San Juan River Historical Ecology Assessment

Changes in Channel Characteristics and Riparian Vegetation

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Introduction

The San Juan River is the third largest tributary of the Colorado River. The river's natural flow regime is modified by Navajo Dam and other smaller dams and diversions. The lower reaches of the San Juan River are submerged under Lake Powell, the reservoir behind Glen Canyon Dam. Portions of the lower San Juan River are classified as critical habitat for the Colorado pikeminnow (*Ptychocheilus lucius)* and razorback sucker (*Xyrauchen texanus)*. These species were listed as endangered by the U.S. Fish and Wildlife Service (USFWS) in 1967 and 1991 respectively.

In 1992 the San Juan River Basin Recovery Implementation Program (SJRIP) was established to recover the Colorado pikeminnow and the razorback sucker while allowing water development and other river management activities to continue. Actions pursued by the SJRIP include stocking the endangered fish, removing non-native fish that compete with and prey upon the native fish, providing fish passage around diversion dams, providing flows that mimic the natural hydrograph, installing screens and weirs to reduce entrainment, and more recently, modifying habitat by removing non-native vegetation and opening up secondary channels and backwaters that have been overgrown with non-native vegetation.

Backwaters, embayments, and secondary channels provide the low-velocity habitats that are used by larval and small-bodied fish, including Colorado pikeminnow and razorback sucker, and are important in the recruitment process (Farrington et al. 2014). Loss of low-velocity habitat is thought to have contributed to the decline of the listed species (Holden 1999). Simplification of the river channel reduces the area of low-velocity habitats (Van Steeter & Pitlick 1998). Channel simplification can have many causes but in the study area is thought to be primarily caused by changes in hydrologic and sediment regimes due to regulation by Navajo Dam, and subsequent encroachment and bank armoring by non-native vegetation, specifically Russian olive (*Elaeagnus angustifolia*) (Holden 1999) and to a lesser extent saltcedar (*Tamarix* spp.) (Brooks et al. 2000).

My study quantifies channel simplification and other changes in river planform morphology and stream bank vegetation using historical aerial photographs. Imagery from the 1930s, 1970s, and 2010s was used to map the active channel and bankside vegetation in each period. Digitized features were then compared to quantify changes. Changes in planform morphology and riparian vegetation likely occurred before the mid-1930s but these antecedent changes occurred before aerial imagery is available so are not included in this analysis.

Study Area

The San Juan River originates in the San Juan Mountains and flows east to west through Colorado, New Mexico, and Utah. The highest elevations of the basin are dominated by spruce-fir, mixed conifer and ponderosa pine forest but the majority of the basin is desert grasslands. The basin is underlain with Mancos shale and oil and gas development is widespread. Cities in the basin include Farmington, Bloomfield, and Shiprock, New Mexico, and Durango, Colorado (Figure 1).

Surface water development includes over 20 agricultural, municipal, and industrial diversions on the main stem and tributaries (NMOSE 2015). Navajo Dam was completed in 1962 as part of the United States Bureau of Reclamation's Colorado River Storage Project and provides irrigation for about 70,000 acres of farmland (Glaser 1998) and 30 MW of hydroelectricity to the City of Farmington (EMNRD 2005).

Geomorphological reaches have been delineated below Navajo Dam (Bliesner & Lamarra 2000). These reaches provide a common reference for research and facilitate comparison of studies. Reach delineations were produced by conducting multivariate analysis of geomorphic characteristics to identify areas with similar characteristics. Reaches 1 and 2 are below the confluence with Chinle Creek and are canyon bound. Reach 1 is heavily influenced by fluctuations in the surface elevation of Lake Powell. Reach 3, between Chinle Creek and Aneth, Utah, has a low gradient and is sand-dominated. Reach 4 is transitional between sand-dominated lower reaches and cobble-dominated upper reaches. Reach 5 is characterized by a wide valley and is primarily cobble. Reach 6 has extensive anthropogenic modification including four diversion dams. Reaches 7 and 8 are heavily influenced by releases from Navajo Dam and banks have been stabilized to control lateral movement of the channel (Bliesner & Lamarra 2000). The reaches included in this study were 3, 4, 5, and 6.

