Shifts in the structure and composition of riparian vegetation in response to sediment aggradation on the San Juan River

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Abstract

Riparian vegetation is highly sensitive to variations in the hydrologic cycle seen on dammed rivers. The San Juan River is unique in that it is impacted by dams both up and down-stream. Upstream, Navajo Dam greatly reduces flows while downstream Lake Powell has decreased the river channel base level. This reduction in stream gradient has resulted in the formation of a wedge of sediment 71.1 feet thick at its deepest point. Differences in channel characteristics and river gradient influence vegetation shifts. This study was conducted to quantify the differences in river gradient, channel width, species diversity, percent cover, and height structure of riparian vegetation above and below sediment aggradation. Results indicate a marked difference between three distinct reaches correlating with the sediment aggradation. Upper sites showed greater species diversity, decreased density and an abundance of bare ground. An intermediate reach correlating strongly with the proposed zone of river sediment deposition by Gianniny et al., showed a significant switch to dense *Baccharis/Phragmites*. Species composition in the lowest sites was more homogenous dominated by the dense growth of willow and tamarisk. These results correlate strongly with differences in environmental conditions between the three reaches, especially related to channel width and river gradient.

INTRODUCTION

Although they make up a relatively minor land area, riparian ecosystems play an extremely valuable role in the desert Southwest. Riparian zones make up less than 0.5 percent of the Southwestern landscape but contain approximately one-third of the area's vascular plant species (Webb,Leake & Turner, 2007). These unique ecosystems serve a variety of other important functions such as stabilizing river channels, enhancing water quality, and providing essential habitat for an array of animal species including fish, insects, amphibians, reptiles, mammals and birds.

The riparian zones of desert rivers in the Southwest seen today are undoubtedly different from the ones observed in the early half of the twentieth century. Beginning around 1935 and extending through the 1960's, the United States went through a frenzied period of dam building to increase irrigation, flood control, navigation, and hydroelectric power (Graf, 2001). While these dams have provided enormous social and economic improvements for millions of people, it is becoming more and more evident that these benefits come with significant impacts to the health, composition and structure of riparian ecosystems (Graf, 2001).

Riparian vegetation has adapted over time to be able to survive in the ever-changing ecotone separating the drier upland from the purely aquatic realms. These areas are highly sensitive to the variations in the hydrologic cycle caused by the construction of dams. Studies have concluded that dams alter flow regimes in many ways including changing the magnitude of discharges, frequency, duration, timing, and predictability of flood disturbances and the rates of change between magnitudes of flooding events (Poff, et al., 1997).

Among the changes commonly seen on dammed rivers are fragmented habitats and habitat inundation, formation of new riparian zones, reduced groundwater recharge, alterations in sediment cycles, increased erosion and channel simplification, changes in species composition, declines in propagation of pioneer species such as cottonwoods (*Populus* spp.*)*, increased salinization, and invasion by exotic species like tamarisk (*Tamarix spp.)* and Russian olive (*Elaegnus angustofloia)* (Webb, et al., 2007; Nilsson & Berggren, 2000). The individual responses to alterations in flow regimes can vary drastically from river system to river system or even within a single river system making shifts in vegetation patterns difficult to predict (Nilsson & Berggren, 2000).

The San Juan River

The San Juan River (San Juan), located in Eastern Utah, offers a unique and interesting opportunity to observe the effects of dams on riparian ecosystems as it is sandwiched between Navajo Dam, upstream in Northern New Mexico, and the waters of Lake Powell impounded downstream behind Arizona's Glen Canyon Dam. Generally speaking, the effects of dams on downstream ecosystems are fairly well understood but considerably less is known about the impacts on systems upstream.

In addition to being affected by both upstream and downstream dam projects, the San Juan River is also unique in the topography of its course. This varied landscape has major impacts on the characteristics of the stream and therefore its responses to flow regime alterations.

Before the completion of the two dams in the mid-1960's, the San Juan was largely a free flowing river with only a few small diversions in the upper reaches. The headwaters are in the San Juan Mountains of Southern Colorado and the river flows west to its confluence with the Colorado River prompting the indigenous Ute Peoples to poetically refer to it as "the River flowing from the Sunrise" (Aton and McPherson, 2000).

On this westward journey, the San Juan flows through the red rock canyon country of the Four Corners region. It is one of the major tributaries of the Colorado River, draining approximately 23,000 square miles. The nature of the river channel changes dramatically as the river cuts through the varied landscape the Colorado Plateau (Webb, et al., 2007). Along its course, the San Juan is joined by a multitude of large drainages including Canyon Largo, Butler Wash, Comb Wash and Chinle Wash. These tributaries, as well as the mainstem river, erode the Mancos shale and other fine-grained layers of the Jurrasic Morrison Formation resulting in a large sediment load transported by the river (Gianniny, Hartle & Dott, 2014).

Under its natural flow regime, the San Juan typically experienced high volume floods both during the spring runoff as well as during large, occasional precipitation events in the fall. These floods would regularly scour the banks and leave large floodplain deposits mostly free of vegetation. Flows of 30,000 cubic feet per second (cfs) were not uncommon. The heavy snow years of 1884 and 1911 saw flows estimated to be over 100,000 cfs in certain sections of the canyon (Aton and McPherson, 2000). Since the completion of Navajo Dam in 1962, the San Juan has experienced only three flooding events that exceeded 20,000 cfs (USGS Surface Water for Utah, 2015).

The "Dam-wich" Effect

In addition to greatly reduced flows resulting from Navajo Dam, the lower San Juan (below Mexican Hat, Utah) is currently experiencing a decrease in the river channel base level caused by the back up of waters from Lake Powell. Today the sediment-laden river hits the "blue water" of the reservoir roughly 20-miles downstream of Clay Hills Crossing (River Mile 84) but at its maximum pool level, reached in July of 1983, Lake Powell reached an elevation of 3,708.34 feet above sea level extending up the San Juan to the mouth of Grand Gulch at River Mile (RM) 70 (Gianniny, et al, 2014).

