Fremont Cottonwood demographics and regeneration along the Verde Wild and Scenic River

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# Abstract

The watershed upstream from the Verde Wild and Scenic River drains central Arizona and the Verde River from its headwaters to terminus at the Salt River is the state’s longest remaining perennial river. Fremont cottonwoods (*Populus fremontii)* are a dominant riparian tree species in the Southwest and are important habitat for native wildlife, highly dependent upon river hydrology and are included as one of the Outstandingly Remarkable Values in the 1984 amendment to the 1964 Wild Scenic River Act. Fremont cottonwood health and demographics along the Verde River are understudied. This study uses seedling plots established after 2023 winter floods and dendrochronology to monitor regeneration and to quantify tree age and growth. Fremont cottonwoods along the Verde River are young, with the mean age being 24 years old. They continue to add biomass at an above average rate and their growth is significantly impacted by summer temperatures and river flows. Seedlings from the 2023 cohort continue to grow rapidly and their survival is governed by a diverse set of environmental conditions.

Keywords: Fremont Cottonwood (Populus fremontii), Verde River, Wild and Scenic Rivers, dendrochronology, riparian

# Introduction and Background

**Verde River Overview**

The Verde River is in central Arizona and its watershed drains over 16 thousand square kilometers. Elevations range from over 3650 m ASL in the San Francisco Peaks to about 400 m ASL at its confluence with the Salt River. The upper reaches of the watershed are largely ephemeral, consisting of the Chino Valley and Big Chino Wash. Perennial flow begins at a series of springs near Paulden, AZ. The river flows through an isolated area until it reaches Cottonwood, Arizona. The river flows then flows through the towns of Cottonwood and Camp Verde, Arizona before it reaches its Wild and Scenic (W&S) designation at Beasley River Access Point (BRAP). Along this reach the Verde River gains volume from a string of canyons with perennial tributaries. These include Sycamore, Wet Beaver, Oak, and West Clear creeks. These perennial tributaries get large portions of their base flow from springs discharging from the regional aquifers (Ecological Implications of Verde River Flows, 2008).

**Riparian Forest Overview**

Riparian forests in Arizona are disproportionately important to the landscape despite their relatively small geographic area. Riparian forests in Arizona cover only about 0.4% of the land surface area yet support more biodiversity and ecosystem functions than surrounding upland habitat (Ffolliott et al. 2004). In Arizona, 80 percent of all vertebrate species complete a part of their lifecycle in riparian areas (Hubbard, 1977). Riparian forests support and enhance terrestrial and aquatic habitat, filter upland sediment and nutrients, store water and recharge aquifers and stabilize stream banks among many other functions (Schultz et al. 2009).

Fremont cottonwood *(Populus fremontii*) and Goodding’s willow (*Salix gooddingii*) are major components of riparian forests along the Verde River. Other important woody riparian plants include Arizona sycamore (*Platanus wrightii)*, Arizona Ash (*Fraxinus veluntina)*, seep willow (*Baccharis salicifolia*)*,* coyote willow *(Salix exigua)* and sedges (*Carex).* Tree diversity is low in Verde River riparian forests with Goodding’s willow and Fremont cottonwood being the dominant species. However, age class structure is usually very diverse. Stands of Fremont cottonwood and Goodding’s willow often occur in spatially separate, but same age cohorts with younger stands closer to the active channel and older stands extending up to 200 meters away (Stromberg, 1993).

## Methods

### Field Site

* 2023 floods

### Seedling Plots

* Plot method

10 monitoring plots were established at two W&S sites. River reaches were walked in Fall 2023 to identify seedlings that had survived most of their first growing season. If regeneration was found and able to be surveyed, a metal pin was pounded into the ground and determined a radius to encompass all or most of the seedlings. We measured seedling heights with a ruler or measuring tape to the nearest centimeter and the diameters near the ground were measured with calipers to the nearest millimeter within the determined radius. These data were recorded along with a site ID and brief description of the environmental setting.

If a regeneration area was too large or there were too many seedlings to feasibly measure, the area was subsampled. First the area containing the cottonwood seedling was mapped using the Arrow100 GNSS (Quebec, Canada). After the polygon was created and the area determined to the nearest square meter, a one square meter hoop was used to create subsample areas. This hoop was placed in representative areas within the plot. The seedlings within the hoop were then measured and recorded. The goal was to sample 15-30% of the total area containing seedlings.