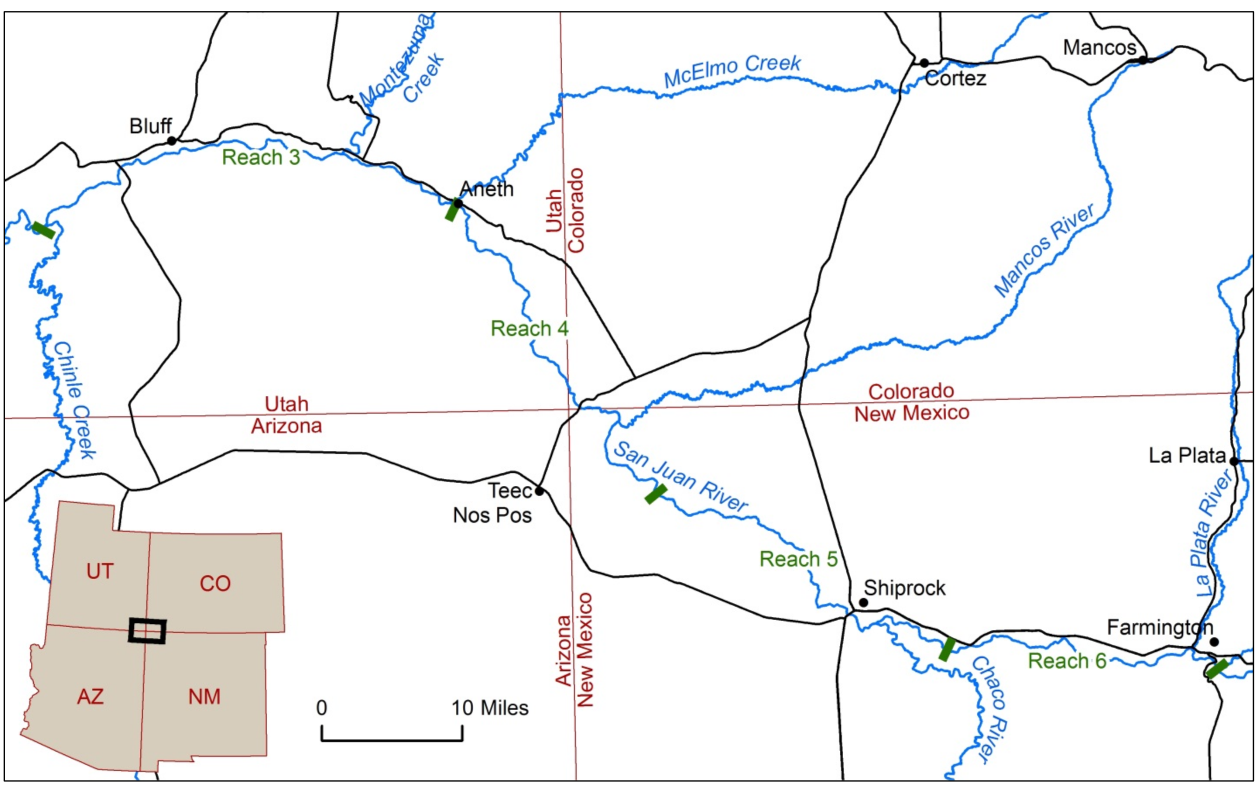

Figure 1. Map of the study area.

Methods

Analysis of historical aerial photographs is a common technique for quantifying landscape-scale habitat changes (Bliesner & Lamarra 2000; Cadol et al. 2010; Jones et al. 2011; Block 2014). Since the 1930s, aerial photographs have been collected regularly over the continental United States. In the San Juan Basin, this imagery is available beginning with black and white photographs taken in 1934, with imagery available for most of the study reach at least once a decade since. These photographs are stored in various archives and libraries but recently much of this imagery has been scanned and published electronically.

For this study, imagery from 1934–1935, 1975–1979, and 2011 was analyzed (Table 1). Additional imagery is available for many other years but was not included in this analysis. The aerial photographs used in this analysis were selected because they offer complete coverage of the study area and allow documentation of pre-dam, post-dam, and current conditions.

Table 1. Aerial imagery used in this analysis.

Year	Series	Extent (VM)	Description	Scale
1934	Soil Conservation Service (via USFWS)	131–150	B&W[1]	1:30,000
1935	Soil Conservation Service(via UNM EDAC[2])	187–249	B&W	1:31,680
1935	NAV 1935 (UTDNR[3])	148–178	B&W	1:31,680
1975	USGS series VDXK0	184–235	B&W	1:30,800
1978	USGS series VEPO0	281–249	B&W	1:32,000
1979	USGS series VETD0	131–189	B&W	1:24,000
2011	USDA National Agriculture Imagery Program	131–249	Color + IR[4]	1m

1 Black and white panchromatic imagery

2 University of New Mexico Earth Data Analysis Center

3 Utah Department of Natural Resources

4 Natural color and color infrared imagery

To prepare aerial photographs for analysis they were scanned at high resolution, collar information was cropped away, and adjacent images taken on the same day were merged using the Adobe Photoshop photomerge utility (Adobe Systems 2010). The utility uses a proprietary feature-matching algorithm to reference images to each other. The proprietary photomerge algorithm is similar to the Scale-Invariant Feature Transform algorithm described in Lowe (2004).

Merged images were then georeferenced to current aerial photographs using manually placed control points for features visible in both the historical and current reference imagery. High resolution imagery from the National Agricultural Imagery Program (NAIP) flown in 2011 was used to reference the historical imagery. The NAIP imagery has a horizontal accuracy of 6m with a 95% confidence interval (USDA 2013). Any error present in the reference imagery is minimized during analysis because all photographs are aligned to the same imagery.

I used a spline transformation in ArcMap to align the historical imagery with the current imagery (Esri 2014). For images with low distortion, as few as one control point per valley mile was used; in other images, as many as ten control points per valley mile were used. Many control points were used for each image with a much higher density of points near the river. Spline transformation distributes distortion between points and is most accurate at each control point (Esri 2015). The spline transformation was particularly suited for use with the historical photographs where image distortion is common. Areas of high relief or where photographs were taken obliquely or off of vertical are difficult to georeference using traditional polynomial transformation, but the spline transformation correctly aligns the images to ground control points.

Figure 2. Sample imagery from each time period used in analysis. Valley miles 203 and 204 are shown.

Imagery Interpretation and Digitization

Georeferenced images where interpreted and digitized at a scale of 1:5,000. The left bank, right bank, and islands were digitized with islands stored as polygon features and banks stored as line features. Left and right banks were digitized to correspond to the edges of the active channel as defined by the U.S. Army Corps of Engineers (Lichvar & McColley 2008). While the active channel is relatively stable compared to wetted area, streamflow at the time of photo and quality of the aerial imagery affected how the channel was interpreted and digitized.

