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 in central Arizona drains over 16 thousand square kilometers and is the longest, perennial river remaining in Arizona. Its watershed has elevations that range from over 3650 m ASL in the San Francisco Peaks to about 400 m ASL at its confluence with the Salt River. The headwaters in the upper Verde Valley originate from a series of springs draining the Big Chino and Little Chino aquifers (Wirt et al., 2005). The river then flows through the middle Verde Valley before it reaches its Wild and Scenic (W&S) designation at Beasley River Access Point (BRAP) just south of Camp Verde, AZ. Along this reach the Verde River gains volume from a string of canyons with perennial tributaries which get large portions of their base flow from springs discharging from the regional aquifers (Ecological Implications of Verde River Flows, 2008).

The Verde River is also one of two federally designated Wild and Scenic Rivers in Arizona. The other, Fossil Creek, is also within the Verde River watershed. The Wild and Scenic Rivers Act designated the Verde River for study in 1978 before being officially designated in 1984. To be designated, a river must possess “outstandingly remarkable scenic, recreational, geologic, fish and wildlife, historic, cultural or other similar values” (Wild and Scenic Rivers Act, 1968). Because of this designation, maintaining these values along the Verde are required. Riparian forests along the Verde contribute to all the values listed in the Wild and Scenic Rivers Act. Therefore, maintaining and regenerating Fremont cottonwoods along the Verde is crucial to maintain its remarkable values.

The Verde W&S River extends from Beasley RAP to Sheep Bridge Dispersed Camping area. The river is isolated and generally inaccessible by road along this reach. The region is rugged and arid with Fossil Creek and the intermittent East Verde River contributing flow to the river. After the W&S portion of the river, the Verde enters Horseshoe Reservoir, the first of two large storage reservoirs on the river. Shortly after Horseshoe Reservoir the river flows into Bartlett Reservoir and then joins the Salt River just northeast of the Phoenix metropolitan area. Because the Verde W&S River is located above the large storage reservoirs, the Verde’s hydrology is largely intact. This allows large winter and monsoon floods to flow through the river and continuously change the ecology and geomorphology of the river.

Although there are no large storage reservoirs above the Verde River Wild and Scenic corridor, the Verde River is still impacted by human use. Aquifers are pumped by municipal, irrigation, and domestic wells near in the Little Chino Basin. Perennial flow in the Verde begins about 5 miles lower downstream than it did historically (Ecological Implications of Verde River Flows , 2008). Surface water diversions between Clarkdale and Beasley RAP reduce base flow during the summer when water levels are historically at their lowest. In total, irrigation ditches withdraw about 34,000 acre feet with about half of that being consumed (Alam, 1997; Blasch et al., 2006). The Verde Valley also is an agricultural area with land being used for: pasture, pecans, grapes, corn, and vegetables. However, most farms are small both in size and revenue (USDA, 2012; Zhao et al., 2019).

**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 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. Tree diversity is low in Verde River riparian forests with Fremont’s 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).

The reproductive ecology of cottonwood and willow influences how and when they regenerate. These trees are pioneer species, meaning they rely on disturbance and large amounts of seeds to establish. Both species produce large amounts (up to 25 million on mature trees) of seeds each spring. The seeds are small and have “tufts'' that are designed for long distance wind and water dispersal. Seeds are released in early spring as winter floods recede (Stromberg, 1993). This allows the seeds to be deposited on bare, moist mineral soil created by high winter flows. Regeneration of Fremont cottonwood and Gooding willow are not consistent in Arizona. A study in Southern Arizona showed that regeneration occurred only about every decade and was dependent on strong winter floods to scour vegetation and deposit fine alluvial soils (Cooper et al. 1999; Stromberg, 1997).

