Upper Verde River Habitat Analysis Executive Summary
2020 - 2023

By:

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Prepared by the U.S. Rocky Mountain Research Station and Northern Arizona University in cooperation with the Prescott National Forest and the U.S. Bureau of Reclamation.

Highlights

The 120-day moving average of stream discharge within the upper Verde River (UVR) has fallen over 40%, from a high of 30.6 cubic feet per second (cfs) in 1995 to recent lows in 2023 of just over 18 cfs.

Current riparian cover consists of 53.8% riparian-woody vegetation, 22.1% herbaceous vegetation, 9.4% cattails, 4.7% water surface and 6.2% non-veg (rock/gravel) along the approximately 50 kms surveyed. Comparison of current conditions with 2007 manned aerial imagery suggests woody vegetation cover has increased approximately 30% since 2007 within the riparian area.

Current instream habitat within transects surveyed consists of 37.6% pools, 32.7% runs, 13.7% riffles and 15.5% backwater cattails, large rocks made up 0.4%.

Comparison of 2021-2022 ground-based, terrestrial lidar data with 2009 USFS topographic survey data indicated that more deposition than erosion occurred in the floodplain at all sites (apart from one) and that most deposition occurred nearest the channel. On average +0.3m of vertical change was observed on streambanks within 20m of the channel.

Analysis of eDNA fish samples suggest that populations of all native fish species have dramatically declined or are now absent within the first 10 kms of the river.

The portion of the study area from Hell Canyon down to Sycamore Canyon are less impacted by human development and may prove to be more resilient in retaining native fish habitat, as illustrated by the current distribution of native fish species.

Introduction

The Bureau of Reclamation (BoR) has proposed to install instream fish barriers at two sites on the UVR, as part of the mitigation for the Central Arizona Project. Prior to implementing this project, the Prescott NF requested that the BoR fund a study to monitor changes in the riparian habitat and fish habitat based on comparison of data collected by the RMRS (USDA Forest Service Rocky Mountain Research Station) in 2009 with current data collected in this study.

Monitoring riparian vegetation and geomorphology on the river began in the early 1990's based on concern for endangered-native fish species found in the upper sections of the UVR. Over the last three decades populations of native fish species (and native amphibians and reptiles) and associated habitats in the UVR have continued to decline. Recently, efforts to reevaluate the status of endangered (and non-endangered) fish populations and associated habitat are being undertaken with the intent of exploring options to improve conditions on the river for native fish, including the construction of two barriers within the study area (Riley et al. 2010). A summary of the results will be presented here with references to more extensive data sets produced by this study.

This report will also update the findings of the *Synthesis of Upper Verde River research and monitoring 1993-2008 (Neary et al, 2012) General Technical Report 291,* which serves as the last major survey of the UVR by the RMRS.

The purpose of this project is twofold:

1. Monitor changes in riparian and stream-habitat features in the UVR based on data acquired in 2009 and compared to data acquired in 2021-2022 (in this study).
2. Utilize new technology to monitor and evaluate these changes, while considering advancements the new technology brings to bear on those procedures.

This study utilized an unmanned-aerial vehicle (UAV) to collect vegetation data across the entire floodplain at each of ten, long-term monitoring sites, thereby replacing the previous woody vegetation plots which were limited to 10 m x 40 m strips on either streambank. Terrestrial lidar was employed to capture elevations across the entire floodplain, 20 m above and 20 m below the existing single line transects. Environmental DNA (eDNA) sampling for the presence and absence of key fish species was employed along the entire study length of the river corridor. Lastly, Real-Time Kinematic (RTK) survey technology was used to improve geomorphology survey methods, greatly increasing the number and accuracy of survey points collected within the stream channel at each long-term monitoring transect.

For this project, a subset of twenty of the original forty-four transects were selected for remeasurement (Figure 1). This decision was made based on the proximity of some transects to one another as well as the greater amount of available data that was collected at each of the transects. The project separated the study area into two sections, naturally divided by Hell Canyon, a major tributary of the upper Verde River. The upper section is defined by wide valley bottoms, historically containing large wetland areas comprised of sedges and rushes, with channels substrates typically ranging from sands and silts to cobble. The section below Hell Canyon contains sections confined by steep canyons where the width of the valley bottoms is reduced in many reaches and the diameter of channel substrate increases, containing greater amounts of course cobble and boulders.

The proposed locations of two fish barriers also coincides with the delineation of our upper and lower sections. The proposed site for the lower most barrier is just above the confluence with Sycamore Canyon, the lower most reach of our study. The upper barrier is proposed just above the Hell Canyon confluence, the mid-point of our study.