Each photo series was digitized by an analyst and then reviewed by a second analyst. In areas where there was disagreement, a consensus was reached. Some of the aerial photographs were low quality which made interpretation difficult. Specular reflection and tone differences between images, as well as damage and scanning errors (scratches, dirt, and fold lines), were common but could usually be avoided by using other photographs of the same area.

Islands were digitized but sand or gravel bars were not. The active channel definition used during imagery interpretation characterizes exposed sand and cobble bars as within the active channel and more permanent vegetated islands that have upland characteristics as outside the active channel (Lichvar & McColley 2008). Vegetation, weathering such as erosion caused by precipitation, and other visible disturbances were indicators used to differentiate islands and bars. Many smaller exposed bars were present only in Reach 3 in the 1930s imagery and appeared to be part of a heavily braided system; these bars were not digitized as islands.

There were several instances of relief displacement in the 1930s imagery where cliffs and canyon walls obscure parts of the river. In the 1930s imagery, high relief areas with oblique imagery obscured 1.85 miles of channel edge or 0.66% of both banks. In these areas, the approximate location of the bank was estimated and digitized. Additional verification of bank location was not completed due to the short portions of the bank that were obscured. The edge of the active channel was not obscured in the photographs from the 1970s and 2011.

Valley Delineation and Linear Referencing

River miles have historically been used for linear referencing in studies on the San Juan River. The most common delineation used by the SJRIP begins with river mile zero just downstream of the Clay Hills boat ramp. In 2003 the SJRIP Biology Committee decided to continue using these mile delineations even though the delineated miles were not one mile in length (Gottleib 2003). There have been significant changes in channel sinuosity that have created discrepancies between current river distance and the standard river miles. Legacy river miles are useful for defining any arbitrary point along the river but are poor for summarizing and comparing linear and areal measures (Novak & Walker 2013). To enable accurate comparisons between reaches through time and to allow percent change measures, valley miles were delineated which address the issues presented by using river miles. Other recent studies have used valley miles for summarizing results along the San Juan River (e.g. Mangano 2013). A crosswalk between legacy river miles and current valley miles is attached to this report (Appendix A).

Valley miles were mapped continuously from the historical confluence with the Colorado River to the top of the study area. To define valley miles, the valley floor was delineated using methods developed by the Vermont Agency of Natural Resources (VANR 2009). Digital elevation data, slope data, and aerial imagery were used to identify the edges of the valley floor. Areas where tributary valleys intersect the main valley floor were only included in the mapped valley floor where they appeared to be influenced by flood flows on the main stem. The valley centerline was derived from the valley floor as the line equidistant from both valley walls (VANR 2009). The valley centerline was then used to create a linear reference framework for the study area. Lines were projected perpendicular to the valley centerline at one mile increments and were used to create valley floor polygons referenced to the valley mile.

Planform Channel Analysis

To compare changes in the active channel, linear bank features and polygonal island features were converted into a polygon representation of the active channel. Valley miles and reach delineations were used to summarize the area of the active channel and islands. Island count, island area, active channel area and valley floor area were summarized for each valley mile and reach, and the whole study area.

The complete coverage for the study area allowed calculation of areal measures that relate to fish habitat. Traditional measures of complexity calculated from river centerline and sample transects such as braiding intensity and sinuosity are possible with the imagery, but were not completed during this analysis in favor of 100% sampling of channel and island features.

Vegetation Sampling

Bank armoring by vegetation is considered to be a significant control on erosion and bank avulsion (Cadol et al. 2010). To quantify the vegetation located on the banks of the river, continuous transects were placed parallel to the digitized active channel on both banks and islands. Sample points were placed at 37.4 meter intervals along the transects throughout the entire study reach (Figure 3). This point density was selected to provide a minimum of 150 sample points per valley mile. Presence or absence of vegetation was recorded for each sample point at a scale of 1:5,000. This protocol was repeated for each series of aerial photos.

The sample point technique overestimates true canopy cover due to gaps in vegetation smaller than the photo resolution and shadows cast by the canopy (Frescino & Moisen 2012). The cover estimates derived from my analysis should not be considered analogous to true canopy cover but do serve as an index to changes in vegetation cover over time.

Figure 3. An example reach including valley mile 203 with vegetation sampling points color coded by vegetation presence.

Trees and large shrubs were easily identifiable from the aerial photos. Stands of cottonwood, Russian olive and tamarisk were classified as riparian vegetation. Willows were difficult to identify in the older imagery and may have been incorrectly classified as non-vegetation. In 1994 willow accounted for 6% of all riparian vegetation cover (Bliesner & Lamarra 2000) suggesting that any error in willow classification would have a relatively small effect on estimates of riparian vegetation cover in this analysis unless there was much more willow in the 1930s than in the 1990s.

Results

Throughout the study area the planform channel has changed dramatically since the 1930s; there has been a large decrease in channel area, island count, and total island area in the study area (Figure 4). Channel area decreased by 77.3% from 14,277 acres in the 1930s to 3,235 acres in 2011. A 34.7% decrease in island count between the 1930s and 1970s did not dramatically decrease total island area due to a corresponding increase in average island size. Island area stayed relatively constant between the 1930s and 1970s but declined from 4,494 acres in the 1970s to 2,725 acres in 2011, a 39.4% decrease.