## Methods

### Study Site

Access to the Verde River Wild and Scenic Corridor is restricted to a few road access points or from rafting along the river. Because of the limited access, sites were chosen that are logistically feasible and realistic to access on a frequent and continuing basis. Beasley Flat River Access Point (BRAP) located downstream of Camp Verde was chosen as one site. Seedling survivorship and size were measured, and tree cores were taken. BRAP is the official beginning of the Verde Wild and Scenic River. The second site chosen was Childs dispersed camping area, upstream from the confluence of the Verde River with Fossil Creek. Seedling survivorship and size as well as tree cores were measured at this site. Childs is located near the middle of the Verde Wild and Scenic River section. A third site at Sheep Bridge River Access Point was used to collect tree cores but was not used to study seedling mortality monitoring because it is too remote to access regularly. Sheep Bridge is located just downstream from the Wild and Scenic portion of the Verde but still above the two large storage reservoirs. All three sites have healthy Fremont cottonwood-Goodding’s willow riparian, gallery forests and have a largely intact hydrology.

A map of a river

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Figure ?? Map of study sites

The winter of 2023 was the one of the largest in Arizona in the past 30 years. On April 1st, 2023, the Verde River basin was at 318% of its normal snowpack (NRCS). As a result, during peak snowmelt the Verde River reached over 61,000 CFS in mid-March. This large flood caused significant flooding and disturbance to the riparian corridor. Trees were toppled and, in some instances, the active channel was reshaped. All this disturbance created conditions for Fremont cottonwoods to regenerate via seed. This created a unique opportunity to study their regeneration and survivorship.

### Seedling Plots

Ten 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. 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.

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 and seedlings within the hoop were then measured and recorded. 15-30% of the total area containing seedlings was sampled.

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 then sieved for 15 minutes and the percent fines (.075mm or smaller) was calculated for each site.

**Analysis Methods**

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. A higher HDR means that a seedling is becoming thinner and taller.

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 alive Fremont cottonwoods across the floodplain were selected for coring. 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.

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.

To measure the ring widths of each core, the cores had to be scanned and uploaded. Dated cores were placed on an electronic scanner and 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**

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=133) were run through COFECHA and cores with a correlation coefficient of +0.30 were separated. This separated series (n=39) was then ran through COFECHA to check for any dating issues. The dplR package created by Dr. Andy Bunn was used (Bunn, 2010) to create Ring Width Indices (RWI) and Basal Area Increment (BAI) for the crossdated series to then be compared to climate variables.

Correlation to climate

Four climate variables were used to run a response function analysis and a correlation analysis on the chronologies. Mean monthly values for: average temperature, precipitation, and Palmer Drought Severity Index (PDSI) were 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>) from 1993 to 2023 for Yavapai County, Arizona. Mean monthly flow was 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 (1988 to current).

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 & Biondi, 2015) I tested 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. An exact bootstrapping method was used because of the small dataset and because it gives an exact distribution as it only uses data within the dataset. A response function analysis was used for water year (September-October) was used to test against the annual growth for that year.

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.

## Results

* Seedlings
  + Size and plot densities

A graph of different sizes and colors

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* + Mean values
  + Significant changes
  + Variables affecting survivorship
* Dendro
  + Age at coring height plots

A graph of ageing height

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Age at coring height distribution is roughly normal. The mean age at coring height was 24 years old. In total, 133 cores were able to be dated. The most recent core was from 2016.

* + BAI plot

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Figure ?? Ring Width Index (RWI) for the crossdated series. RWI has generally been declining since 1996 before having a sudden increase in 2023.

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Figure ??. Showing the basal area increment (BAI) for the crossdated chronology.

* + Response function analysis table

The final crossdated series (n=39) produced an interseries correlation of +0.395 and a mean sensitivity of .533.