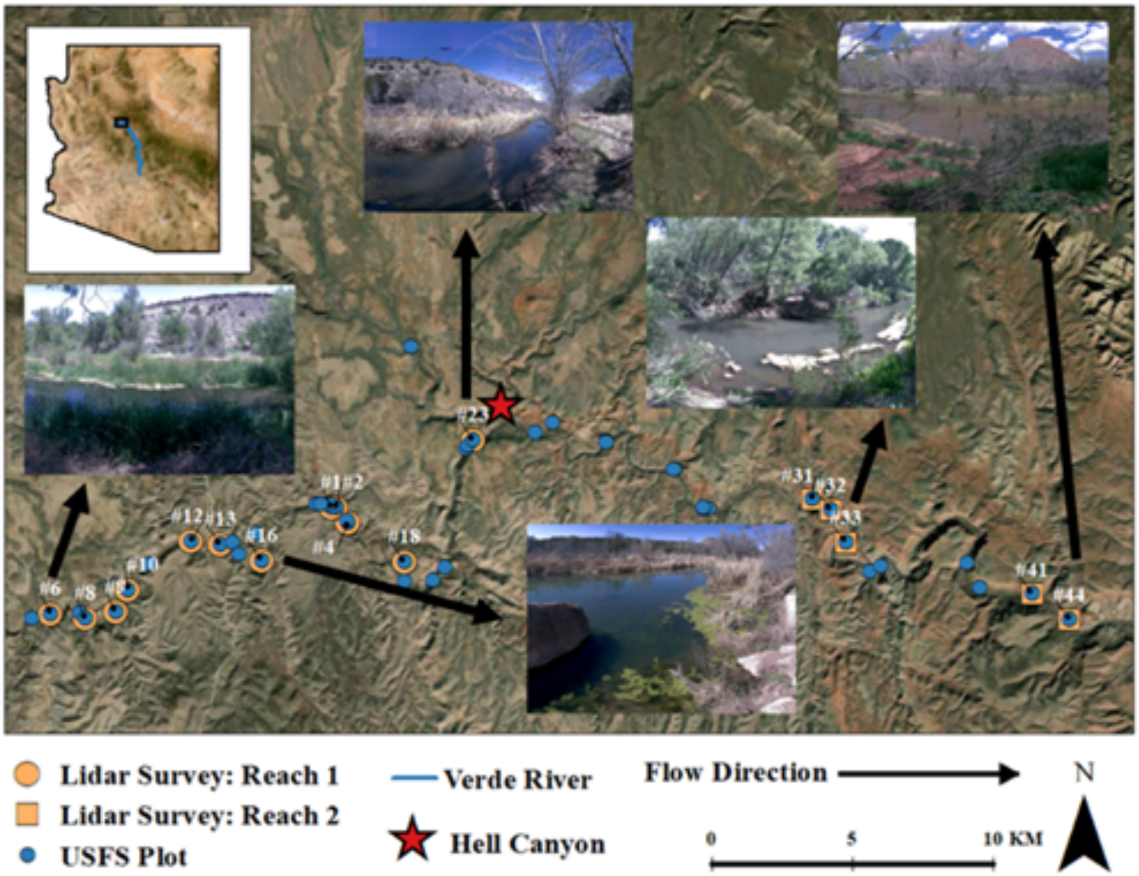

Figure 1: Project study area from the confluence with Granite Creek on the western end to the confluence of Sycamore Creek on the eastern end. Sites highlighted in orange represent the subset of sites sampled for this study. The red star denotes the confluence of Hell Canyon, the midpoint of the study area.

Study Area

For a more detailed description of the UVR please refer to the General Technical Report 291 (Neary et al. 2021) referenced at the beginning of this summary. The UVR study area is defined as that portion bounded by the eastern edge of the Prescott National Forest near Tapco to Sullivan Dam on the west. The area lies within the transition zone between the Basin and Range and Colorado Plateau provinces. As such, the landscape displays lithologies common to both provinces, interspersed throughout the riparian corridor and uplands. Granitic materials are most common to the south, while limestone, sandstone, and basalt rock types are most common north of the river (Krieger 1965).

The UVR watershed lies mostly within one of the fastest growing non-metropolitan counties in Arizona (Yavapai County). The growth rate of 4.2% is four times the national average. Population in the county has increased from 37,000 in 1970 to 246,000 in 2022 (www.census.gov). Since there are no significant surface water sources in the area surrounding the metropolitan areas, much of this growth has relied on groundwater in the Big Chino and Little Chino aquifers (Figure 2). Since 1940, groundwater levels in Little Chino Valley sub-basin have receded by more than 30 m (100 ft) in the margins of the basin (Arizona Department of Water Resources 2021). Although the Little Chino and Big Chino Valleys route all surface-water drainage to the UVR above Hell Canyon, there have been on-going discussions between local, State, and Federal officials and scientists over the fate of groundwater within these aquifers and the potential impact that additional groundwater pumping might have on the remaining UVR baseflows (Barks, 2023).

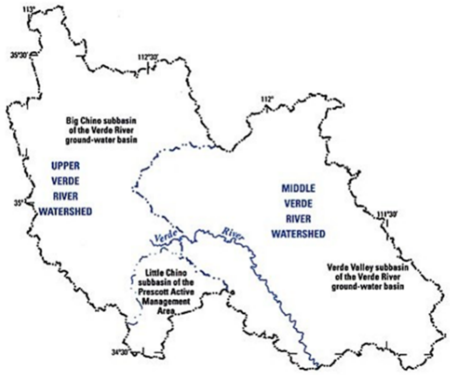

Figure 2: Upper Verde River watershed central Arizona. The Big Chino and Little Chino sub basins contribute to the upper most section of the Verde River. The Verde Valley sub basin contributes to below Hell Canyon. Credit Arizona Department of Water Resources (2009).

Climate

The UVR section of the Verde River Valley is semi-arid in nature with precipitation averaging less than 460 mm (18.0 in) (Blasch and others 2006). The signature characteristic of climate of this region is not the average, but the wide range in extremes. Except for higher terrain to the north that provides streamflow for Sycamore Canyon and Hell's Canyon, most of the precipitation occurs as rainfall rather than as snow. Monthly precipitation varies by over a factor of five from the spring dry period (13 mm or 0.5 in) to the summer monsoon period (70 mm or 2.8 in). Over the past century, rainfall in the UVR region has gone through several cycles of wet and dry periods. Blasch and others (2006) analysis of rainfall records since 1900 has shown that the UVR is in a lower rainfall cycle that started in 1994 and that snowfall for the UVR and Middle Verde watersheds has been mostly below normal since 1955. Potential evapotranspiration rates average in excess of 1520 mm (60.0 in yr-1), which creates the semi-arid conditions.

Baseflows

The combination of increasing average temperature and below average precipitation over the last four decades dating back to 1980 suggests the likelihood of the beginning of a period of consistently warmer and drier conditions (Figure 3) in the southwestern United States (Wahl et. al 2022). Less water input due to groundwater pumping and increased evapotranspiration due to higher average temperature will continue to put increasing pressure on baseflow inputs in the upper Verde River from the Big and Little Chino aquifers. Wirt et al. (2005) estimated that contributions to the Verde River springs from the aquifers of Big Chino Valley are about 81 percent, contributions from the western part of the Coconino Plateau are 19 percent, and contributions from the Little Chino subbasin are negligible due in part to the extensive groundwater pumping that has already occurred. Baseflows in the UVR have continued to decline since peaking in the mid-1990s. The 120-day moving average has fallen over 40% from a high of 30.6 cubic feet per second (cfs) in 1995 to recent lows in 2023 of just over 18 cfs (Figure 4). Inputs from the upper Verde Valley sub-basin, the portion of this study which extends from Hell Canyon down to Sycamore Canyon, while subject to climatic trends are less impacted by human development and may prove to be more resilient (Garner et al. 2013).

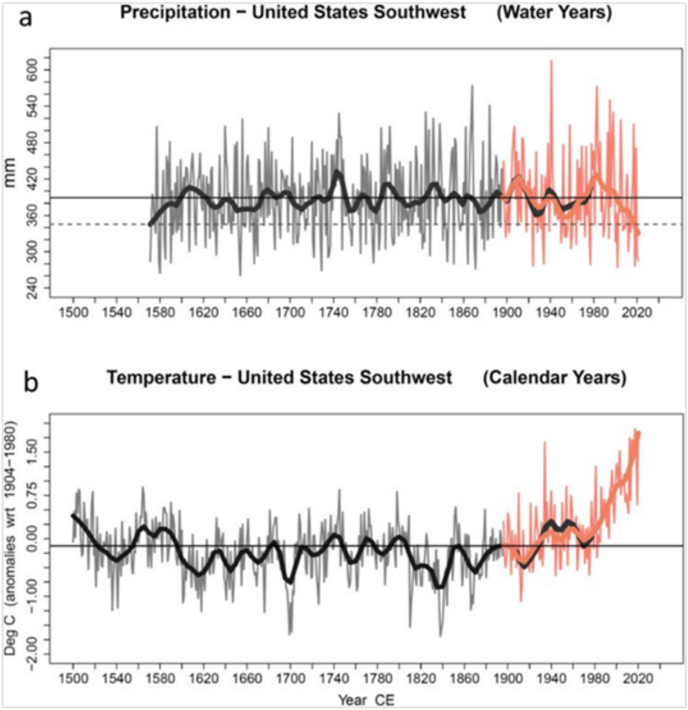

Figure 3: Average precipitation and temperature within the southwestern United States over the last 500 years (Wahl et al. 2022).