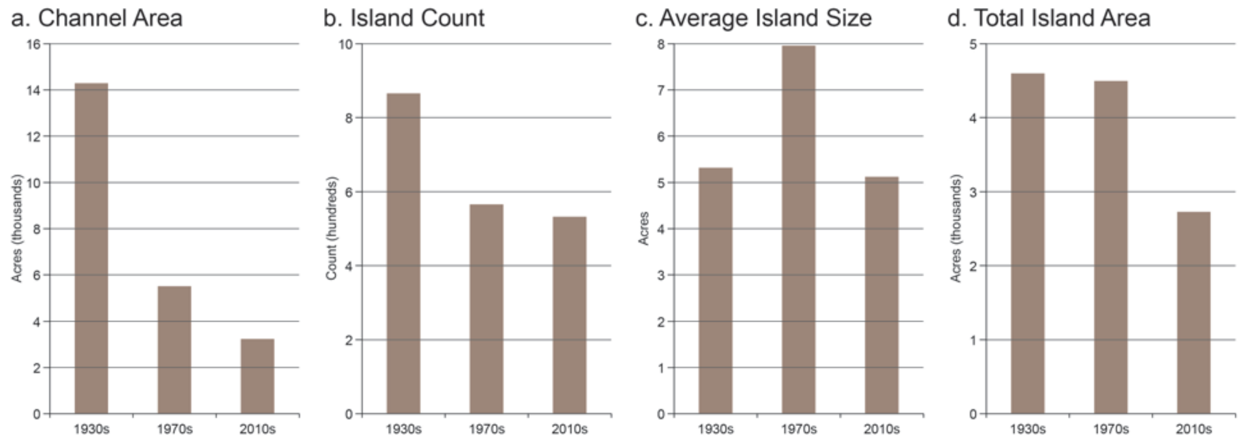

Figure 4. Planform channel characteristics for the study area in the 1930s, 1970s, and 2010s.

The geomorphic reaches identified by Bliesner and Lamarra (2000) exhibit distinct differences in channel characteristics and change (Figure 5). During the study period Reach 3 experienced the largest decrease in channel area (83%). The other study reaches demonstrate the same trend but with less severity (decreases between 58% and 76%). Between the 1930s and 2011, island count increased by over 200% in Reach 3, stayed relatively constant in Reach 4, and decreased dramatically in Reach 5 and 6 (by 67% and 61% respectively).

Between the 1930s and 2010s, average island area increased in Reach 5 but decreased in all other reaches (Figure 5c). The largest decrease in average island area occurred in Reach 3 (12.1 acres to 2.8 acres, 76%). Despite the large decrease in average island size, total island area decreased only slightly in Reach 3 because of the increase in island count over the study period.

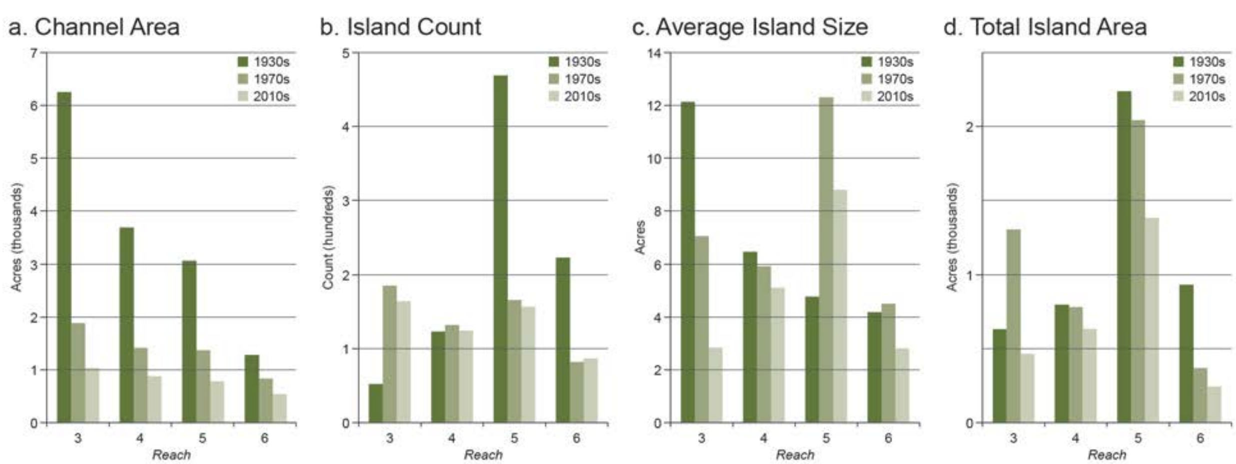

Figure 5. Planform channel characteristics summarized for each reach.

Reach-level summaries conceal the high variation along the river. No two valley miles are alike. Despite similarities between each reach's river miles, there are many river miles that do not follow the patterns seen in other parts of the reach (Figure 6).

Channel area, when expressed as a percent of valley floor illustrates how the channel area has changed over time relative to maximum possible river area (Figure 6d). The percent of valley floor occupied by the river channel is a measure of channel confinement by the valley walls. Channel confinement by valley walls was high in the 1930s throughout reaches 3 and 4 but confinement by valley walls has since decreased as channel area decreased. Valley miles 135, 136, 233, and 234 have a consistently low level of confinement but this is likely the result of incorrect delineation of the valley walls. The decreasing amount of confinement by valley walls suggests that the river is being confined by other mechanisms.