Interestingly, sediment has aggraded in the river channel 3.1 miles upstream of the highest reservoir level, infilling the rapid that once existed at the mouth of Slickhorn Canyon. Gianniny et al. (2014) have inferred that accumulated lake sediments have reduced the river gradient to the extent that there is a backup of river sediment that settles out in the channel in response to the slowing of the river's flow. The combined sediment accumulation currently forms a wedge that is 71.1 feet thick at its deepest point.

The influences of Navajo and Glen Canyon Dams have had significant effects on the makeup and structure of riparian vegetation along the San Juan River. These effects have been fairly well documented through the use of repeat photography on the upper stretches of the river between Bluff and Mexican Hat, Utah (Webb et al., 2007) but in-depth studies of the lower reaches are lacking.

Riparian Vegetation: Then and Now

Photographs taken between Bluff and Mexican Hat before the construction of the dams show a wide, largely un-vegetated riparian zone sparsely populated with broadleaf cottonwood (*Populus fremontii)*, coyote willow (*Salix exigua)* and some low-statured riparian species. Photographs taken in the same locations between 1997-2000 show a much narrower, very densely vegetated riparian zone dominated by coyote willow. Other species present in the post-dam ecosystem include some locally abundant cottonwoods, non-native tamarisk (*Tamarix sp.)*, non-native Russian olive (*Elaegnus angustofloia)* and some smaller native shrubs like rabbitbrush (*Chrysothamnus nauseosus*) and netleaf hackberry (*Celtis reticulata)* (Webb, Boyer, Orchard & Baker, 2005).

The vegetation of the lower canyon below Mexican Hat has not been as well studied. In their 2014 study of sediment aggradation in the lower canyon, Gianniny et al., observed that the decrease in stream gradients resulting from slowing stream flows and increased sediment deposition above the confluence of the San Juan River and Lake Powell were correlated with a shift in vegetation from coyote willow to seep willow (*Baccharis salicina)* and reedgrass (*Phragmites australis*).

The effects of increased riparian vegetation have not been thoroughly examined on the San Juan River but elsewhere in the Southwest woody riparian vegetation has been observed growing in high densities across low floodplains acting as a catchment for sediment. This trapping of sediment induces a small positive feedback loop wherein the trapped sediments provide extended habitat for more woody vegetation, which in turn traps more sediment eventually producing the narrowing channels observed on many flow-regulated rivers across the Southwest (Webb, et al., 2007).

History of Succession

Another area that has not received in depth study is the successional history of the vegetation shifts in both the upper and lower parts of the river. The changes to river systems following the construction of dams are not instant. Shifts can be ongoing for decades as the system adjusts to the new "normal" conditions. The San Juan is no exception and at this point in time it seems likely that the current vegetation patterns are not completely stable and will continue to fluctuate as the influences of the two dams continue to alter the physical structure of the riverbed.

There is some debate regarding just how "pristine" the un-vegetated floodplains observed in the early, pre-dam photographs really are. Mormon settlers inhabiting the area in the late 1800's engaged in floodplain agriculture and livestock grazing and it has been well documented that large cottonwood stands were removed from certain areas. These activities surely had some influence on flooding and landscape changes. Despite these potential alterations, it is likely that the pre-dam vegetation was sparse and limited to flood disturbance-obligate species such as native coyote willow and cottonwoods which require barren, moist soils to propagate (Webb, et al., 2007).

Following the construction of the dams and the inundation of Glen Canyon, a notable increase in streamside vegetation has been well documented but the exact timing of succession remains vague. Coyote willow seems to be the most abundant species contributing to the dense vegetation that now lines the river banks in many sections of the river canyon (Webb, et al., 2007).

Early Successional Species: The role of Willows

Coyote willows are important, early riparian colonizers that depend on frequent disturbances and access to water to successfully propagate from seeds. On rivers where disturbance events are restricted by dam operations populations of willows are often the result of vegetative propagation and dominated by a few large clones (Douhvnikoff, McBride & Dodd, 2005). The genetic diversity of the San Juan coyote willows has not been investigated to date but it remains a reasonable possibility that much of the dense growth stems from a limited number of successfully propagating individuals.

Invaders! The Role of Non-Native Species in Flow-regulated Succession

Exotic species of tamarisk and Russian olive have proliferated along certain stretches of the river corridor. The exact timing of their arrival has not been pinned down. It seems probable that the species were established before the construction of the dams and multiplied significantly afterward along with coyote willow and cottonwoods (Webb, et al., 2007).

Given the variability in river systems' responses to flow regime regulation, sediment aggradation and the relatively short time period since the construction of the Navajo and Glen Canyon Dams, the structure of the riparian vegetation on the San Juan is unstable. Change appears to be the only reliable constant, thus, it is likely that the riparian ecosystem will continue to see more shifts in composition and structure. Due to the complex nature of the topography and the uneven distribution of sediment aggrading upstream from Lake Powell, the fluctuations in riparian vegetation on the San Juan will probably vary significantly within the river corridor.

Above Slickhorn Canyon (RM 66.5) there is no evidence of sediment aggradation and the river channel remains relatively narrow. Moving downstream towards Grand Gulch (RM 70.5) the river channel widens slightly. The sediments' migration slowly upstream is an indicator that this stretch of the river is seeing the early phases of aggradation. Grand Gulch marks the peak of the sediment wedge and downstream from here, the river channel becomes much shallower and wider with a decreased river gradient (Gianniny et al. 2014). These differences in channel characteristics along with differences in the river gradient are likely to play a significant role in vegetation shifts.

To date, the status of the riparian vegetation in the lower reaches of the San Juan River has not been documented or quantified despite concerns from the resource managers at Glen Canyon National Recreational Area (GCNRA). John Spence, the Chief Scientist and Terrestrial Natural Resources Branch Chief for GCNRA has expressed the need for quantitative vegetation surveys in this reach to determine the extent of exotic species invasion and habitat suitability for the endangered Yellow Billed Cuckoo (*Coccyzus americanus*).