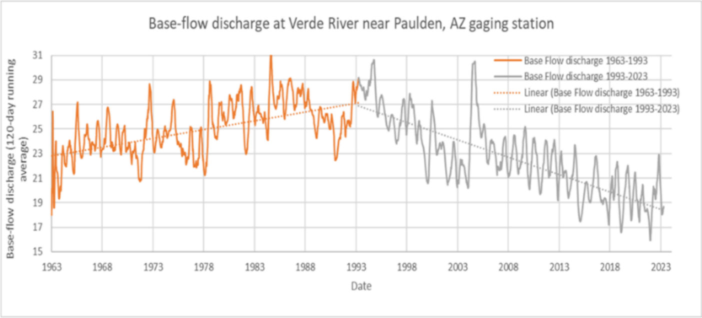

Figure 4 Baseflow decline in the Upper Verde River since 1993. Data taken from the USGS stream gauge at Paulden, Arizona. Credit Joel Unema, USGS URL: https://waterdata.usgs.gov/nwis/monthly?

Methods

The methods described here are an abbreviated description of the full methods. Full descriptions of each method can be found along with descriptions of the data in the summary files for the project found on external the hard drive for this project. Our new data collection in 2021-2022 focuses on the Upper Verde River downstream of Paulden, AZ to Sycamore Canyon, which includes approximately 50 river kms. The USFS established 44 plots beginning in the early 1990s and monitored them in 1997, 2001/02, 2009, and 2021, of which the 2009 data was used to compare to the new remote sensing data collected via unmanned aerial vehicle (UAV) and terrestrial lidar scanner (TLS) sensors in this study.

The USFS Prescott National Forest plots are distributed over the entire 50 km of the UVR from Paulden, AZ to Sycamore Canyon, but at uneven distance intervals. We resurveyed 20 of the 44 plots with previous geomorphology, woody vegetation as well as updated real-time kinematic (RTK) survey methods (Wyrick et al. 2014). We successfully imaged 17 of these plots with the ground-based, terrestrial lidar scanner (three other plots were excluded from the analysis due to missing 2009 data to match). Of these 17 plots, we then imaged ten with a UAV multispectral sensor in this study.

UAV image analysis for riparian cover type classification

We imaged ten of the UVR transects in summers 2021 and 2022 with a Sensefly Ebee X UAV platform equipped with a multispectral sensor that images in four spectral bands: green, red, red edge, and near-infrared, centered at 550, 660, 735, and 790 nm, respectively (SenseFly, Lausanne, Switzerland). The Sensefly Ebee X flew at 70m AGL in interlaced, perpendicular lines with 85% and 90% latitudinal and longitudinal overlaps, respectively (Sankey et al., 2021; Donager et al., 2021; Belmonte et al., 2019). Each flight lasted for ~25 minutes, on average, centered at each transect location. Flight mission planning and data parameters were customized and executed in SenseFly eMotion 3 software (SenseFly, Lausanne, Switzerland). The resulting multispectral image had 14 cm spatial resolution spanning, on average, a 10 ha (~22 acres) centered at each transect location. Each UAV image was subset to focus on the transect area and excluded distorted areas along the edges of the multispectral image.

Using a random forest classifier in the machine learning classification tool, a total of eight different target cover types were classified: 1) water, 2) gravel bars, 3) herbaceous cover, which consisted of forbs and sedges/rushes (*Cyperus esculentus, niger* and spp.), 4) cattail species (*Typha spp.*), 5) riparian woody cover which combined all woody species 6) junipers (*Juniperus monosperma*) outside of the narrow riparian corridor, 7) bedrock/bareground, and 8) shadows (Figure 5). We focused on exposed water surface area and gravel bars because their relative abundance is an important indicator of riparian habitat condition.

We also emphasize cattail (*Typha spp.*) detection because cattails can rapidly encroach into the shallow riverbanks resulting in high density and cover, which deteriorate habitat quality. High density cattail stands can also capture sediment, which can further narrow the river channel (Neary et al., 2012). The UAV image-derived land cover type classification was then used to train and classify a coarser spatial and spectral resolution image from the National Aerial Imaging Program (NAIP), which covered the entire stretch of the UVR including the subset of transects imaged by the UAV and TLS.

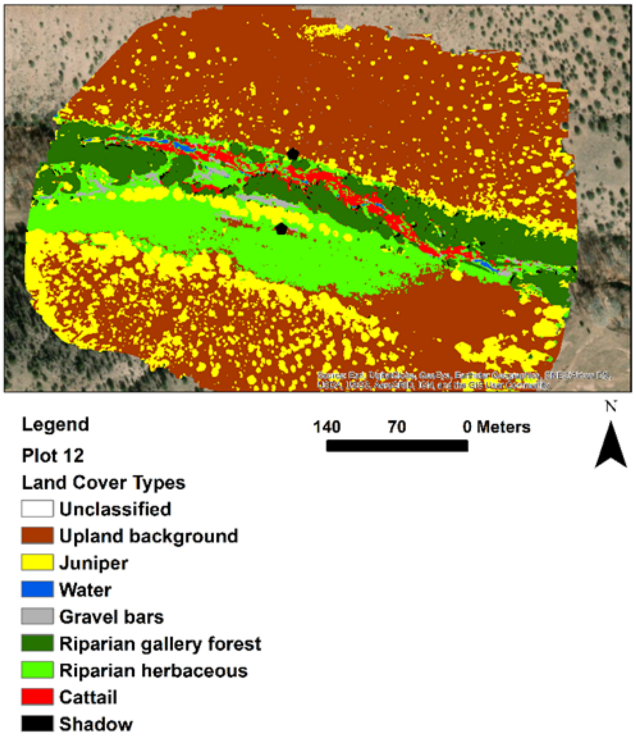
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 5: Multispectral areal vegetation survey using Unmanned Aerial Vehicle.

National Aerial Imaging Program data classification

We used manned airborne images from the US National Aerial Imaging Program (NAIP) for the entire UVR corridor to examine riparian-woody vegetation cover changes across a larger spatial extent beyond the UAV image extents. The riparian-woody vegetation cover change over time was of specific interest given its significant role and impact on riparian habitat conditions. The NAIP image is typically collected for each US state, on average, once every five years providing an opportunity for riparian-woody-cover change estimates, whereas our UAV images represent a single year at each transect. We used the available NAIP images in 1 m spatial resolution from 2019 and 2007 in four spectral bands: blue, green, red, and near-infrared to classify three different land cover types: 1) water, 2) bareground, and 3) woody vegetation cover (Figure 6). After the 2007 and 2019 NAIP images were classified, we compared the classification outputs via a pixel-to-pixel change detection to only examine changes in riparian-woody– vegetation cover.

