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Daniel Louis Keller
Utah State University

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EFFECTS OF FLOODING AND TAMARISK REMOVAL ON HABITAT FOR SENSITIVE
FISH SPECIES IN THE SAN RAFAEL RIVER, UTAH:
IMPLICATIONS FOR FUTURE RESTORATION EFFORTS

By

Daniel Louis Keller
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A capstone report submitted in partial
fulfillment of the requirements for the degree

of

MASTER OF NATURAL RESOURCES

Committee Members:

Frank Howe, Chair
Layne Coppock
Judy Kurtzman

UTAH STATE UNIVERSITY
Logan, Utah
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Abstract

Part I of this report is focused on assessment of habitat changes on the San Rafael River after the abnormally high water year in 2011. Having habitat data and aerial imagery collected in 2010 (pre-flood) provided an opportunity to assess how a flood of this magnitude changed river habitat. In 2011 we commissioned a second aerial flight of the San Rafael River to serve as post flood imagery, then used Geographic Information Systems (GIS, ArcMap 10) to analyze river changes due to tamarisk removal and flooding. Our tamarisk removal project appears to have increased the potential for spring floods to diversify river habitat. The lack of complex habitat (pools, riffles, backwaters) is a limiting factor for native fish in the lower San Rafael River.

Part I of this report also includes investigations into the importance of large woody debris (LWD) in creation of complex river habitat. Pools, riffles, and backwaters occurred more frequently within 30 m up and down stream of LWD piles (LWD buffers) compared to areas within 30 m of random points (random buffers). In addition to a greater number of pools around LWD, the pools inside LWD buffers were also significantly larger than those associated with the random buffers. The size of riffle and backwater habitat was not significantly different between the LWD buffers and the random buffers. LWD piles strongly influence the formation and distribution of complex habitat along the lower San Rafael River. Due to the importance of LWD in creating complex habitat and thermal refuge, several management options are discussed that would increase the LWD in the San Rafael River. Part I primarily covers the ecological component of this study, however the recommendations section of Part I discusses some of the policy and economic issues concerning restoration of the San Rafael River.

Part II of the report will include human dimension, policy, and economic aspects of restoration efforts on the San Rafael River. Here we evaluate how water use could be impacted by further declines in native fish species and how potential listing of the 'three species' would affect water users in the San Rafael River Drainage. The roundtail chub (*Gila robusta*) has been petitioned for listing under the Endangered Species Act in the Lower Colorado Basin. If roundtail chub were listed in the Upper Colorado Basin, the San Rafael River could be listed as critical habitat for recovery of the species.

Part II also consists of a literature review of the current research available on the San Rafael River. The literature review is a synthesis of past research that illustrates the importance and need for restoration of the San Rafael River. Part II also identifies future research needs, such as evaluating the reintroduction of beaver as a restoration technique. This section will also discuss the pros and cons of current and proposed management practices, as well as identify how changes in local water policy and management could benefit native fish populations of the San Rafael River. Many of the proposed management practices such as installing more efficient irrigation systems, and working with water users to coordinate release of water in the spring time, will assist in the large undertaking of providing more flows for the benefit of native fish. The economic and ecological aspects of various tamarisk control methods is discussed with costs given for the current methods of tamarisk control being used on the San Rafael River.

Introduction

The Green and Colorado River systems are home to a unique group of native and endemic suckers and chubs that historically used a wide range of habitat types and were thought to have moved among tributary and mainstem systems (Budy 2008). The flannelmouth sucker (*Catostomus latipinnis*), the bluehead sucker (*Catostomus discobolus*) and the roundtail chub (*Gila robusta*) all maintain populations in the San Rafael River. Collectively, these three species are generally managed as a unit (hereafter; ‘three species’ UDWR 2006). The flannelmouth sucker once occupied the rivers and streams of the Colorado River Basin from Wyoming to Mexico, including a variety of habitat types (pool, riffle, run) within each system (Bezzerrides and Bestgen 2002). The bluehead sucker historically occupied small headwater, and large mainstem streams of the Snake, Weber, Bear, and Colorado River basins (Bezzerrides and Bestgen 2002), and healthy populations were often found in cool (~20 °C), fast flowing rivers dominated by rocky substrates (Sigler and Sigler 1996). Populations of roundtail chub were historically found from southern Wyoming to central Mexico, where they have a tendency to prefer deep complex pools intermixed with riffles (Bestgen and Propst 1989; Bezzerrides and Bestgen 2002).

The range and abundance of all ‘three species’ have declined dramatically throughout their historic range. The ‘three species’ currently occupy only ~50 percent of their historic range,

largely due to habitat perturbations, fragmentation, and interactions with non-native fish (Bezzlerides and Bestgen 2002). The roundtail chub has been petitioned for listing under the Endangered Species Act in the Lower Colorado Basin. Despite the range wide declines, all ‘three species’ are found in the San Rafael River, for this reason the San Rafael River is an area of high conservation priority. In the past five years numerous university graduate projects have been conducted on the San Rafael River (Bottcher 2009; Walsworth 2011; Fortney et al. 2011). These projects have added greatly to our understanding of the physical habitat requirements and status of fish communities in the San Rafael River.