It is clear that the riparian zone of the San Juan River is an ecosystem in flux but many questions remain regarding how it arrived at its present status and what it might look like in the future. This study has been designed to provide quantifiable data on the vegetation patterns above and below the extent of the sediment aggradation on the Lower San Juan River. This information may reveal patterns in vegetation succession and change over time for river systems impacted by downstream dams. Additionally, this study could provide valuable information for land managers concerned about the establishment of exotic species and habitat suitability for endangered species.

METHODS

Study Area

This study of riparian vegetation zones was conducted on the Lower San Juan River between River Miles 46 and 84, based off Whitis and Martin, 2009 (Figure 1). This reach was chosen to include sites that have been heavily impacted by upstream aggrading sediment and a comparable number of sites that are thus far untouched by sediment aggradation in order to allow for a good comparison of the vegetation structure and composition between sediment impacted and un-impacted locations. In their 2014 study, Gianniny et al. identified Slickhorn Canyon (RM 66.5) as the furthest upstream extent of the sediment wedge. Un-impacted study sites were identified in the 20-river mile reach above Slickhorn Canyon. Likewise, the impacted sites are located in the 18-river mile reach below Slickhorn to the boat ramp at Clay Hills Crossing (RM 84).

Each of the two reaches was divided into one-mile sections and one study site was chosen per section using GoogleEarth prior to the start of any field work. Designation of sites was made based on the following criteria: sites had to be located in an area where there is an existing point bar, or at the mouth of a side canyon to ensure that there would be a large, representative vegetated area. A stratified random sampling technique was used to ultimately choose sites for field surveys. Ten sites were initially chosen for each reach but due to time constraints and the logistical difficulties of reaching sites, nine sites were surveyed in the upper reach and seven in the lower.

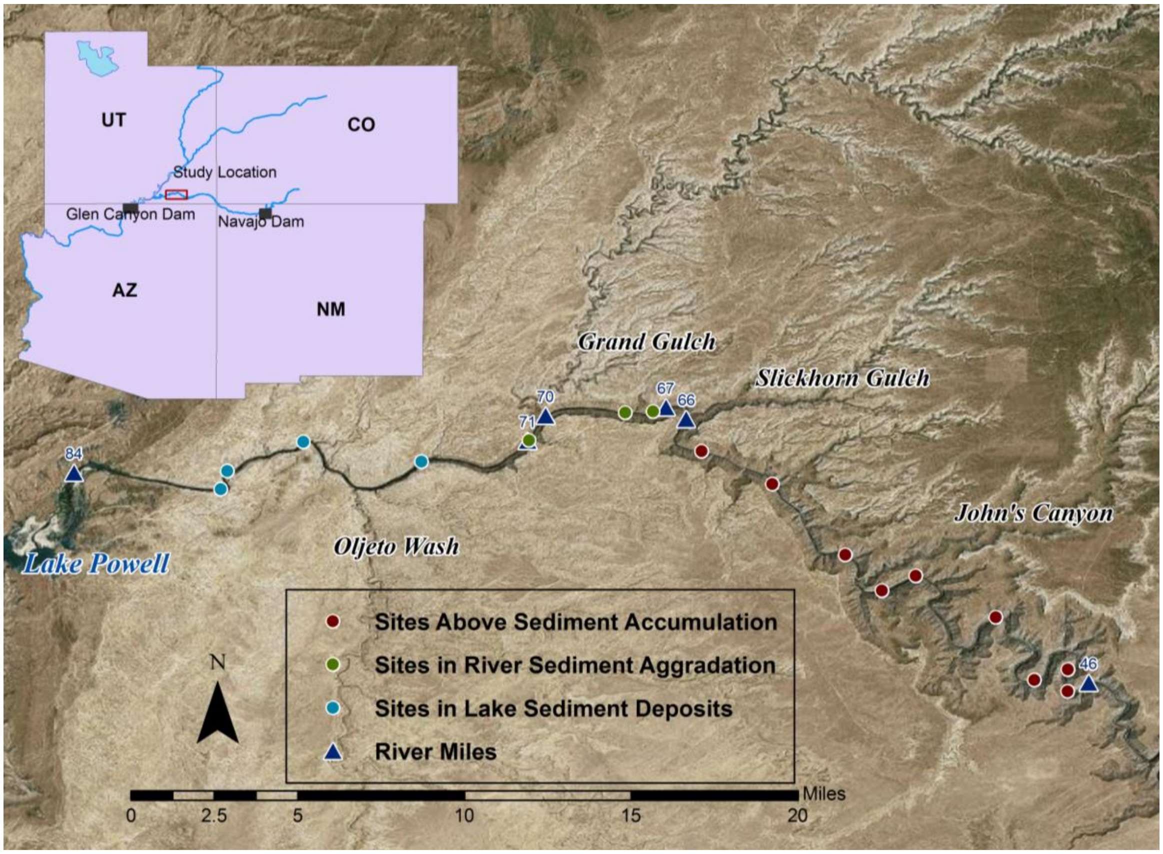

Figure 1: Map showing river miles (46-85) and three groupings of study sites: above sediment accumulation (RM 46-66), river sediment aggradation (RM67-70), and lake sediment deposits (RM 71-84).

The study reach is located at the bottom of a deep, narrow canyon just downstream of the Goosenecks State Park. It is most easily reached by raft or kayak, usually taking between 3-6 days to traverse this 56 mile section of the canyon between Mexican Hat, Utah and Clay Hills Crossing. Two river trips were conducted in fall of 2015 to survey the vegetation along the San Juan.

Environmental Variables

Channel width, river gradient and soil texture were the primary environmental variables examined in the study. Channel width was measured at each of the three transect line starting points for every site. A Nikon rangefinder was used to determine the channel width at bank full.