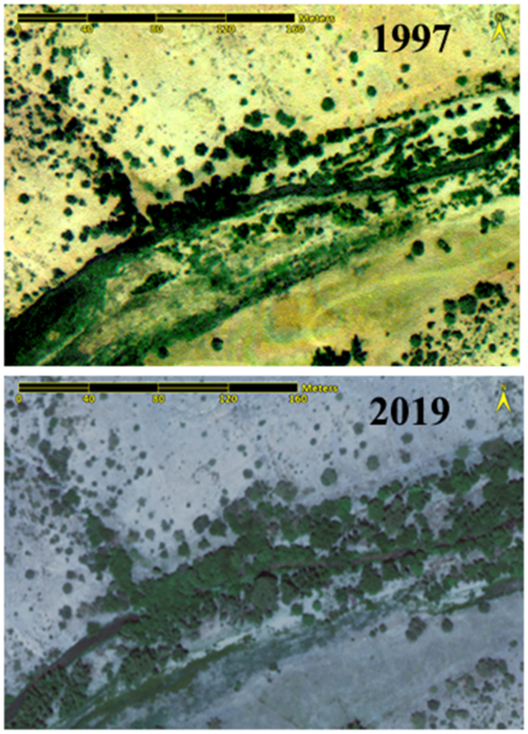

Figure 6: Aerial images from 1997 (top panel) and 2019 (bottom panel) illustrating riparian woody vegetation cover increases over time along the UVR corridor.

Riparian woody vegetation classification

We used a modified Daubenmire methodology (Bonham et al. 2004) along both right and left streambanks to classify species, density, diameter at breast heigh (DBH) and height of each woody stem. This method uses five plots, each 5 meters x 8 meters long established along 40 meters of streambank with the permanent single-line geomorphology transect acting as the midpoint (Figure 7). Stems per hectare was calculated by dividing the total stems per species by the plot area. Importance values (IVs) indicating how dominant a species is in a certain location were calculated by summing relative density and relative DBH and scaling the result between 0 and 200. Comparisons were made for:

1) Stems/ha. (all species) between 2009 and 2021/22
2) Stems/ha. between stations above and below Tri-Canyon in 2021/22

IV bar charts were created comparing:

1) IVs of all species in 2021/22 (twenty-six stations)
2) IVs of all species in 2009 compared to 2021/22 (nine stations)
3) IVs of all species above and below Tri-Canyon in 2021/22.

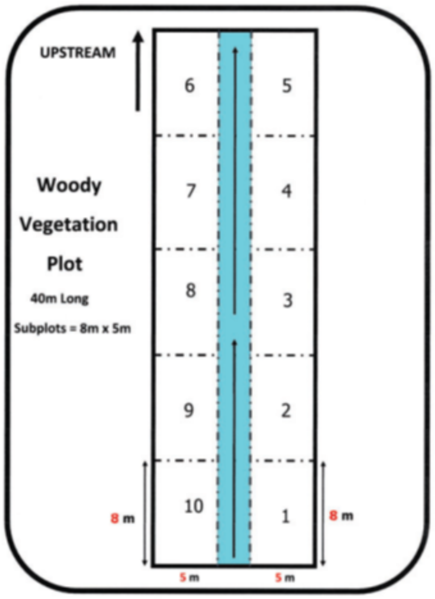

Figure 7: The sampling layout for woody vegetation consisted of a 40 m long plot, subdivided into 10-40 m2 macro plots 5 x 8 m.

Terrestrial Lidar Data and Geomorphic Change Detection

To quantify geomorphic changes over time, we completed two different comparisons: 1) USFS survey-USFS survey comparison, and 2) USFS survey-TLS survey. In summers 2021 and 2022, we imaged nine field transects with a Leica BLK360 terrestrial lidar scanner to compare to transect-based riparian cross-section data collected by the US Forest Service in 2009, which provided opportunities to estimate geomorphic changes since 2009 at matching locations, whereas the other transect locations had shifted slightly over time. Our lidar scan extents included the entire lengths of the transects, which varied between 30m and 115m, and a consistent 40m widths. As a result, the lidar-imaged areas ranged in dimensions and total area, but with constant 40 m widths. A total of fifteen-to- twenty-five individual scans from different scan positions were acquired at each plot to cover the entire spatial extent. The Leica BLK360 scanner laser pulse is centered at 830nm wavelength and has a maximum range of 60m with a vendor-reported accuracies of 8mm at 20m.

The fifteen-to -twenty-five individual scans were registered and mosaicked together to create a single point cloud with a total of thirty-to-sixty million points at each transect location (Figure 8). The point cloud data were then used to create digital elevation model (DEM) centered on the USFS line transect location for each plot. The original USFS line transects were permanently marked with stakes on both north and south banks of the channel with a measuring tape stretched between the two stakes. Using a laser level, the USFS measured the vertical distance from the tape to the ground at typically 1-5m intervals starting on the north bank of each plot. The 2009 vertical distances were then used to create a single-line cross-section of the channel geometry and then compared them to the lidar-derived DEMs to estimate geomorphic changes along the UVR over the thirteen-year period between 2009 and 2022.

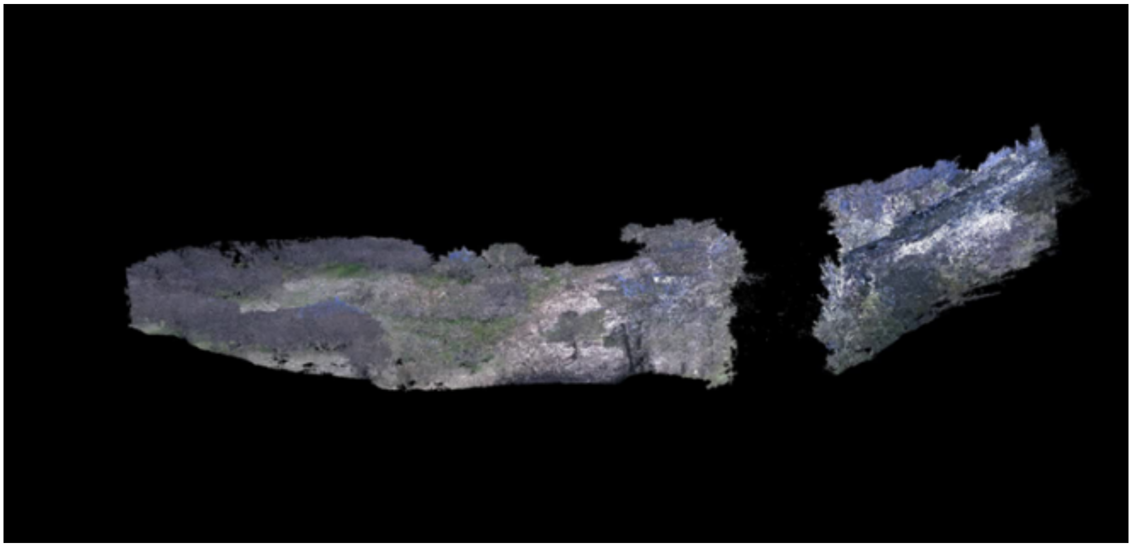

Figure 8: Mosaicked image of riparian vegetation along a long-term monitoring transect.