For the reach and valley-mile summaries, islands are split at divisions between analysis units. This is apparent in island count tabulations because islands that span a unit division will be double-counted if the island counts for adjacent units are added together. When analyzing the datasets that accompany this report, island count for individual valley miles or reaches should not be aggregated or added because islands that extend between multiple valley miles or reaches will be counted twice.

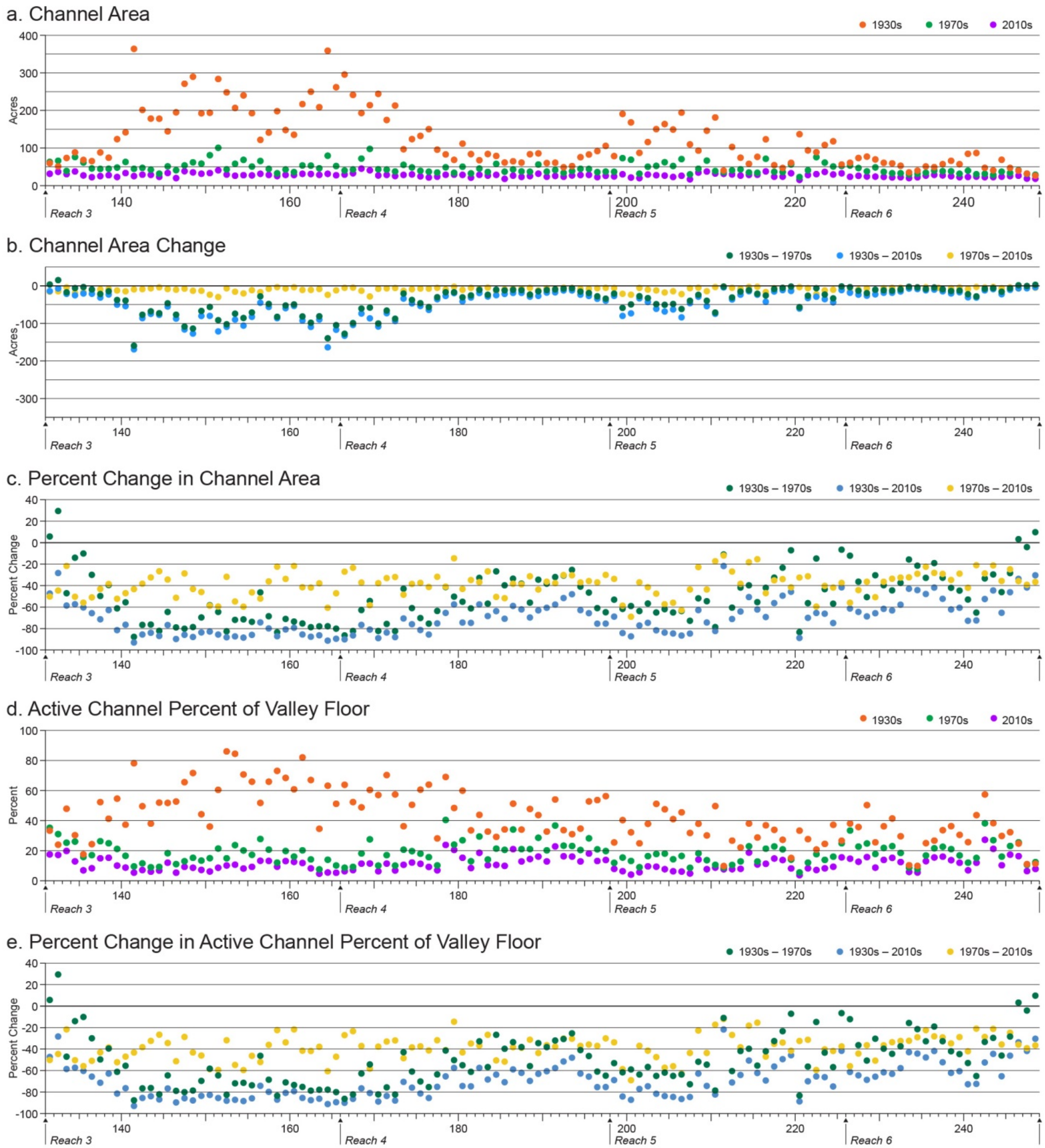

Figure 6. Planform channel characteristics summarized for each valley mile.