Light

Light intensity was taken with a Li-COR LI-1500 Light Sensor Logger (Lincoln, NE). The pyranometer sensor was placed in the or near the plot and allowed to acclimate. Then, a reading was taken every minute for 5 minutes. These readings were then averaged to get an average W m-2 value at each plot.

Herbaceous

Herbaceous competition was estimated using the Braun-Blanquet 6 step scale (Braun-Blanquet 1964). Plants within the plots and rooted at the same elevation as the cottonwood seedlings were considered.

Soil

Soil samples were taken inside the seedling plots using a trowel. Soil samples are from the first few inches of the soil horizon where the cottonwoods originally germinated. The soil samples will then be sieved to get the soil texture in which seedlings germinated.

Samples were then dried in an oven for 6 hours at 70 degrees Celsius. The samples were ten sieved to

**Analysis Methods**

A combination of Excel and R were used to calculate summary statistics. Height and diameter values were converted into a single Height-Diameter ratio (HDR). This was done so that each seedling had a single value describing its size.

Equation 1.

Changes in density and seedling size were determined by subtracting the June 2024 values from the November 2023 values

To measure between significant changes between visit (Fall 2023, Spring 2024 and Fall 2024) and growth (mean height, diameter and HDR) an Analysis of Variance (ANOVA) was used to test for significant changes and then Tukey’s HSD test was used to test for significant changes between variables. A critical P-value of less than or equal to 0.05 was used to test for significance.

To see if variables were significantly impacting seedling survival, a Spearman correlation test was used. Measured variable values were correlated to the change in seedling density. A critical P-value of less than or equal to 0.05 was used to test for significance.

### Dendrochronology

To determine the age and growth of Fremont cottonwood trees, cores were collected October of 2023 at all three study sites. A variety of size classes of Fremont cottonwoods and Goodding’s willow across the floodplain were selected for coring.

Cores were collected with a Haglof 406 mm, 2 thread, 5.15 mm increment borer attached to Stihl 044 saw motor. A core was taken as low on the tree trunk as possible, at an angle perpendicular to the tree’s lean and aimed to be as close to the pith as possible.

The borer was then drilled into the tree far enough to ensure that the pith had been passed. This ensured that an age could be estimated. For trees with a radius larger than 40 cm, the borer was inserted all the way to record as many years as possible. After the borer was in the tree, the spoon was inserted into the borer and the core was extracted. While this was being done, another crew member measured the diameter of tree at the elevation the core was taken, a GPS point was recorded, and notes were taken. The core was placed into a paper straw with the tree ID, diameter and species written on it.

* How were cores prepared

To prepare the cores for ring measurement, they were air dried and then mounted. The cores were sanded with an electric sander, starting with 120 grit, followed with 240 grit and 400 grit sandpaper. Cores were polished with 1200 grit sandpaper as needed at the dissecting microscope.

The cores were placed under a dissecting microscope and rings were counted. For cores without a pith, a concentric circle ruler was used to estimate position and determine the number of the few missing rings. Ages of the innermost ring as well as the estimated pith date were recorded. For cores where a pith date could not be estimated, a minimum age was recorded. Some cores were unable to be dated due to fractures, missing segments, rotten wood, or other problems.

To measure the ring widths of each core, the cores had to be scanned and uploaded. Dated cores were placed on an electronic scanner. The cores were scanned to produce an image of 1200 dpi resolution. The scanned images were uploaded into Cybis CooRecorder software (<https://www.cybis.se/forfun/dendro/index.htm>). Each ring was marked in the software so that the date could be verified, and ring widths measured.

**Crossdating**

Collections were created so that cores could be analyzed. Dated and scanned cores are saved as a .RWL file and uploaded into Cdendro. Files were separated into 4 different sites: Upper Beasley, Lower Beasley, Childs and Sheep. All the cores (n=148) were run through COFECHA as a dated series with no undated series. Because of the short nature of the cores, the segment length was set to 30 years and the lag length was set to 15 years. With all the cores run through COFECHA, cores with a correlation coefficient of +0.3 were pulled out to use. This series (n=39) was run through COFECHA again and produced an interseries correlation of +0.395. The COFECHA fun for this series

Limitations/Assumptions

The series and cores collected are short in nature. This makes it difficult to produce high correlations for crossdating. I used COFECHA to select cores that were correlated to each other and the overall collection of tree cores to use for further analysis. Because Fremont cottonwoods grow in riparian areas with access to year around water, it is unlikely that rings are missing which means that the trees are likely dated correctly even though this may be difficult to statistically prove.