The river gradient for the reach between river mile 46 and 84 (Whitis and Martin, 2009) was determined using cartographic analysis in ArcGIS 10.3.1. The most recent (2014) and highest resolution (10-meter) digital elevation model (DEM) was obtained from the USGS National Map Viewer. River miles ascertained from Whitis and Martin (2009) were manually plotted and elevation values were derived for each mile point from the DEM.

Gradients were calculated by dividing the differences between river mile points by the number of miles between them to get drop in meters per mile. Values were converted from meters to feet to maintain consistency of units with the river miles used to determine study site locations. In some reaches of the river with a lower gradient, the 10-meter resolution was too coarse to determine different elevations for every river mile. For analysis river gradient was averaged over five-mile reaches with the study sites in the middle.

Each site was divided into three zones based on geomorphological traits. These zones were well defined at the upper reach sites and included a beachfront zone, a terrace, elevated roughly ½ meter, and an upper bench sitting another meter or so above bankfull. Soil samples were taken and a ribbon test was used to estimate soil texture at the middle of each zone for each of the three transects at each site. These zones were not as well defined at the lower sites so soil samples were taken from the river front, the back of the site and the middle of the site for each of the three transects per site.

Vegetation Survey

Each randomly selected site in the upper reach was measured in length across the point bar, parallel to the river and divided into even quarters. A modified Line Intercept Sampling Method (LI) was used at each third division to document diversity, percent cover, and height structure of the vegetation perpendicular to the river (Caratti, 2006). Transects varied in length depending on the extent of the riparian zone away from the bank of the river. Transects began at the start of vegetation near the river and terminated at the beginning of biotic soil crusts signaling the end of the riparian zones.

Sampling methods for the lower reaches were very similar with a few notable modifications. Point bars in the lower reaches were much less defined than those encountered in the upper sites. In order to sample a similar sized area, a standard length of 100 meters was chosen based off the average length of sites in the upper reach. The geomorphology of the canyon is slightly different in most of the lower reach, with the riparian zone terminating at the base of the cliff instead of transitioning to soil crust.

Vegetation encountered along the transects was identified to species or genus using the Flora of the Four Corners Region, Vascular Plants of the San Juan River Drainage: Arizona, Colorado, New Mexico, and Utah (Heil et al., 2013). Due to the immense diversity of graminoids, these were an exception and were only identified to family: Poaceae, Juncaceae, or Cyperaceae. *Phragmites sp.* was an exception to the exception as it is easily identifiable and made up a significant portion of vegetation cover. Other herbaceous vegetation identified to species only showed up on a limited number of transects and so were lumped together in an "other forb" category for more concise analysis.

The start and stop points for homogenous clumps of vegetation along the transect were recorded as well as status (alive or dead) and height; small (less than 0.15 meters), low (between 0.15 – 0.5 meters), medium (0.5 – 1.5 meters, tall (1.5 – 2.5 meters) or very tall (greater than 2.5 meters) based on Caratti, 2006. In order to streamline field sampling, vegetation clumps had to occupy .2 meters along the transect and gaps in vegetation of less than .1 meter were not recorded. The meters of ground covered by individual species were divided by the total length of the transect to get percent cover.

Although it was not the primary focus of this study, had it been observed, suitable habitat for the endangered yellow billed cuckoo would have been measured and documented. The United States Fish and Wildlife Service has determined that the migratory species prefer to breed in extensive willow-cottonwood or mesquite (*Prospis* spp.) habitat along low-gradient rivers like the San Juan. However, the birds generally do not reproduce in narrow, steep-walled canyons or sites measuring less than 50 acres (U.S. Fish and Wildlife Service, 2014). Due to these constraints, no suitable habitat was observed.

Data Analysis

The study was designed only to look at the differences in vegetation above and below the sediment aggradation, however as the data were analyzed it became clear that a third, distinctive reach existed in between the two zones. Study sites were broken into three categories for analysis: RM 46-66 (the reach above sediment aggradation), RM 67-70 (reach within river sediment aggradation hypothesized by Gianniny et al., 2014), and RM 71-84 (the lake sediment reach).

Quantitative data was analyzed statistically using SPSS. Channel width and height class data were each averaged for the three site categories and compared using a one-way ANOVA and post hoc Tukey's test for significant differences. Species richness was determined for each study reach by a simple count of the number of plants identified to the lowest reliable taxon (species, genus, or family).

Limited by the 10-meter resolution DEM, river gradient data could not be distilled to a precise enough level to determine the drop per mile. For each selected study site, river gradient was averaged over a 5-mile reach with that site in the middle. River gradient was also calculated over the distance of each of the three study reaches.

Ordination was used to identify the biggest differences between the vegetation composition of sites and the primary factors driving those differences. A Bray Curtis Analysis was conducted in PC-ORD 6. Additionally, an Indicator Species Analysis was conducted to quantify the significance of differences in vegetation cover for the three sites.

RESULTS

Environmental Variables

Data derived from GIS analysis of a 2014 DEM for the study reaches showed a pronounced decrease in river gradient moving from the reach above sediment aggradation into the reaches impacted by the sediment wedge (Figure 2). Between river miles 46 – 66 the river drops an average of 8.4 feet/mile. Between RM 67-70, the average drop is 4.9 feet/mile. Between RM 71-84 the river drops so subtly that a 10-meter resolution DEM could barely produce differences in elevation, showing a drop of less than one foot (.92 feet)/mile. Elevation uncertainty for a 10-meter resolution DEM is ±1.87 meters or 6.14 feet (Haneberg, 2006).