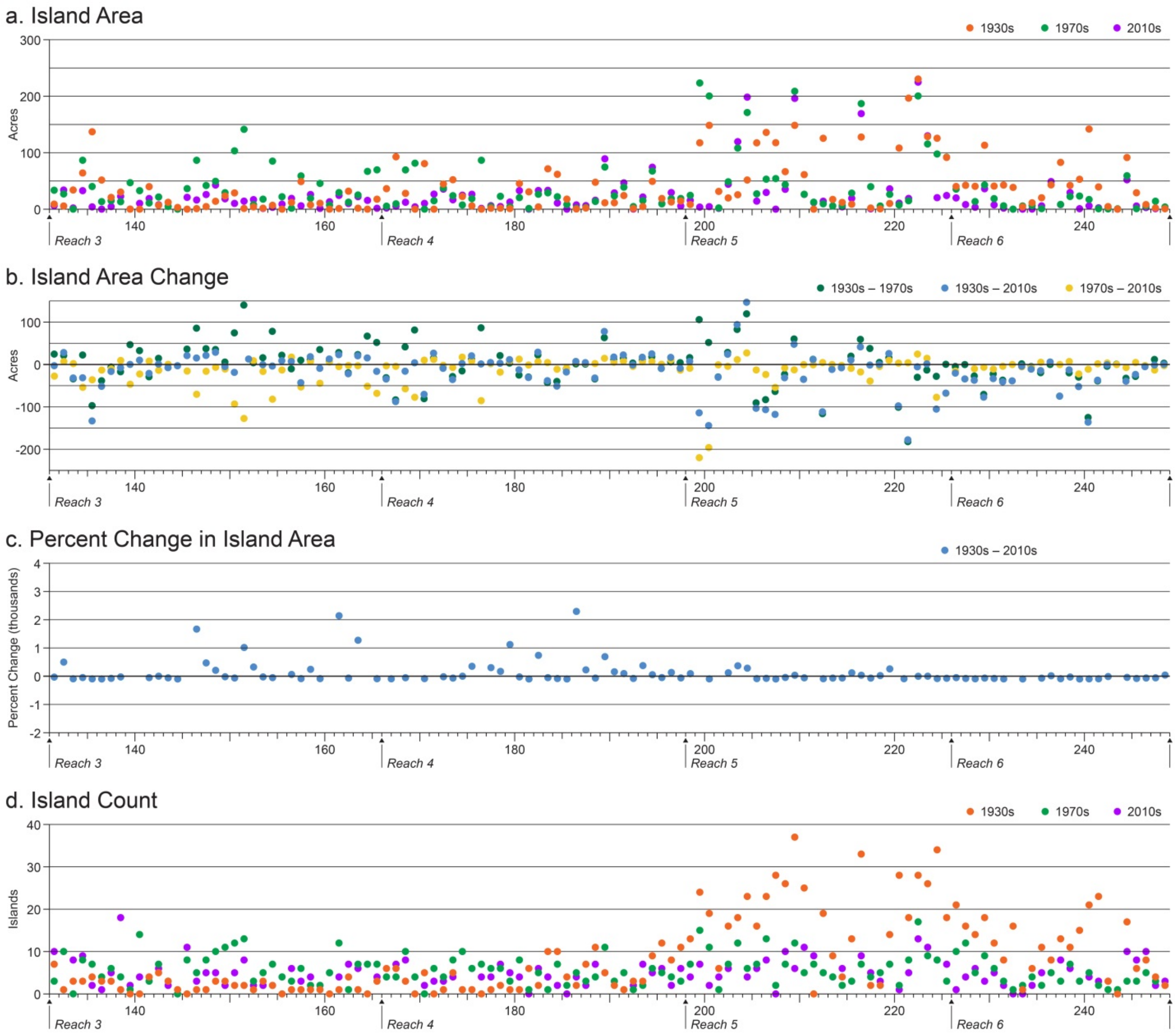

Figure 7. Planform island characteristics summarized for each valley mile.

Island area statistics follow much less consistent patterns than channel area. Figure 7a demonstrates the highly variable nature of island area both spatially and temporally. The large decrease in island area in valley mile 199 and 200 is due to the loss of very large islands in the area called "the Mixer" in some Recovery Program documents. Island area changed dramatically between the 1930s and 2010s (Figure 7c). The percent change can be misleading in areas where the change is undefined (i.e. 1930s island area equal to zero). The largest percent increases in island area occur where the island area in the 1930s was very small (e.g. valley mile 161 increased from 1.1 acre to 23.4 acres, a 2027% increase). In the areas where the percent change is negative, the lowest possible negative value is -100%. Half (50.0%) of the valley miles in the study area lost over 50% of their island area during the study period. Over a quarter (39.2%) gained island area. The net loss of island area throughout the study area was 1888 acres.

Digitization error was calculated from repeat digitization of a sample reach following methods used in other recent studies (Downward et al. 1994; Block 2014). An average error of 2.02 meters was calculated for linear features. Errors in area measurements vary based on feature geometry but in the sample reach an error of 0.02 acres per acre or 2% was calculated.

Bank Vegetation

Bank vegetation has increased dramatically throughout the study area. Between the 1930s and the 2010s there was a 1996% increase in vegetation cover (Figure 8). This can be reported with very high certainty due to the large number of sample points (17,300–23,223 sample points each decade).

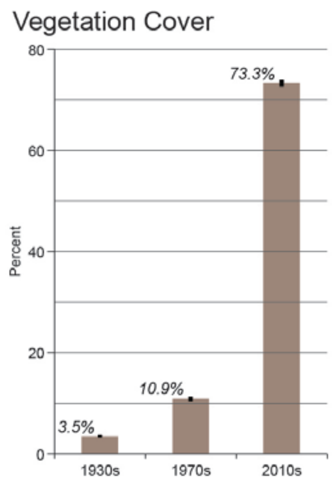

Figure 8. Study-area wide stream bank vegetation cover with 95% confidence intervals for each time period.

In the 1930s, vegetation cover was below 7% in all reaches and deviated between reaches by less than 5%. Reach 5 experienced the first dramatic increase in bankside vegetation, with 24% bankside vegetation cover observed in the 1970s. The other reaches had less than 10% cover until the 2010s (Figure 9). By the 2010s Reach 3 had over 60% and the other reaches had over 70% vegetation cover. In 2011, Reach 3 had 10% less bankside vegetation than any other reach.

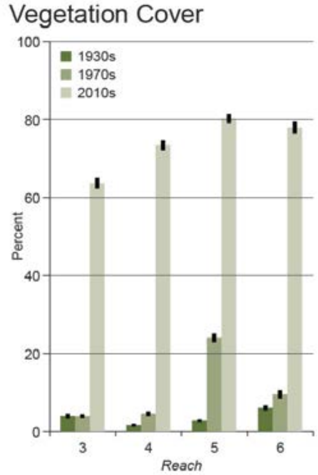

Figure 9. Stream bank vegetation cover with 95% confidence intervals for each reach.