## Discussion Seedling survivorship and demographics

Densities decreased or stayed constant in 80% of plots surveyed across the two sites. The remaining 20% of plots increased, possibly indicating 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

Light

Herbaceous

Soil

* No soil trench was dug like in: rio grande paper and DM paper

## Dendrochronology

**Minimum ages**

Most of the cottonwoods along the Verde River are young. The mean age at coring height goes back to around the year 2000. There has been a relative absence of large winter floods since 2005 (Figure ??) which could help explain. Their young age could also be because of the relatively intact hydrology along the Verde River. The Verde River floodplain has been largely depositional. Tree root collars are submerged under sediment leading to uncertainty about their exact age.

Previous research on riparian forests found that Cottonwood-Willow forests in the Verde Valley have spent the most of the 1900s recovering Cottonwood-Willow forests covered only 270 acres of the Verde Valley in 1940. This then peaked in 1977 with 551 acres before stabilizing following large floods in 1983 and 1993 (Sharon Masek Lopez & Abraham E. Springer, 2002). This could help explain why there are few cottonwoods dating back to this time. It is possible that Cotton-Willow forests were limited from heavy human influences such as: agriculture, land clearing and a copper smelter before being allowed to recover by the 1970s. Then, large floods in 1983, 1993, 2005 and 2023 have kept riparian forests young and refreshed.

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 respectively. 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.

(R. Willms et al., 2006) describes cottonwoods in Canada as following a general growth pattern, reaching their peak growth at about 20 years after their germination before entering the mature stage of their growth. Cottonwoods along the Verde River seem to follow this trend. Basal area increased slowly during the establishment phase (for about 10 years). This was then followed by another decade of rapid growth before leveling off and entering the mature growth stage. A key difference between the Canadian study and this study being the large increase in BAI following 2023 winter floods. This drives up the 5-year average curve. In addition, the units described by R. Willms et alt. are in 1-9 cm2 while the cottonwoods along the Verde are within the 10-30 cm2 range. So, while Verde Cottonwoods growth follows a similar trend, they grow much more rapidly.

A comparison of a graph

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Although cottonwoods are pioneer species, they are still relatively young at 25-30 years old. Fremont cottonwoods are shorter lived species compared to other North American cottonwoods. It is generally accepted that few Fremont cottonwoods live to be over 150 years where Plains and narrowleaf cottonwoods have been documented over 200 and 300 years ,generally in colder climate (Rood & Polzin, 2003). However, Verde River cottonwoods growth may already be at a mature stage.

**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 (Table??). Annual tree growth has a negative response to September streamflows.

June and July streamflows had the highest correlation to tree growth. In the Verde River, June streamflows are typically the lowest of the year. Although the monsoon season officially begins June 15th, meaningful precipitation usually arrives in mid-July. Therefore, June and July before the arrival of the North American Monsoon often have the lowest flows and highest temperatures.

Groundwater and surface water are highly related in the Southwest . Higher flows, and therefore higher groundwater levels, could also saturate more of the rhizosphere allowing for more roots to be able to access water. This water could then contribute to tree growth or cooling.

Recent research found that Fremont cottonwoods can cool themselves remarkably well from high summer temperatures as long as they have adequate water (Moran et al., 2023). 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.

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.

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. 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.

Different cottonwood species in different geographic areas respond differently to seasonal streamflows. For example, cottonwoods in the Northern Rockies had growth most correlated to March to June or April to July streamflows (Schook et al., 2016). While cottonwoods along a regulated reach of the Rio Grande in New Mexico were most correlated to July-September streamflow (Varani et al., 2024).

Verde river cottonwood growth seems to be more somewhere in between with June and July streamflow being the most correlated to annual growth.

Challenges

The study sites along the Verde River are all above large storage reservoirs. This allows them to have a relatively intact hydrology. A challenge associated with this is that many areas of the river are depositional. This means that the root collar of the tree is buried and the depth it is buried is also unknown. This means that their exact age cannot be determined therefore all we can determine is their “age at coring height”.

Another challenge with this project is that most trees are young. This makes it more difficult to crossdate series as well as could make reaching a critical P-value of .05 more difficult for statistical tests.

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.

A pile of wood on a hill

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