Prior to water alterations (e.g., dams, irrigation projects) the hydrograph of the San Rafael River was driven by large snow melt resulting in spring flood events as well as fall monsoonal events that carried high sediment loads and shaped new channel forms. The formation of complex habitat (pools, riffles, backwaters) is dependent on these flood events (Fortney et al. 2011). Currently, much of the peak flows are diverted or held back in storage reservoirs often creating abnormally reduced flows in the lower river. In fact, during drought years large sections of the lower San Rafael River completely dry up. The altered hydrograph has also assisted the invasion of tamarisk that has resulted in the replacement of much of the native vegetation along the riparian zone (Stromberg et al. 2007). Extensive tamarisk invasion is further contributing to the dewatering problem on the river. In addition, tamarisk trap sediment that can result in a narrow and deep river channel, reducing the capacity to transport floods (Fortney et al. 2011). The bank stabilizing effects of the tamarisk reduce access of water to the floodplain and limits the creation of complex habitat.

The ‘three species’ are present in much higher abundances in the upper San Rafael River, where non-native fishes have not established populations. The Hatt's Ranch diversion has prevented movement of non-native fish from the Green River into the upper San Rafael River (Figure 1). The diversion is approximately 64 km upstream of the confluence with the Green River.

The current diversion was constructed in 1953 and is a complete barrier to fish movement, therefore in this report the diversion is the point of reference between what will be referred to as the upper and lower San Rafael River. Preventing movement of non-native fish into the upper river has been beneficial; however the dam also excludes native fish in the lower river from utilizing the upper river where better habitat exists.

The established populations of nonnative channel catfish (*Ictalurus punctatus*), black bullhead (*Ameiurus melas*), and green sunfish (*Lepomis cyanellus*) are a year-round source of predation for all except the largest individuals of the ‘three species’ (Budy 2011). Stable isotope data also suggests that small invasive fish red shiner (*Cyprinella lutrensis*), sand shiner (*Notropis stramineus*), and fathead minnow (*Pimephales promelas*) in the lower San Rafael River likely present another novel predator consuming eggs and larval life stages of ‘three species’. Previous studies have shown red shiners to be significant predators on larval and juvenile stages of native Colorado River fishes (Tyus and Saunders 2000).

The altered hydrograph is considered to be one of the most important impacts to the ‘three species’ and it is recognized that the tamarisk invasion was a significant impediment to the ability of the river to create complex river habitat. For this reason, the Utah Division of Wildlife Resources (UDWR) and Natural Resource Conservation Service (NRCS) teamed up to remove tamarisk along the lower San Rafael River. The San Rafael Restoration Committee (SRRC) has since been assembled in order to guide future restoration efforts on the San Rafael River. The SRRC is composed of multiple state and federal agencies, Utah State University (USU), and water users. Funding for the restoration work has been through Wildlife Habitat Incentive Program (WHIP). Currently, 424.5 hectares (1,049 acres) of tamarisk have been removed which equates to 24 river km. Projects to re-establish native vegetation within the treatment areas are ongoing. Thus far, 216 hectares (534 acres) have been seeded with native plants. The focus of restoration efforts have been the lower 62 km stretch of river between Hatt's Ranch and the confluence with the Green River. Approximately half of this stretch was donated to UDWR by PacifiCorp Energy. The other predominant land owner along the lower San Rafael River is the Bureau of Land Management (BLM).

Approximately \$1.3 million has been awarded from multiple sources for restoration of the San Rafael River. Original plans were made to use available funding for removal of fish barriers (Hatt's Ranch diversion) as well as channel reconfiguration. Due to complications and prohibitive cost estimates current efforts have focused on improving the physical habitat template through non-native vegetation removal (primarily tamarisk). Across the western states multiple federal and state agencies are conducting similar tamarisk removal projects. While the economic and ecological damage of tamarisk invasion is evident in its ability to decrease

palatable forage, displace native vegetation, and disrupt ecological function, few research projects have focused on impacts to fish habitat, and little research is available assessing the benefits of tamarisk removal.

Part I of this report is focused on assessment of habitat changes on the San Rafael River after the abnormally high water year in 2011. Above average snowpack within the San Rafael River drainage resulted in essentially a 30 year flood event, as comparable spring flows (magnitude and duration) have not been reached since the 1983-1984 flood years. In 2011 flows peaked at over $56.6 \text{ m}^3/\text{s}$ ($2,000 \text{ ft}^3/\text{s}$), compared to the average peak of approximately $8.5 \text{ m}^3/\text{s}$ ($300 \text{ ft}^3/\text{s}$) (Figure 2). The San Rafael River was at flood stage ($> 8.5 \text{ m}^3/\text{s}$, $300 \text{ ft}^3/\text{s}$) for approximately 65 days between 21, May and 24, July. (Figure 2). The high flows seen on the San Rafael River in 2011 resulted in considerable habitat changes. While a flood of this magnitude is unusual, evaluating its impact on the river can provide insight into what benefits could be expected if a more natural hydrograph were to be restored. Having habitat data and aerial imagery collected by USU in 2010 (pre-flood) provided an opportunity to assess how a flood of this magnitude changed river habitat. Evaluating habitat changes inside our tamarisk treatment areas and comparing them to those outside the treatment area allows us to evaluate the effects of tamarisk removal on formation of river habitat. Tamarisk removal is a costly endeavor, therefore the ability to better understand whether or not it can improve conditions for native fish is very critical to future management decisions on the San Rafael River; this question is investigated in Part I of this report.