The same trends seen in the study area and reach level summaries are present in the valley mile summaries as well. Average vegetation cover is low in the 1930s, increases slightly between the 1930s and 1970s and increases dramatically between the 1970s and 2011.

Confidence intervals were calculated for vegetation cover estimates for each valley mile, reach, and the whole study area using the methods for calculating the confidence interval for proportions described in Elzinga et al. (2001). A 95% confidence level was used which yielded confidence intervals that ranged between ±0.2% and ±0.7% for the study area and ±0.3% and ±1.5% for individual reaches. Confidence intervals for valley miles ranged from ±0.5% to ±11.0%

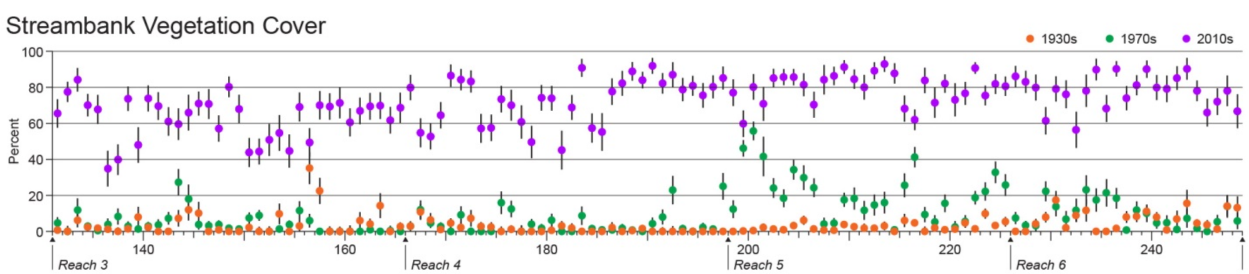

Figure 10. Stream bank vegetation cover and 95% confidence intervals for valley miles in the 1930s, 1970s, and 2010s.

The large spike in vegetation in the 1930s in valley miles 156 and 157 (figure 10a) is likely due to misinterpretation of the aerial imagery. This section of river has poor imagery quality where some features that appear to be vegetated islands may be dark sand bars. Similar errors may be present in other areas but other photo interpretation errors are likely much smaller due to better photo quality throughout the rest of the study area.

Discussion

The aerial photo analysis completed for this project was similar to the "historical analysis of fluvial morphology" included in the geomorphology study completed in 2000 as part of the 7-year research period (Bliesner & Lamarra 2000). Changes in channel area, island count, and island area were documented in the 2000 study and were reported for each geomorphological reach. Aerial photographs from four time periods were used in the 2000 study: 1934–35, 1950–52, 1959–62, and 1986–88. The only aerial imagery duplicated in this study is from the 1934–35 period.

Within the study area, there is strong agreement between the two studies despite differing methods and technology. Island area was roughly 4,000 acres in the mid-1930s (Bliesner & Lamarra 2000) while I identified close to 4,600 acres, a difference of 14.9%. Channel area estimates were even more similar; just over 14,500 acres of channel were reported in the earlier study for the mid-1930s and my study showed less than 14,300 acres, a difference of 1.8%. Island count is the most variable between the two studies; 616 islands were reported in the earlier study compared to 865 islands in this study. Because channel and island area are relatively consistent between the two studies I, hypothesize that the island counts varied because different criteria were used to define islands and a different scale was used during feature digitization.

In addition to Bliesner and Lamarra (2000), aquatic habitat has been mapped annually as part of the SJRIP since 1995 using high resolution sub-meter videography georeferenced to USGS topographic maps or NAIP imagery (Lamarra & Lamarra 2013). Because the imagery is very high resolution, classification of features into descriptive categories of habitats and vegetation types was possible. The lower resolution imagery used in my analysis does not allow characterization of aquatic habitats.

The annual mapping project has documented no significant change in any habitat category except backwater and low-velocity categories which have declined over the study period (Miller 2006). Island count has been used to measure channel complexity which only changed significantly in Reach 4 where it decreased by 35% between 1992 and 2002. This suggests that most of the changes observed between the 1970s and 2010s occurred before the 1990s. Previous research indicates the rate of channel simplification decreased for the majority of the study area by 1988 (Miller 2006).

The large changes in island count and channel area that are documented in this study are consistent with changes observed throughout the Colorado River Basin in reaches downstream of dams. Similar patterns of stream simplification (island count decrease), invasion by non-native vegetation, and channel area reduction have been documented in the Middle Rio Grande (Richard & Julien 2003; Massong 2004; Sixta 2004), Colorado River (Van Steeter & Pitlick 1998), and Lower Green River (Birken & Cooper 2006).

Changes in sediment regime are thought to contribute to the planform changes seen in the study area (Thompson 1982; Holden 1999). Changes in climate, impoundments, flow regimes, land management, and riparian vegetation occurred as the sediment regime changed. Thompson (1982) found Navajo Dam to have no significant effect on the relationship between stream discharge and suspended-sediment load at Bluff, though Navajo Dam did have a significant impact on sediment closer to the dam (Heins et al. 2004)

During digitization the most common mechanism for island loss appeared to be secondary channels closed off through vegetation encroachment and sedimentation, or abandoned by downcutting of the main channel. In these cases the secondary channel was abandoned and the island became part of the shoreline.