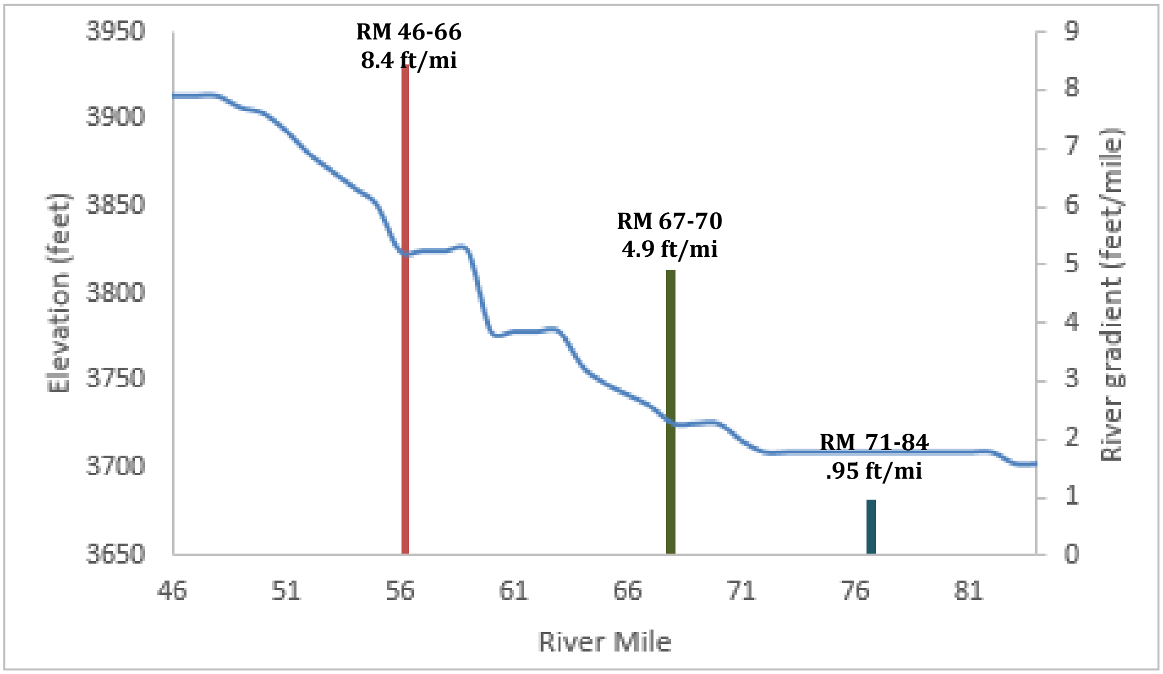

Figure 2. Elevation profile of the river across the study area (River Mile 46 – 84) derived from 10 meter-resolution DEM. Flat-line sections reflect stretches of the river with a gradient too minor for the pixel resolution (less than 10 meters (32.8 feet) per mile). Bars represent the gradient across each of the three study site groupings. Elevations reported in feet/mile to remain consistent with the river miles (Whitis and Martin, 2009) used to define study reaches.

Channel width increased significantly from the sites above Slickhorn Canyon, the upstream-most extent of the sediment wedge measured by Gianniny et al. (2014), to the sites below (Figure 3). The 27 transects surveyed in the upper reach had a range of widths between 29 meters at river mile 56 and 47 meters at river miles 46 and 65 with an average width of 39.86 meters. The nine transects in the middle reach (RM67-70) ranged in width from 47 meters at RM 68 to 73.5 meters at RM 70. The average channel width for this reach was 60.79 meters. The lower 12 transects reflected a further widening of the channel with a range of widths from 80 meters at RM 77 and 129 meters at RM 73. The average across the lower sites was 101.31 meters.

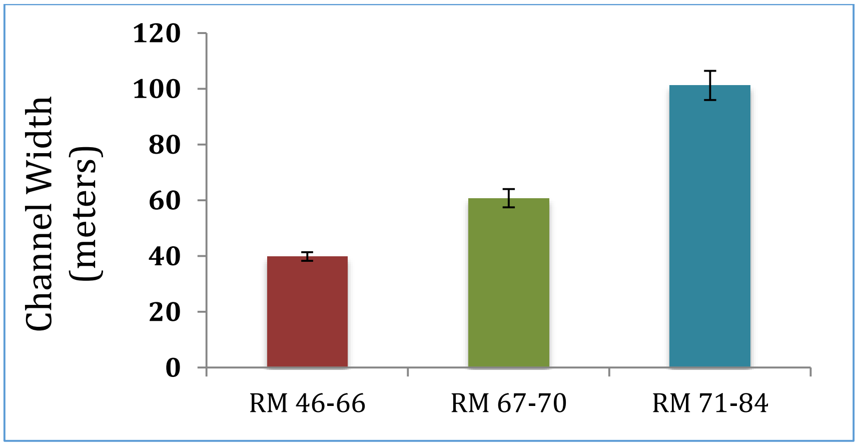

Figure 3. Difference in average channel width between three study reaches. A 1-way ANOVA and post hoc Tukey HSD indicate the differences in channel width between the three zones are highly significant ($p<.001$).

Soil samples were fairly uniform across the three geomorphological zones in the study reach above the sediment wedge (RM 46-66). A majority of the samples had a loamy sand texture. There was more variability observed in the soil samples taken at study sites within the sediment wedge (RM 67-84). Textures observed were silty loam, loam, silty clay loam, clay loam, silty clay, and clay. Soil textures did not show any significant correlations with study reaches or biological variables measured.

Biological Variables

Sites in the reach above the sediment wedge generally had higher species diversity (Table 1; Figure 4) and included a much higher proportion of bare ground. Sixteen taxa were encountered including a variety of woody vegetation, graminoids, and herbaceous vegetation. The intermediate reach between river miles 67-70 had only 9 taxa observed along transects consisting mostly of woody vegetation and *Poaceae* with a significant percent coverage of *Baccharis* and *Phragmites.* The lower reach towards the thicker end of the sediment wedge (RM 71-84) had only six taxa and was dominated by woody vegetation, especially *Tamarix.*

Table 1. Table of species/families encountered on transects and percentage of sites within each study reach containing them.