Channel morphology change detection

Stream-Cross-sectional data were collected in 2021/22 with a laser level and staff rod in the field and later digitized into excel spreadsheets. Elevation points were collected at least every meter along the transect. Other important points along the transect were recorded including bankfull, water's edge, water depth, and thalweg. Comparison of 2009-2021/22 data included 16 stations. Entrenchment ratios (ER) compares the width of the bankfull channel to the width that the water surface would have during a standard flood. This ratio is often used to help determine energy dissipation, stability, and stream channel evolution. ER was calculated as flood prone width / bankfull width. Flood prone width is calculated as 2x the bankfull maximum depth. Width-to-Depth ratios (W/D) are key to understanding the distribution of available energy within a channel, and the ability of various discharges occurring within the channel to move sediment. Width-to-Depth ratio is calculated as the bankfull width / average bankfull depth.

Stations that are located above Tri-Canyon include 5-23, and stations 32-44 are located below Tri-Canyon. A paired t-test was performed on the ER and W/D comparison between 2009 and 2021/22. A two-sample unequal variance t-test was performed on the ER and W/D comparisons above and below Tri-Canyon. Entrenchment Ratio (ER) and With to Depth (W/D) ratio variables were calculated from the data in the excel spreadsheets. ER of 16 stations in 2009 compared to 2021/22.

Real-Time Kinematic survey

Bathymetric surveys were conducted at nineteen long-term a monitoring sites using RTK GPS in 2023. Survey data was captured to characterize the below water bathymetric profile of the stream channel. Surveys focused on capturing breaks in lateral and cross channel morphology. Characterization and estimate of the stream- channel habitat area was defined as riffle, pool, run, cattail backwater and large rocks. Each reach (plot) was surveyed from 20 meters upstream and downstream of previously measured cross channel transects yielding approximately 40-meter reaches centered on the historic transects. When mapped in ArcPro these additional points create a three-dimensional survey layer (Figure 9) which allows for the classification of instream habitat features (Wyrick et al. 2014). Data was then exported to Excel to quantify percentages of instream habitat.

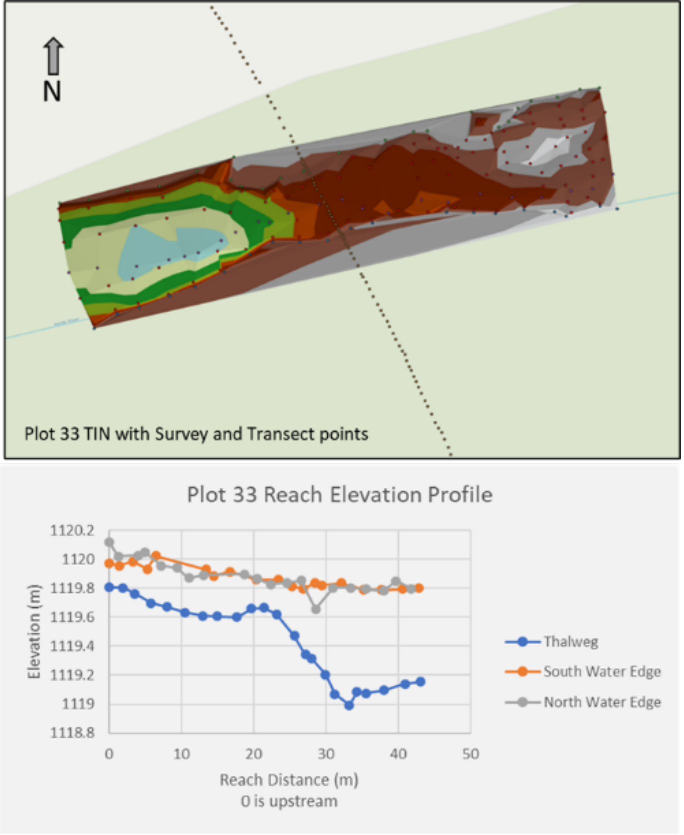

Figure 9: Image and profile created from RTK survey conducted at long-term monitoring plot.

Fish Population and eDNA sampling

In November of 2021 and 2022 a total of twenty-nine sites located along the entirety of the study area were sampled using eDNA sampling methods developed RMRS and the National Genomics Center for Wildlife and Conservation (Carim et. al 2016). The method requires 5 liters of stream water to be drawn through a 1.5-µm-pore, fiberglass filter which is then packaged and sent to the lab for DNA analysis. Specific sampling locations were located within the 40-meter reach length of a long-term monitoring site in well-mixed water, near the center of the channel. Sampling sites were co-located with long-term, quantitative sampling sites using electro fishing methods established by the USFS in the 1990s.

Sample analysis was conducted to determine the presence/absence of four native species including Sonora sucker, desert sucker, spikedace and roundtail chub. Two native species still present in the river, the longfin dace and speckled dace were not screened because the DNA assays for these two species are still in development. However, once developed, samples can be re-run to detect the presence of these species.

Figure 10: Locations sampled with eDNA species detection methodology. Of the native species sampled, Red pins = no native species present, orange pins = 1 species present, yellow pins = 2 species present, and green pins = 3 species present.

Results

Results presented here are abbreviated. Full descriptions of the results for each transect can be found within the summary files for the project and may prove useful to examine an individual transect depending on desired comparisons in the future. The objective of these most recent efforts is to classify the current conditions on the landscape. Where possible we attempted to make comparisons with previous monitoring data.

Hydrology

Daily discharge of the UVR between Paulden, AZ and Sycamore Canyon has decreased over the last thirteen years. Specifically, the US Geological Survey (USGS) gauge data indicates that the mean daily discharge of the UVR at the Paulden, AZ gauge decreased 39% from 1.2 m^3/s (44 ft^3/s) between 1963 and 2008 to an average of 0.8 m^3/s (27 ft^3/s) between 2006 and 2021.