Growth

To analyze the collections that were created I imported the collections into R. The dplR package created by Dr. Andy Bunn was used (Bunn 2010). Collections were first detrended using an age-dependent spline method and then mean Ring Width Indices (RWI) were created for each collection as well as an overall mean RWI plot for all the cores collected. The “bai.in” function was used to calculate the Basal Area Increment among the trees in each plot as well as a plot containing all the trees.

Correlation to climate

Three climate variables were used to run a response function analysis and a correlation analysis on my chronologies. Average temperature, Precipitation, and Palmer Drought Severity Index (PDSI) were all downloaded from the NOAA climate monitoring website (<https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/county/time-series/AZ-025/tmin/1/0/1993-2023?base_prd=true&begbaseyear=1901&endbaseyear=2000>). Monthly data were downloaded from 1993 to 2023 for Yavapai County, Arizona.

Flows

To correlate interannual growth and Verde River discharge, mean annual flows were gathered from the Verde River near Camp Verde (09506000) USGS gauge from 1988-2023. I used data exported from the USGS National Water Information System. I chose this location as it is located near the Wild and Scenic portion of the river and had the longest continuous discharge record.

Response Function Analysis

Response function analysis is used to help determine relationships between climate variables and tree growth. They differ from simple correlations in that they address the autocorrelation that is usually prevalent in both climate and tree growth data. Response functions and their results are more robust than correlations. Using the Treeclim package in R (Zang and Biondi 2015) I correlated my chronologies to the 4 climate variables A critical P-value of less than or equal to 0.05 was used to determine if a trend was significant and an exact bootstrap method was used. A response function analysis was used for water year (September-October) was used to test against the annual growth for that year.

## Results

* Seedlings
  + Size and plot densities
  + Mean values
  + Significant changes
  + Variables affecting survivorship
* Dendro
  + Age at coring height plots
  + RWI plot
  + BAI plot
    - Standardized?
  + Response function analysis table

## Discussion

## Seedling survivorship and demographics

Densities decreased or stayed constant in 80% of plots surveyed across the two sites. However, densities did increase in the remaining sites. This could indicate that there was recruitment following the seed release in Spring of 2024. Sites that are suitable may be able to recruit seedlings in successive years. Both sites had all three-size metrics increase between the beginning and end of the study. Mean density also decreased between all 3 visits. Densities at Childs decreased quickly to about the same level as the densities at seedling plots. Seedlings grow and thin themselves out over time as they get larger. It is expected that they will continue to grow and decrease in density as the seedlings continue to mature. How quickly seedings grow could determine how quickly seedling densities decrease.

Seedling sizes is being used a proxy for seedling health and potential. Seedlings at Childs grew larger than seedlings at Beasley. Seedling sizes may have changed and grown quicker at Childs due to the more disturbance created at this site from 2023 floods. The river now has two active channels near the where the site is and large deposits of flood debris. This added and extra disturbance could create more ideal conditions for seedling growth.

Causes of mortality are difficult to determine. At some sites the seedlings were showing signs of desiccation while sites LB 3 and LB 4 had encroachment of Common Cocklebur (*Xanthium strumarium*). The Common Cocklebur seems to be most highly concentrated in the sandy center of the depressions while Fremont cottonwood seedlings ring the outside of the depression. Fremont cottonwoods within the center were taller as they were forced to grow quickly to compete with the cocklebur. Browsing was infrequently observed and at no plots did browsing seem to be a significant impact.

Variables impacting survivorship

Each site had different variables significantly impact changes in density. Light availability was the only variable that impacted survivorship at Childs. Meanwhile at Beasley, herbaceous coverage (positive), distance above river stage (positive) and changes in HDR (positive) were all related to seedling survivorship. It is interesting that herbaceous coverage was positively correlated to seedling survivorship. One would expect that more herbaceous competition would negatively impact seedling survival, but the opposite was true. I suspect that herbaceous coverage, including cottonwood seedlings, are highest in sites with favorable conditions. For example, areas near the water table and with lots of sunlight might recruit the most plant material. On the other hand, sites with low herbaceous coverage might be unsuitable for either cottonwoods or their competitors. Distance above river stage was another significant variable. The closer a plot was to the river stage; the higher seedling survival was. This is also consistent with cottonwood ecology as seedlings must be able to reach groundwater to grow and survive in such a hot, arid environment (Cooper et al. 1999; Kalischuk, Rood, and Mahoney 2001). Increases in HDR was also a significant factor for seedling survival at BRAP. As HDR increases, so does survival. A higher HDR indicates that a seedling is taller and narrower. Plots where seedlings grew taller and narrower saw higher survivorship. This could indicate that at some plots, seedling height can help drive survivorship.

