintaining riparian-healthy communities; and nature will provide a healthy disturbance regime along the river.

Seed germination for many species (particularly riparian-associated species) can be critically dependent on flood pulsing into the zone to disperse seeds, followed by flood drawdown to allow for germination and establishment of seedlings. (Junk and Piedade, 1997). Because species become increasingly tolerant of flooding as plants mature, recruitment depends on episodic flooding during the growing season into the overbank regions. Recommendations of flow regimes for the rivers (as mentioned in each river's Recommendations Section) should take into account the seed dispersal and sapling needs of the key indicator species for that river to ensure that they are receiving adequate pulsing and drawdown periods to ensure maximum survivability. Because of the large spatial difference between floodplain and active channel, river maintenance should ensure that flows on an annual to semi-annual basis are adequate to provide both the soil moisture for young regenerates as well as alluvial recharge to the groundwater to facilitate optimal rooting establishment as they mature.

Plant invasions into the active channel do not appear to be an issue for either river. Though *C. laevigata* appears to be expanding along both rivers and represents a dominant specie in the community, it was not seen to be establishing inside the bank channel. Seed dispersal along the channels follows mature tree spatial distributions and does not appear to be reducing size of the channel in any way. The relatively young ages of even the largest/oldest *S. nigra* along both rivers indicate that very few trees reach half their expected lifespan, barely making it to reproductive maturity, as it appears they are lost to erosion before they can reach their full age potential. This is likely the case for *A. negundo* as well. Because recruitment is strong, *S. nigra* appears to be relatively stable. When compared to one another, the majority of all tree species had reduced counts along the Brazos River in all age classes. *S. nigra* still appear stable enough to maintain themselves and/or recover future episodic flooding or drought events, but do not appear to be invading a channel whose high rate of erosion appears to provide frequent scouring of channel-dwelling plants. *A. negundo* should be monitored for future survivability, and *F. pennsylvanica* appears poised for disappearance along this river given its current state.

In summary of river flow maintenance and subsequent riparian invasion, those species that are most prevalent consist of plant communities that have root masses (Coder, 2009) sufficient to stabilize channel slope soils but not jeopardize the stream width. Given the severe downcutting of banks along this river, rather than a flow necessary to prevent riparian invasion of the channel, the bigger concern is probably maintenance of those plants that can provide for soil stability and protect against even further erosion of the channel.

## STUDY CONCLUSIONS

The San Antonio and Brazos Rivers are both highly-incised streams with steep banks and floodplains that are largely disconnected hyporheically from groundwater/stream water - and have been for the life spans of current tree communities along those rivers. In contrast to one another, the San Antonio River has seen considerable increase in discharge rates over the past several decades, while the Brazos River has experienced little changes, save for naturally occurring drier and wetter fluctuations. Despite these differences, similarities do exist between their flow regimes, riparian vegetation communities, and tree responses to stream flow. Importantly, examination of these tree communities has provided valuable insight into their future health. Management of each of these streams depends on a full understanding of processes within the riparian zone and how stream processes affect the functionality of those zones. Stromberg and Patten (1990) eloquently underscored the need for including riparian zones in instream flow studies: "the high flow needs of riparian vegetation question the validity of the assumption that if needs of the aquatic resources are met, needs of terrestrial vegetation will be satisfied. Because of riparian vegetation dependence [on sufficient soil wettings], requirements of plants may be greater than those of aquatic in-channel organisms." Prichard (1998) went further in justifying this need for understanding riparian importance: *a properly functioning riparian forest is necessary to maintain the integrity of the stream system itself* (paraphrased). If we are to meet the needs of these two river systems, then we would do well to maintain the health of their riparian components.

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