UAV Classification

We successfully classified eight different cover types at the ten imaged by the UAV. The UAV image extent covered both the riparian corridor and surrounding upland vegetation and bedrock/bare ground. Within the riparian corridor defined by the flood prone area, riparian woody vegetation was the most common cover type covering on average 53.8% of the narrow sub-section of the images. Herbaceous vegetation (sedges/rushes) was the second most common cover type comprising 22.1% of the riparian corridor. In addition, on average 9.4% of the riparian corridor was covered with cattails, which are considered a nuisance species. Water surface and gravel bars only covered 4.7% and 6.2% of the riparian corridor, respectively. While these cover type estimates are from a single data and do not indicate changes, the estimated respective area extents are consistent with trends, observed in the field, of potentially increasing cattail cover and decreasing channel width. The 2021-2022 UAV images will provide important benchmark data for future estimates of land cover-type changes.

Outside of the narrow riparian corridor, much of the UAV images (10 ha, on average) covered the steep slopes and upland bedrock/bareground areas. Within these larger extents, we additionally classified exposed bedrock/bareground as well as juniper. The mean areas for each cover type (%) across the entire larger UAV image extent (~10 ha) at each plot location is summarized in Table 1.

Table 1: UAV multispectral image-derived land cover types and their mean area distribution (in percent) across the entire UAV image extent of approximately 10 ha, on average, including the riparian corridor and adjacent upland areas.

Plots	Water	Gravel bars	Herbaceous Cover	Cattails	Riparian woody cover	Juniper	Upland bedrock/ bareground	Shadow
1-2	0.6	1.7	4.4	5.5	5.8	7.3	34.3	38
12	0.3%	0.9%	18%	2.8%	10.5%	16%	51%	0.4%
13-14	0.4	0.8	0.7	0.5	10	20.4	63	3.8
7-8	0.4	1	1.6	1.4	14	6.6	74	0.9
9	1.5	2	1.1	3.5	8.9	11	69	3
10	0.8	0.5	2.6	1.5	14.6	9.1	62	8.7
23	1.8	1.6	0.4	0.5	5	24	65	1.3
Mean	**0.8**	**1.2**	**4.4**	**2.2**	**9.9**	**13.5**	**59.8**	**8**

NAIP imagery

We used the coarser spatial resolution NAIP images to quantify woody cover change from 2007 and 2019 due to the lack of any previous UAV data. This comparison indicates that riparian-woody vegetation cover has increased approximately 30%. Specifically, 6% of the area classified as bareground in 2007 and 23% of the area classified as water in 2007 were classified in 2019 as riparian woody cover indicating that riparian-woody vegetation might have encroached on the river channel that might have narrowed over time.

A similar trend of riparian-woody vegetation cover is observed from a few older aerial photographs we acquired. For example, Figure 6 compares manned aerial images from 1997 versus 2019. The figure illustrates that riparian-woody cover has increased over the twenty-four-year period. While this trend may not be observed everywhere, it is observed in many portions of the areas imaged in 1997. This trend of increasing riparian-woody vegetation is notable given that invasive tamarisk and Russian olive trees have been removed along the riparian corridor over the same twenty-four-year period.

Changes in Woody Vegetation 2009 - 2021/22

A paired t-test was performed on the stems/ha. comparison between 2009 and 2021/22. A two-sample unequal variance t-test was performed on the stems/ha. comparisons above and below Tri-Canyon in 2021/22. No comparisons were statistically significant ($\alpha=0.05$). IV comparisons between 2009 and 2021/22 showed:

1) Goodding's willow (*Salix gooddingii*) was the most dominant species within the plots in 2009 and remained the most dominant in 2021/22.
2) Coyote willow (*Salix exigua*) was the 7th most dominant species in 2009 but became the 2nd most dominant in 2021/22.
3) Velvet ash (*Fraxinus velutina*) was 2nd most dominant in 2009 and became the 3rd most dominant species in 2021/22.
4) Tamarisk was the 6th most dominant species in 2009, but there were no recordings of this species in any of the plots in 2021/22.

Importance Value comparisons between above and below Tri-Canyon in 2021/22 showed:

1) Coyote willow, Gooding's willow, and Velvet ash are the most dominant species both above and below Tri-Canyon.
2) Arizona alder was the 25th most dominant species above Tri-Canyon but was the 5th most dominant below Tri-Canyon.

Lidar-derived geomorphic changes

A total of seventeen plots were successfully surveyed with the terrestrial laser scanner. Each plot was scanned with fifteen to twenty-five scans from different scan-position locations. The individual scans at each plot were all successfully registered together to create a full image of the area. Lidar points within the channel were not included in any analysis because the near-infrared laser of the lidar scanner does not penetrate through water to the channel bed. Tables 2 and 3 summarize our channel and floodplain characterization in 2021-2022 from the terrestrial lidar scanner at the seventeen plot locations along the Upper Verde River.

Topographic data from the 2009 USFS survey were compared to the 2021-2022 lidar data for geomorphic change detection which indicated that there were statistically significant changes at all nine plots available for comparison (Table 4). Other than Plot #16, more deposition than erosion occurred at all plots, and most of the changes, whether deposition or erosion, ranged between 0cm and 50cm. The deposition largely occurred in the floodplain nearest the channels. The notable exception is again Plot #16, which has eroded on the south bank further away from the channel (Figure 11). Importantly, the results were consistent with the change detection results from the comparison between the 2009 and 2021 USFS survey data.

The comparison of single line transect data with ground-based lidar data is a novel approach developed through this study. The successful comparison of these two datasets suggests this approach could be applied in other instances where single-line transect data exists.

Table 2: Summary of USFS survey data along the Upper Verde River for 2021-2022. Variables not measured in this survey are left blank in this table. Reach #1 denotes the study area from the Granite Creek confluence to Hell Canyon Confluence, Reach #2 denotes study area from Hell Canyon Confluence to Sycamore Canyon confluence.

Plot #	Reach #	Channel Slope	Bankfull Width (m)	Bankfull Depth (m)	Width/Depth Ratio
1	1		43.3	1.1	40
2	1		49.5	0.9	56
4	1		6.1	0.4	15
6	1		13.2	1.6	8
8	1		14.6	1.6	9
9	1		19.1	0.7	18
10	1		14.3	0.7	22
12	1	2.95%	18.3	1.4	13
13	1				
16	1		25.1	2.3	11
18	1		9.6	1.3	7
23	1	0.54%	14.8	1.2	13
31	2	0.01%			
32	2	1.11%	7.5	0.9	8
33	2	0.09%	7.9	0.6	12
41	2	0.075%	12.7	1.3	10
44	2	0.0625%	18.4	0.8	24

Table 3: Lidar-derived variables from 2021-2022 for the 17 individual plots.