Plots at Childs and BRAP had different factors influencing survivorship. The variety of significant variables shows that seedling regeneration and survival is very site and plot specific. Seedlings regenerate in a diverse set of geomorphic settings and can be influenced by anything from light availability to distance from river stage.

## Dendrochronology

**Minimum ages**

Most of the cottonwoods along the Verde River are young. The mean inner pith date goes back to around the year 2000. Very few trees have piths dating after 2010 which means that regeneration has been sparse since the mid-2000s. There has been a relative absence of large winter floods since 2005 (Figure ??). Their young age could also be because of the relatively intact hydrology along the Verde River. Large floods occur frequently enough to constantly remove trees and recruit a younger cohort. The Verde River floodplain has been largely depositional. Tree root collars are submerged under sediment leading to uncertainty about their exact age. However, based on the understanding of Fremont cottonwood ecology and the gauge record, it is likely that most of the cottonwoods cored germinated in winter floods in 1993 or 1995. In two growing seasons, seedling heights reached an average of 36 cm and 64 cm at BRAP and Childs specifically. To get from 1995 to the average inner pith date of 2000 means that the average Fremont cottonwood germinated .9 and 1.60 meters under the current land surface. However, this assumes that seedling growth is linear and constant.

There is also a very weak correlation (r2 = .06) between the age and diameter of cottonwoods cored. With no strong trend between age and diameter, it means that other factors may be influencing size. For example, competition between trees for sunlight may be suppressing smaller trees. Cottonwoods are shade intolerant species and because they tend to regenerate in short, distinct timeframes suppressed trees may be much smaller than dominant trees of the same age.

**Tree growth**

Basal Area Index (BAI) is generally increasing since about 1995. This means that the trees have been adding basal area at an above average rate. Meanwhile, Ring Width Index (RWI) has been generally decreasing since about 2000. This means that tree rings have been getting smaller. As a tree gets taller over time, a larger volume of wood is produced with a smaller ring. The above average BAI suggests that the riparian forests along the Verde River are continuing to grow and are yet to reach a mature, steady state. Although cottonwoods are pioneer species, they are still relatively young at 25-30 years old and continue to grow at a quick rate. Both growth metrics also saw a sharp increase in 2023 where large floods could have cleared out competition or recharged local aquifers.

**Response to climate**

When the water year is considered, June and July streamflows, June PDSI, and October temperatures cause a positive response in tree growth. September streamflows negatively impact growth. Higher October temperatures may help prolong the growing season for riparian trees which would allow them to increase their growth. Higher June and July flows could help alleviate high summer temperatures and recharge the alluvial aquifer that these trees draw water from. Higher flows (and therefore higher groundwater levels) could also saturate more of the rhizosphere allowing for more roots to draw water and increase growth. Recent research found that Fremont cottonwoods can cool themselves remarkably well from high summer temperatures as long as adequate water. Higher flows could increase water availability and allow them to cool themselves better. These responses are more consistent with the North American Monsoon. In this case, summer precipitation and the monsoon season drives tree growth.

September streamflow and annual growth were negatively correlated and June PDSI positively impacts tree growth which is inconsistent with a monsoon driven system. These are also relatively weak correlations even though they are significant. One would expect September streamflow to positively impact streamflow. June PDSI could positively impact tree growth because if temperatures are higher in June and trees have adequate water, they may be able to grow quicker.

## Conclusions and Implications

Fremont cottonwoods that established after the 2023 winter floods continue to grow and reduce in density. Seedling plots seem to be impacted by different variables depending on their location. In addition, the wide variety of significant variables impacting seedling survival shows that a combination of factors is important in maintaining seedlings. Most Fremont cottonwoods on the Verde are relatively young and date about to the year 2000. They continue to grow and add basal area at an increasing rate, suggesting that the forest has yet to reach a mature state. Fremont cottonwood growth appears to be driven by summer streamflow. This also is when streamflows are the lowest and temperatures are the highest. As baseflows continue to decline, their growth and resilience could be at risk. Maintaining higher flows during the summer irrigation season would positively benefit riparian forests. Keeping the natural systems and hydrology along the Verde River is crucial to maintaining and protecting its riparian forests.