Correlation between vegetation presence and channel simplification was not analyzed but may be possible with the collected data. Due to the time lapse between documented vegetation and planform morphology, additional aerial imagery and interpretation may be necessary.

During digitization I noted that the vegetation cover present in the 1930s was primarily stands of cottonwood. By the 2011 imagery most of the vegetation was Russian olive and tamarisk. This is supported by a vegetation composition study completed in 1994 where exotics accounted for 67% of all riparian vegetation (Bliesner & Lamarra 2000). Stream bank vegetation was not categorized during this study so the location and spread of non-native vegetation can't be documented. Anecdotally the first stands of Russian olive along the San Juan River appear in the 1970s imagery near river mile 200.

Some of the spatial differences observed in bankside vegetation cover could be due to external controls on vegetation such as bridges and other built infrastructure and natural features such as exposed bedrock. Temporal changes in streambank vegetation are due to invasion by non-native plants (Holden 1999) and possibly to changes in land management (Fleischner 1994, Stromberg 1997). Livestock grazing has been prevalent in the basin since the 1800s (Merlan 2010). Historical grazing patterns in the San Juan basin have not been documented but riparian areas were heavily utilized throughout the western U.S. (Kovalchik & Elmore 1992). Antecedent vegetation conditions cannot be documented from aerial photographs but should be kept in mind when interpreting the results of this study.

No matter the cause, simplification has reduced the quantity of habitat available to native fish. Backwaters, embayments, and secondary channels provide the low-velocity habitats that are used by larval and small-bodied fish, including Colorado pikeminnow and razorback sucker, and are important in the recruitment process (Farrington et al. 2014). Loss of low-velocity habitat is thought to have contributed to the decline of the listed species (Holden 1999).

Increasing channel area and complexity through mechanical restoration or designed releases from Navajo Dam could increase potential habitat for Colorado pikeminnow and razorback sucker by increasing areas of low-velocity habitat—including secondary channels—and increasing water temperature. Higher flows create the opportunity for channel widening and wider channels allow for habitat heterogeneity (Pitlick & Wilcock 2001). Wider channels also increase the rate of warming (Boyd & Sturdevant 1997). Water released from Navajo Dam is colder than the thermal niches of the endangered fish, which limits upstream population movement (Lamarra 2007). Below the dam the rate of warming was found to be 0.91 ATUs/mile from river mile 205 to river mile 51 (Lamarra 2007). This rate would increase if the river width and surface area were increased, thereby expanding potential habitat for the Colorado pikeminnow and razorback sucker.

Some researchers have suggested that channel complexity and habitat heterogeneity can be restored in semiarid streams through non-mechanical means, specifically by increasing the channel width through increased discharge (Holden 1999; Pitlick & Wilcock 2001; Rathburn et al. 2009). As discharge and depth increase, stress increases in the near bank region. When shear stress exceeds that required for incipient motion, bank erosion occurs and the channel is widened (Pitlick & Wilcock 2001). As with other rivers throughout the West, this mechanism is constrained by the prevalence of non-native vegetation in the study area (Dott 2012; Mangano 2013). Additionally, the outlet works of Navajo Dam limit discharge to 5,000 cubic feet per second so timing releases to augment tributary discharge is critical for creating flows needed to destabilize the channel (Holden 1999).

In response to the apparently limited effectiveness of large environmental flow releases in maintaining or restoring low-velocity habitats, the SJRIP has recently turned to mechanical channel treatments to restore channel complexity (Stamp et al. 2006; Blienser et al. 2007; USFWS 2010). Mechanical treatments have removed sediment plugs and non-native vegetation from secondary channel inlets, and throughout historical secondary and tertiary channels. Over 67 acres of aquatic habitat were restored within the study area between 2008 and 2014 (S. Bassett, unpublished data). Early monitoring results suggest that this work may be producing the intended results: restored channels and naturally occurring secondary channels have similar fish population density and species composition (Franssen et al. 2015).

Trends in channel morphology may be useful in selecting and designing channel and floodplain restoration sites. Areas that have been particularly resilient to reductions in channel area and island area may have distinct hydrological and geomorphological attributes that can be selected for when identifying prospective restoration sites, perhaps increasing the likelihood that treatments will remain effective over longer time periods. In addition, the large variation in channel morphology between river miles suggests that an analysis of changes in channel area and island area in response to external factors such as valley slope, valley width, sediment supply, and bankside cover by non-native species may be useful in understanding the factors that maintain channel complexity in the San Juan River.

Supporting Information

Open access is provided to the imagery and derived data used in this analysis: http://nmconservation.org/sanjuan/historicalhabitat/.

Acknowledgements

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Appendix A: Crosswalk between River Mile and Valley Mile Linear Referencing systems used on the San Juan River, NM, CO, and UT

Location	River Mile[a]	Valley Mile[b]
Confluence with the Colorado River	-	0
Neskahai Canyon	-	46
Clay Hills boat ramp	2	56
Slickhorn Canyon	17	71
Mexican Hat, UT	51	111
Chinle Creek	68	131
Bluff, UT	80	143
Montezuma Creek confluence	92	156
McElmo Creek confluence	100	165
US 160 bridge	119	186
Red Wash confluence	132	200
Shiprock, NM	148	217
The Hogback	158	227
La Plata River confluence	177	245
Animas River confluence	180	248

a. From Bliesner and Lamarra, 2000.

b. Linear referencing used in this report.