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 river 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 which get large portions of their base flow from springs discharging from the regional aquifers (Ecological Implications of Verde River Flows, 2008).

The Verde W&S River extends from Beasley RAP to Sheep Bridge Dispersed Camping area just below the Wild and Scenic reach. 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.

Although there are no large storage reservoirs above the Verde River Wild and Scenic corridor, the Verde River is still impacted by human use. Base flow in the upper Verde Valley comes mainly from the Big Chino and Little Chino aquifers (Wirt et al., 2005). These 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)

**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).

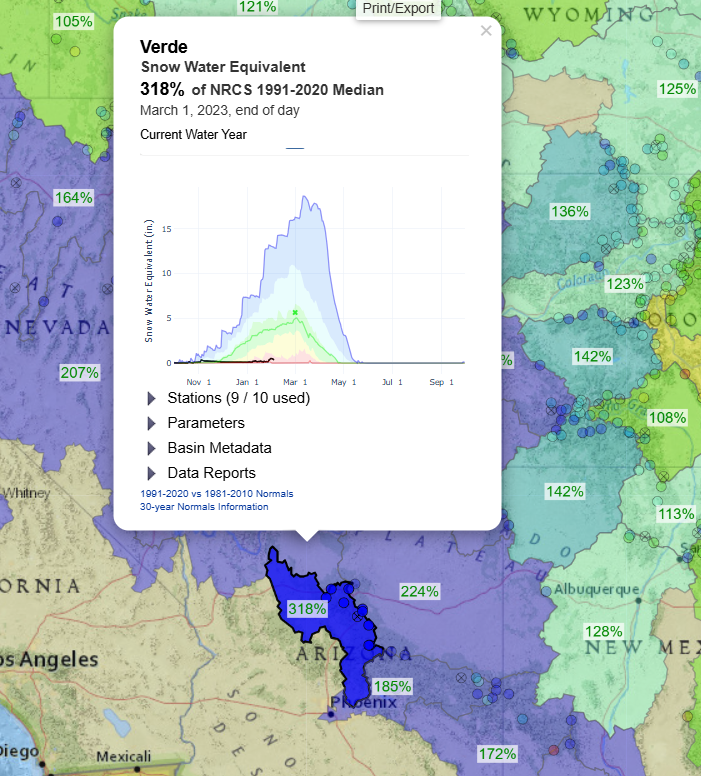
Fremont cottonwood *(Populus fremontii*) and Goodding’s willow (*Salix gooddingii*) are major components of riparian forests along the Verde River. Tree diversity is low in Verde River riparian forests with Fremont’s cottonwood being the dominant species. However, age class structure is usually very 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).

## Methods

### Field 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 mortality was measured, and tree cores were taken here. Beasley RAP 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 mortality and 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.

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, 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 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 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. This ensured that an age could be estimated.

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**

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 and cores with a correlation coefficient of +0.3 were separated.

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

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.

Correlation to climate

Four 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. 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.

## Results

* Seedlings
  + Size and plot densities
  + Mean values
  + Significant changes
  + Variables affecting survivorship
* Dendro
  + Age at coring height plots

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The mean age at coring height was 24 years old.

* + Chronology
  + RWI plot

Ring Width Index (RWI) plot for the crossdated series

* + BAI plot
    - Standardized?

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Basal Area Increment for crossdated series.

* + 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. 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

* 3 consistent variables: light, herbaceous, soil.

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 et al., 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 age at coring height 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.

(R. Willms et al., 2006) describes cottonwoods in Canada as 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.

A comparison of a graph

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Although cottonwoods are pioneer species, they are still relatively young at 25-30 years old. 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.

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.

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 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 (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.

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

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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