Species	RM 46-66	RM 67-70	RM 71-84
Salix exigua	96	56	50
Tamarix sp.	52	22	92
Baccharis salicina	22	100	8.3
Eleagnus angustifolia	0	0	8.3
Chrysothamnus spp.	30	33	0
Poaceae	41	44	16
Juncaceae	7.4	0	0
Phragmites	3.7	89	33
Saccharum ravennae	0	11	0
Melilotis officianalis	78	22	0
Salsolla spp.	15	0	0
Stephanomeria tenuifolia	3.7	0	0
Heterotheca villosa	7	0	0
Dieteria sp.	3.7	0	0
Amsonia eastwoodiana	3.7	0	0
Oenothera spp.	3.7	0	0
Toxicodendron vadicans	3.7	0	0
Aster (unknown sp.)	*7.4*	22	0

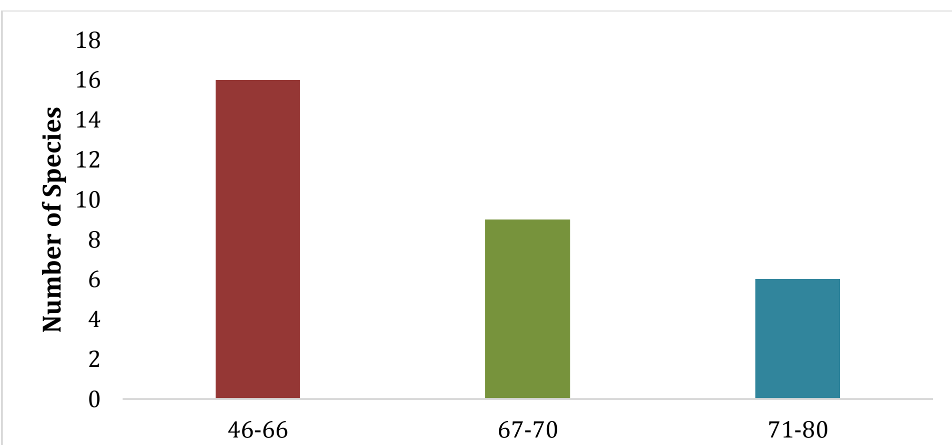

Figure 4. Species Richness determined for each of the three study reaches. Lowest reliable taxon (species, genus, family) groupings used for counts.

Height class distribution observed reflected vegetation composition across the study site categories. Sites in the upper and intermediate reaches of the sediment wedge had a much higher proportion of medium statured vegetation (between 0.5-1.5 meters) than sites in the lower end. Vegetation height increases downstream correlated with the shift from *Salix exigua* and forbs to *Baccharis* and *Tamarix* (Figure 5).

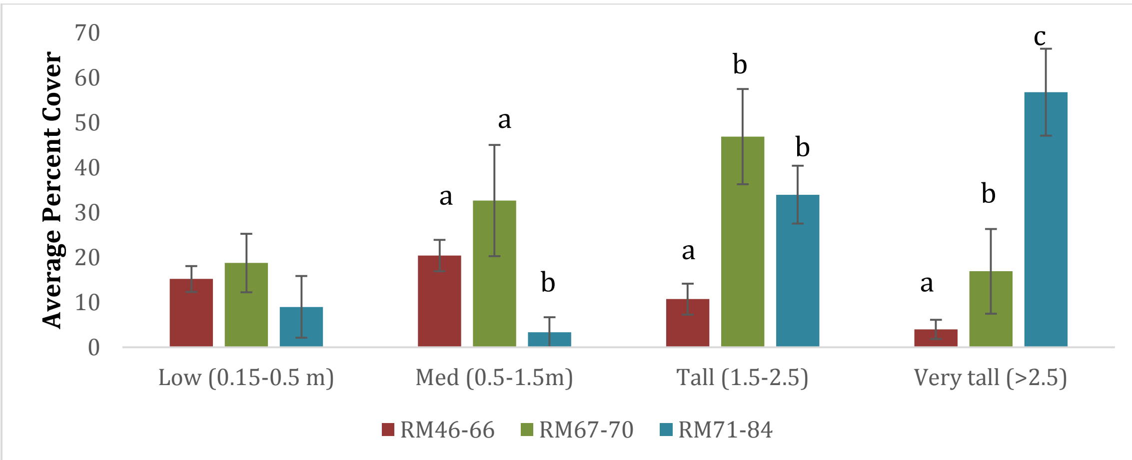

Figure 5. Distribution of height categories across three study site categories. A one-way ANOVA and post hoc Tukey's test indicate a few significant differences. Bars with the same letter indicate groups that showed no significant differences. Different letters signify groups that showed highly significant differences ($p \leq 0.01$).

A Bray-Curtis Ordination analysis revealed significant patterns in the correlation of the species composition and environmental variables measured at each of the three study site reaches. Channel width and stream gradient were inversely related and expressed a strong correlation with Axis 1 ($r = .841$ and $r = -.756$ respectively) (Figure 11).

Axis one accounted for 33.79% of the variance in species composition. Study sites between RM 46-66 are clustered together on one end of axis 1 with a high percentage of bare ground and forbs. At the other end, study sites at the bottom of the sediment wedge (RM 67-84) are clustered together reflecting monotypic stands of *Tamarix* spp.

Axis 2 accounted for 23.36% of the difference in species composition for a cumulative 57.15%. Axis 2 appears to be driven by the abundance of *Baccharis salicina* and *Phragmites* observed in the sites at the start of the sediment wedge between Slickhorn Canyon and Grand Gulch (RM 67-70).

An Indicator Species Analysis showed strong correlations between various taxonomic groups and the study site reaches. Sites above the sediment wedge were indicated by the presence of bare ground and mixed forbs. Bare ground was a highly significant indicator ($p = .0002$) and forbs were significant ($p = .028$). *Baccharis* and *Phragmites* were both highly significant indicators ($p = .0002$) for the intermediate study reach and *Tamarix* was the highly significant ($p = .0002$)

indicator species for the thickest end of the sediment wedge between RM 71 and 84 (Table 2).