Plot	Reach	Slope	Channel Width	RMSE (m)	Length	Width	Relief
1	#1	0.9%		0.024	92m	90m	6.4m
2	#1	0.6%		0.024	54m	97m	3.8m
4	#1	2.7%		0.001	44m	51m	6.4m

6	#1	0.6%	14.5m	0.027	42m	98m	7.8m
8	#1	1.1%		0.023	21m	35m	7.4m
9	#1	0.3%	19.1m	0.025	45m	92m	8.9m
10	#1	0.4%	14.8m	0.024	50m	51m	6.9m
12	#1			0.025	Corrupted		
13	#1	0.7%		0.031	71m	85m	7.2m
16	#1	0.5%	21.5m	0.019	46m	111m	8.3m
18	#1	0.4%	20.4m	0.022	50m	84m	5.6m
23	#1	0.9%	12.9m	0.028	66m	54m	9.3m
31	#2	0.4%		0.027	53m	76m	6.2m
32	#2	1.6%		0.028	40m	78m	6.9m
33	#2	0.7%	9.6m	0.021	40m	82m	8.3m
41	#2	0.5%	11.6m	0.025	48m	74m	6.1m
44	#2	0.5%	19.2m	0.026	51m	113m	3.7m

Table 4: Summary of the geomorphic changes observed from the lidar data at 9 plots with matching USFS survey data from 2009.

Plot	**Reach**	**Avg. Vert Change**	**Min Deposition/Max Erosion**	**Max Deposition**
6	#1	0.27m	-0.34m	0.90m
9	#1	0.10m	-0.37m	0.30m
10	#1	0.37m	0.13m	0.76m
16	#1	-0.22m	-0.37m	0.15m
18	#1	0.25m	0018m	0.60m
23	#1	0.10m	-0.23m	0.23m
33	#2	0.34m	0.11m	0.97m
41	#2	0.28m	0.13m	0.59m
44	#2	0.29m	-0.36m	0.54m

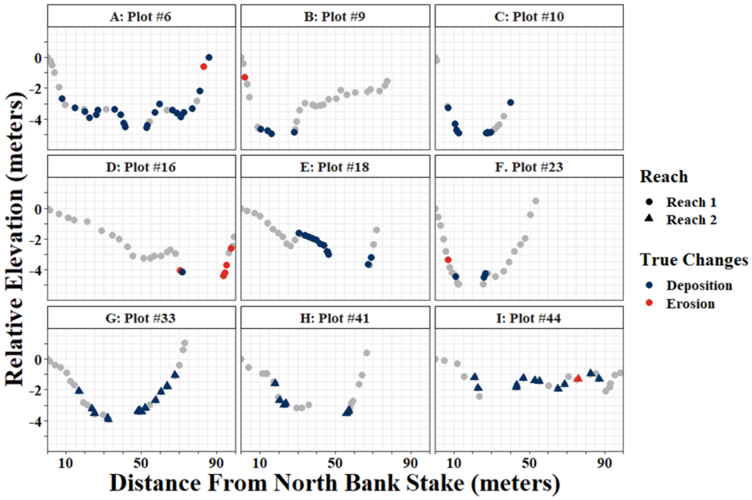

Figure 11: Lidar-derived change detection results. Channel cross-sections showing where the significant changes have occurred, colored by whether they are deposition or erosion.

Geomorphic survey

Channel width to depth rations ranged from 8.71 – 86.77 m with a mean of 34.7 m in 2009 compared with a range of 8.97 – 71.38 m and a mean of 29.4 m in 2022. Statistical comparison (α=0.05) showed that this change was a statistically significant decrease in W/D ratio (narrowing and deepening of the channel) between 2009 and 2021/22 (p-value=0.04). Entrenchment ratios that are between 1.0-1.4 are considered entrenched, between 1.41-2.2 to be moderately entrenched, and >2.2 are slightly entrenched. Only three stations (11, 16, and 44) in 2009 and two stations (13 and 16) in 2021/22 were moderately to slightly entrenched. All other stations in 2009 and 2021/22 were not entrenched according the Rosgen Classification System (Rogen 1994).

RTK Habitat Classification

Pools were classified as any depths over 1.8m and/or very slow-moving water generally with larger cross-sectional stream widths than average, and "deep" sections of river where velocity was low and bathymetric profile was significantly lower than upper or lower sections of the stream channel. Pools were also identified in plots where water's edge was relatively level. Runs were identified by deeper stream channels approx. > = 0.5m depth with small changes in water edge elevations. Riffles were identified by water edge to thalweg depths of generally < 0.5 m, with simultaneous decreases in elevation of thalweg and water edge, and often preceded by an upstream increase of thalweg elevation to the start of a riffle and termination of a pool or run designation. Of the total instream habitat across all transects surveyed, pools represented 37.6% of total stream reaches with run habitats representing 32.7%, riffles habitats representing 13.7% and shallows and cattails 15.5%, large rocks made up the remainder of 0.4% (Table 5).

Table 5: RTK survey data detailing in stream habitat from the upper half of the study area which include the headwaters to Hell Canyon and lower half of study area from Hell Canyon to the confluence with Sycamore Creek. Results of cattail distribution are in bold.

	Upper Study Area Above Hell Canyon					
15 Plots Surveyed	Area Surveyed	Riffle	Run	Pool	Shallows/Cattails	Rock
Total Area (m^2)	5784.7	727.9	1700.9	2117.7	1205.1	30.5
% of Total Cover		13%	29%	37%	**21%**	1%
	Lower Study Area Below Hell Canyon					
4 Plots survey	Area Surveyed	Riffle	Run	Pool	Shallows/Cattails	Rock
Total Area (m^2)	2002.3	342.8	848.1	811.4	0.0	0.0
% of Total Cover		17%	42%	41%	**0%**	0%

Fish Populations

Analysis of eDNA fish samples taken suggest that populations of all native fish species have declined or are absent within the first 10 kms of the river. Electofisher sampling conducted in the early 2000s by the RMRS along this same stretch of river found all native species sampled for in this study were present, with the exception of spikedace (Rinne 2012). Of the twelve uppermost sites most recently sampled, native species were not detected at eight. Desert sucker was detected at the first site near the river's origin. Roundtail chub was detected at two sites near kilometers three and four from the confluence with Granite Creek. The next positive desert sucker detection occurred approximately 10 kms downstream and the first positive detection of Sonora sucker occurred nearly 11 kms downstream. Spikedace were not detected at any site sampled for this study and is assumed to be extirpated (Rinne 1999).

Both species of sucker were detected at the seventeen remaining sites with the exception of desert sucker at a single site near kilometer twelve. Roundtail chub was detected at eleven of the remain seventeen sites, continuously present from the confluence with Hell Canyon down to the confluence with Sycamore Creek, approximately the lower half of the study area (Table 6). The results of this sampling is supported by similar results gathered by the Arizona Game and Fish Department in 2022/23 using canoe mounted electrofishing methods at several sites along the UVR (Stites and Chmiel 2022, Jackson and Chmiel 2023).

Table 6: Presence or absence for native fish species sampled for on the UVR. Color coding represents upstream transect to downstream transects. Light green = headwaters to Verde Ranch, green = Verde Ranch to Hell Canyon, Orange = Hell Canyon to Perkinsville, Yellow = Perkinsville to Sycamore Canyon.