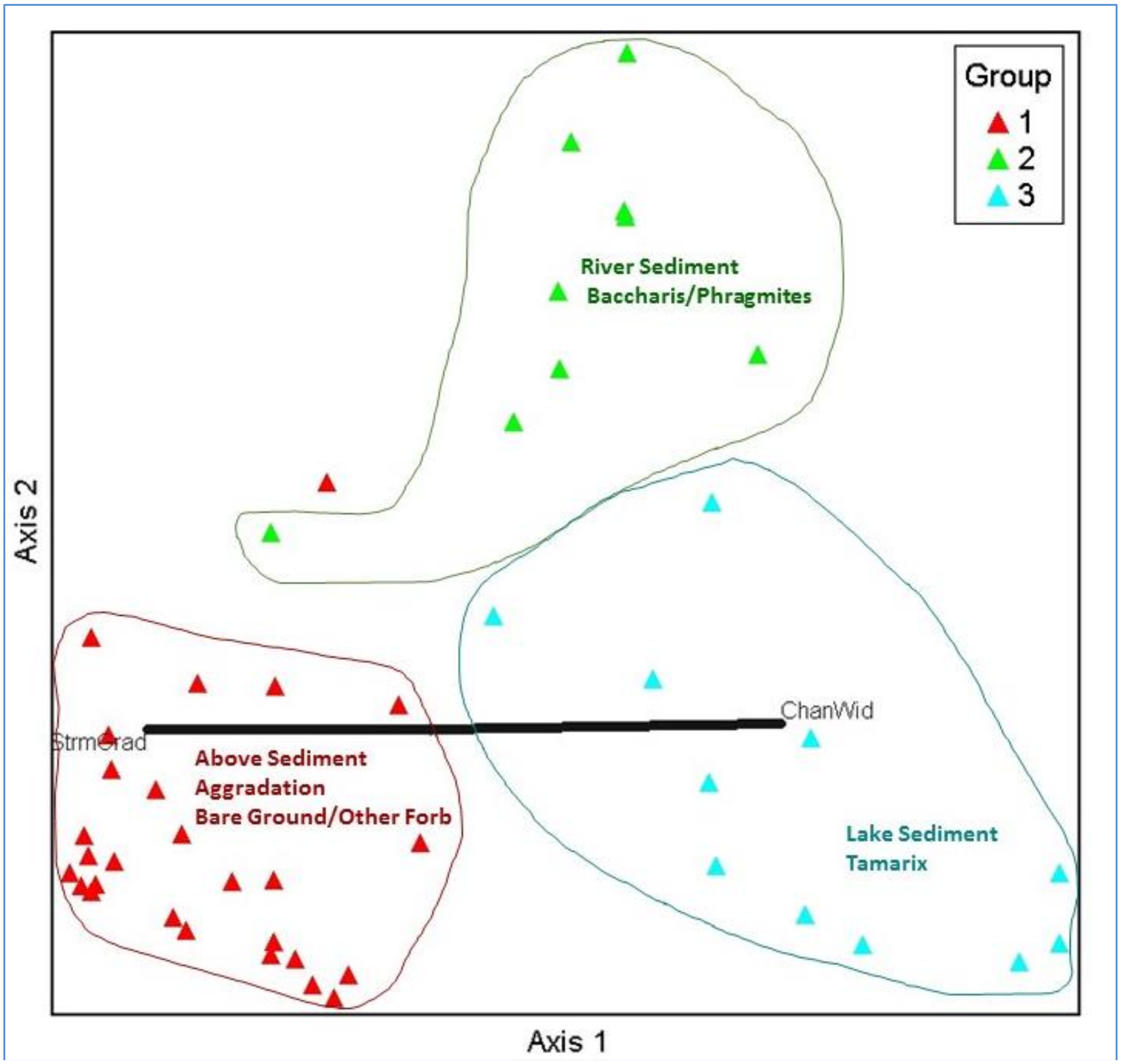

Figure 6. Bray Curtis Ordination of vegetation data with stream gradient and channel width joint overlays. Each point represents a vegetation transect. The position of each point is based on the total species composition of each transect. The distance between points illustrates the relative similarity or difference in species composition. Group 1 (red) includes the study sites between RM 46 – 66, Group 2 (green) is the river sediment sites between RM 67 – 70, and Group 3 (blue) are sites in the lake sediment accumulation between RM 71 – 84. Stream gradient and channel width are inversely related and correlate strongly with axis one. Stream gradient has a correlation coefficient of -.756, channel gradient .841.

Table 2. Species that were specific to a single study reach and serve as indicator species for each of the study site reaches.

Indicator Species	Study Reach	Indicator Value	Standard Deviation	Significance (p value)
Bare Ground	RM 46-66	95.5	5.86	0.0002
Other Forb	RM 46-66	41.4	6.94	0.028
Baccharis	RM 67-70	76.4	6.79	0.0002
Phragmites	RM 67-70	78	7.27	0.0002
Tamarix spp.	RM 71-84	75.2	7.1	0.0002

DISCUSSION

In their 2014 study of the effects of Lake Powell on sediment aggradation in the San Juan, Gianniny et al. proposed that the wedge of sediment beginning immediately below Slickhorn Canyon (RM 66) can be attributed to the combined effects of lake sediment deposition and the resulting feedback of rapid river sediment accumulation in the channel. Lake Powell reached a peak elevation of 3700 feet (at RM 70) in 1986 and has not reached that level again since, however there is significant sediment accumulation above this point. The lake sediment that accumulated below the maximum pool level greatly decreased the river gradient and velocity. This combined with the reduction of large scouring floods by Navajo Dam (the "dam-which") produces an ideal setting for the aggradation of river sediment upstream of lake sediment deposition (Gianniny et al., 2014).

The results of this study on the vegetation patterns along the lower San Juan correlate well with the hypothesized division of lake and river sediment zones below Slickhorn Canyon by Gianniny et al. (2014). Stream gradient, channel width, species richness and species distributions observed expressed significant differences between three categories of study sites: above the sediment wedge (RM 46-66), in the river sediment aggradation zone (RM 67-70) and in the reach of lake sediment deposition (RM 71-84).

Given that the hypothesized differences between study site reaches are based on the accumulation of different types of sediment, it was surprising that the soil samples taken along the transects did not correlate well with the other patterns of differentiation observed. This may be attributable to the small sample size for the two reaches below Slickhorn Canyon. Vegetation in these reaches was often so dense, it was impossible to actually reach the soil for a sample as the observer was elevated off the ground by the matrix of branches.

In addition, the area received significant rainfall around the time of the study resulting in large flashfloods that transported large amounts of sediment into the channel. After the floods subsided, a visible coating of fine sediment was observed on the shore below Slickhorn Canyon. This likely influenced the results of soil samples and may have contributed to the lack of strong patterns observed.

The distribution of vegetation across the three study reaches suggests a successional pattern that is still unfolding. The older, lake sediment deposits in the lower reach support well developed, more or less monotypic stands of *Tamarix* spp. with some intermixed *Salix exigua.* Lacking specific data for the ages of the vegetation in these reaches it is impossible to say for sure, but the dominance of tall and very tall vegetation in this reach suggest that this vegetation has been established longer than the predominately medium to tall statured vegetation found in the more recently deposited river sediment reach.

The three woody species most commonly found below the formation of the sediment wedge were *Salix exigua*, *Baccharis salicina,* and *Tamarix.* All three of these are considered early successional species that are well adapted to recolonize areas after disturbance (Merrit and Poff, 2010; Drezner et al., 2001). Only one, individual secondary colonizer, *Eleagnus angustifolia* was observed below Slickhorn Canyon. The dominance of pioneer species strongly suggests that the vegetation communities in the lower reaches have yet to reach a stable equilibrium and will continue to shift in the future as sediment continues to aggrade in the river channel.

The potential for continued aggradation of sediment upstream remains great. As sediment accumulates in the channel decreasing the channel base level, stream gradient and flow velocity diminish, reinforcing the feedback potential for more river sediment to accumulate (Gainniny, et al., 2014). The abundance of dense woody vegetation growing in the sediment impacted reaches compounds this self-reinforcing cycle. The vegetation structure traps sediment creating more habitat for woody, riparian species which in turn traps more sediment (Webb et al., 2007).

There remains an abundance of sediment to be moved downstream into this catchment area. Currently, the San Juan transports an average of more than 8000 acre feet of sediment per year (Spillyards, et al., 2006). The suspended sediment load observed today is at the lower end of what the San Juan has transported in the past. Shifts in land use practices, climatic conditions, and precipitation patterns can drastically alter the sediment inputs with the potential to double the current amount of sediment transported by the San Juan River into Lake Powell (Gianniny, et al., 2014).

Based on the patterns of homogenization and reduction of species richness observed in the sediment-impacted reaches of this study, the perpetuation of sediment aggradation could have significant impacts on the riparian ecosystem beyond the vegetation. Of particular interest are native, endangered species, such as the yellow billed cuckoo and the southwestern willow flycatcher (*Empidonax traillii extimus)* found in riparian habitats of the southwestern United States.

Both native bird species are adapted to the traditionally diverse riparian ecosystems once found along most desert rivers in the Southwest. These systems once provided continuous, diverse vegetation communities supporting the birds' nesting and feeding behaviors (U.S. Fish and Wildlife Service, 2014; Graf et al., 2002). The disruption of the natural flow regime in general, and the simplification of vegetation communities in sediment impacted reaches of the San Juan River in particular have reduced the suitability of habitat for both the cuckoo and the flycatcher (Graf, Stromberg & Valentine, 2002).

The optimal habitat for yellow billed cuckoo are large patches (greater than 81 ha) of densely canopied forest made up of mostly mature cottonwood (*Populus* spp.) and willow (*Salix* spp.) (U.S. Fish and Wildlife Service, 2014). Coyote willow was found, dispersed across the study reaches but not in large continuous patches and the conditions on the lower San Juan do not appear to meet the requirements for successful cottonwood establishment (Mahoney and Rood, 1998). Further, monotypic stands of *Tamarix* sp. have proven to be unsuitable habitat for the cuckoo (U.S. Fish and Wildlife Service, 2014).

For the southwest willow flycatcher, the ideal habitat is a riparian forest with open canopy of larger trees and a dense understory of small trees, shrubs, and low growing herbaceous vegetation. Cottonwoods are the ideal canopy tree species, providing important nesting habitat. Typically, the dense understory is made up of willow, *Baccharis,* arroweed (*Pluchea* sp.) and *Tamarix* with a variety of herbaceous vegetation that supports the food base for the flycatcher (Graf, et al., 2002). Components of this system were observed in the lower reaches of the San Juan, but only as independent fragments. The continued pattern of vegetation response to sediment accumulation does not appear to provide suitable habitat for the flycatcher.

The San Juan River is unique in the high suspended-sediment load it transports downstream and the historically low gradient of the river channel at its confluence with the Colorado River. Therefore, the responses of this system to the impacts of both upstream and downstream dams that alter the natural flow regime and sedimentation processes are also unique. Despite these site-specific responses, the alteration of the channel width and gradient and correlated shifts in species composition and vegetation structure highlight the effects dams can have on desert rivers and riparian ecosystems.

Most importantly, the findings of this study indicate that, although not well studied to date, dams have significant impacts not only on the systems downstream, but also have far reaching consequences for riparian systems upstream. This remains an important area for continued research to develop a more complete understanding of the full ecological impacts of dams on riparian ecosystems.

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