Site #	Spikedace DNA Detected?	Roundtail Chub DNA Detected?	Sonora Sucker DNA Detected?	Desert Sucker DNA Detected?
VEG5	N	N	N	Y
VEG6	N	N	N	N
VEG7	N	N	N	N
VEG8	N	N	N	N
VEG9	N	Y	N	N
VEG10	N	Y	N	N
VEG11	N	N	N	N
VEG12	N	N	N	N
VEG13	N	N	N	N
VEG14	N	N	N	N
VEG15	N	N	N	N
VEG16	N	N	N	Y
VEG17	N	N	Y	Y
VEG1	**N**	Y	Y	Y
VEG2	**N**	**N**	Y	Y
VEG3	**N**	**N**	Y	Y
VEG4	**N**	**N**	Y	**N**
VEG18	**N**	**N**	Y	Y
VEG23	**N**	**N**	Y	Y
VEG38	N	Y	Y	Y
VEG37	N	Y	Y	Y
VEG24	N	Y	Y	Y
VEG31	**N**	Y	Y	Y
VEG32	**N**	Y	Y	Y
VEG33	**N**	Y	Y	Y
VEG41	**N**	Y	Y	Y
VEG44	**N**	Y	Y	Y

VEG29	N	Y	Y	Y
VEG30	N	Y	Y	Y

Discussion

Riparian vegetation changes

The results of this study suggest that an approximate 40% reduction in baseflow over the last two decades has coincided with an approximately 30% increase in woody species and nearly 10% increase in cattail cover, especially in the upper reaches of the river above Hell Canyon. These changes have served to confine the stream channel in many areas. Reductions in base flow in other studies have also been linked to vegetation encroachment and channel confinement. In these cases, a lack of large scouring flood events (Dean and Topping, 2019; Grams et al., 2020) and dewatering of wet streamside areas, allows for the expansion of deeper-rooted, woody species (Sankey et al., 2015). It appears that these shifts in vegetation are influencing channel shape and size on the upper Verde away from wider more shallow channels to narrower deeper channels illustrated by the reduction in exposed water surface in NAIP imagery comparisons over the last fifteen years.

Merritt (2022) found that floodplain development is associated with flow duration, frequency, and vegetation establishment. During periods of lower flows, floodplain accretion is often associated with increases in bank vegetation (Merritt, 2022). Plots surveyed in this study have experienced a mean vertical change of +0.3m suggesting that the small to medium-sized flows which have occurred over the last decade have primarily deposited sand and gravel near the channel which has been trapped by streambank vegetation. Decreasing width to depth ratios suggest that the channel has become both deeper due to incision as well as the aggradation of the adjacent streambanks. Flooding events that occur with regular periodicity (< twenty-five-year return intervals) appear to be concentrating energy within the channel which disconnects the channel from the floodplain and serves to reinforce the confinement of the stream channel in many areas. While we do not have previous instream habitat data to compare newly gathered RTK data to, comparisons of repeat photography through time suggests that this cycle is leading to a reduction in the number and size of shallow riffle habitats (Figure 12) which support several native species including spikedace, speckled dace, longfin dace and desert sucker (Rinne 2006).

Figure 12: Photographs from 2009 (Panel A) and 2021 (Panel B) at Plot #1 illustrating the changes in riffle habitat and cattail density over the study period.

Research along other river systems within the region have shown similar trends. Dean and Topping (2024) recently documented an example of the effect of vegetation encroachment on the geomorphology within Moenkopi Wash, a tributary to the Little Colorado River. The results of the study suggest that reductions in total annual flow and annual peak flows dating back to the 1940s coincided with the establishment of dense woody-vegetation along the streambank resulting in channel narrowing and vertical aggradation of the streambank. These changes have had far reaching effects on how sediment moves through the river system. In this case, it has reduced the amount of sediment ultimately supplied downstream to the Colorado River because much of the available material is locked up in the floodplain and inaccessible during peak flow events due to confinement by woody vegetation. They go on to suggest that a re-widening of the channel is unlikely to occur on its own and could require large-scale vegetation removal to reverse the encroachment on the channel.

Restoration

We suggest that the results presented here are not definitive enough to justify restoration efforts on their own, there is still too much we still don't understand about the physical processes influencing the system. While the loss of baseflows, particularly in the uppermost reaches of the river, may weigh disproportionately on the future ability of the river to support native species, restoration to restore functionality between the main channel and the adjacent floodplain may provide for the retention of native species habitat in at least some portions of the river. However, we recommend that further investigation of the current hydrologic and sediment dynamics along the river corridor are needed to better understand the influence of physical processes on habitat suitability prior to the development of future restoration plans.

With that being said, an example of potential restoration techniques which may be worth exploring on the UVR includes the deleterious effects of stream channelization that have been well documented in the Pacific Northwest. In some instances, stream channels that once meandered or were braided across valley bottoms were channelized and confined to one side of the valley for a variety of reasons including dam construction, gravel mining, farming, road construction, etc. The entrenchment of stream channels has been documented to result in the disconnection of the channel from the floodplain, decreasing habitat heterogeneity and total aquatic productivity, as well as negatively impacting important plant and animal species including sensitive salmon and trout species (Schneider et al. 2022).

Restoration techniques to reconnect the stream channel with the adjacent floodplain have been undertaken using what has been termed a “Stage 0” approach (Hinshaw et al. 2022). This technique physically manipulates the impacted channel using the redistribution of sediment and large woody debris to redirect the flow from the main channel into multiple smaller channels across the floodplain, increasing wetted area which increases habitat diversity and benefits targeted species. The current state and history of the UVR is undoubtably unique, however the dynamics of floodplain disconnection and the negative impacts on native aquatic species habitat is similar to other examples and may benefit from similar approaches to restoration.

Final notes on assessment methods

Repeated measurements of a single line transect over a long period of time are less preferrable than the new RTK methods employed in this study for a couple of reasons. Physically maintaining precise beginning and end points is difficult due to loss of monument locations or changes in vegetation which results in loss of accuracy or in some cases loss of monitoring site altogether. Also, previous methods with just a few dozen data points were very limited in scope, providing only a snapshot of the landscape at a single point in time, making it difficult to interpret the scale of change. New methods provide degrees of magnitude greater numbers of data points over a much larger area which makes interpreting observed changes intuitive in some cases. The ability to scale up data collected on the ground to UAV collected data and even further with satellite derived data opens a multitude of possibilities for evaluating ecological conditions across a large area.

The use of eDNA sampling methods to detect the presence and absence of native fish species in this project proved to be a cost-effective sampling technique which allows for easy replication and the ability to continue to monitor the presence or absence of key fish species in the river. It allows for a single individual to take samples along an extended river corridor which would be much more challenging to sample with backpack electro-fishing methods. However, we found that eDNA sampling should be used in addition to, and not as a replacement of, previous backpack electro-shocking methods since it does not quantify current fish populations which is essential to determine if populations are increasing or decreasing over time.

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