Part I of this report also includes investigations into the importance of large woody debris (LWD) in creation of complex river habitat. The distribution of LWD in large and small channels and the processes by which LWD influences pool frequency and channel shape (Keller and Swanson 1979; Lisle 1981; Montgomery et al. 1996) have implications for the quantity and distribution of fish habitat (Hyatt 2001). Baillie and Davies (2002) found that LWD pieces influencing channel morphology contributed mainly to sediment storage as well as flow deflection and debris collection. They also found that wood aligned either perpendicular or obliquely to stream flow and positioned on or partly buried in the stream bed had the greatest influence on channel morphology.

The quality of instream habitat can also be influenced by LWD. Angermeier and Karr (1984) found that increases in the amount of LWD can be expected to increase fish species diversity and individual abundance. The same authors found similar results for invertebrate abundance and diversity. While most studies on LWD have focused on salmonid fish species, LWD is important for native fish of the Colorado River Basin as well. In the petition to list the roundtail and headwater chubs (*Gila nigra*) as endangered species in the lower Colorado River (2003), reduction of LWD was listed as a contributing factor in the decreasing quality or quantity of pools. The rarity of pools in the lower San Rafael River may also be limiting for roundtail chub, which have been found to prefer deep areas and slow water velocities among a variety of substrate sizes (Budy 2011). The majority of large pools found in the lower San Rafael River are found within close proximity to LWD. Cottonwoods (*populus fremontii*) that likely once provided an important source of LWD have been replaced by non-native tamarisk along much of the lower San Rafael River. We know that tamarisk invasion has serious consequences on the structure and stability of native plant communities. The decline of riparian stands of cottonwood along the Rio Grande in New Mexico is partially attributed to the invasion of tamarisk. The thick stands of exotic plants along the floodplain have severely limited the number of germination sites that are suitable to cottonwood (Howe and Knopf, 1991). Furthermore, as the river has become channelized and disconnected from the flood plain, large cottonwoods have less opportunity to fall into the river.

By affecting the flow of abrasive materials, woody debris can lead to scour, which results in deeper pool habitat and provides cover for fish. Research has shown that LWD improves fish habitat by increasing types and sizes of pools, sediment storage, and scour (Skaugset et al. 1996). The deep scour pools present on the San Rafael River provide thermal refuge during the low water years when surface temperatures can exceed 35 °C (Bottcher 2009). The formation of many of the scour pools present on the San Rafael River can be attributed to the affect of water plunging over LWD.

The ecological component of this study (Part I of this Capstone Report) focused on two major topics: 1) broad scale effects of tamarisk removal and flooding on creation of fish habitat and 2) finer scale effects that woody debris piles have on post-flooding fish habitat.

In order to test the effectiveness of our tamarisk removal project we developed the following study question:

Did the 2011 flood result in more change within our tamarisk removal site than outside the removal site?

To investigate the correlation between complex habitat and LWD piles the following study questions were developed for the San Rafael River:

- 1) Is there more complex habitat associated with woody debris piles than at random locations along the lower San Rafael River?
- 2) Is there more woody debris within the tamarisk treatment area than the adjacent untreated area?

Part II of the report will include human dimension, policy, and economic aspects of restoration efforts on the San Rafael River. Part II also consists of a literature review of the current research available on the San Rafael River. This review will summarize the existing knowledge and identify future research needs. This section will also discuss the pros and cons of current and proposed management practices.

A complete list of objectives for this study is listed below:

Objectives:

Ecological

1. Determine fish habitat changes in the San Rafael River due to the 2011 spring flood event combined with tamarisk removal.
2. Determine the effect of Large Woody Debris piles on fish habitat quantity and quality for the ‘three species’ in the San Rafael River.

Human dimensions

Policy

1. Evaluate how water use could be impacted by further declines in native fish species and how potential listing of the ‘three species’ would affect water users in the San Rafael River Drainage.
2. Identify how changes in local water policy and management could benefit native fish populations of the San Rafael River.

Economics

1. Identify the most cost effective methods for tamarisk removal and control on the San Rafael River.

Other

1. Conduct a literature review of the current research available on the San Rafael River. This review will summarize the existing knowledge and identify future research needs, and potential restoration strategies.

Study Area

The San Rafael River is formed by the confluence of Huntington, Cottonwood (Straight Canyon), and Ferron Creeks (Figure 3). Headwaters of the three creeks are in the Manti La-Sal Mountains at approximately 3,350 m (10,990 ft) elevation. The San Rafael River incised and uplifted sedimentary formations of the San Rafael Swell, forming an anticline approximately 160 km long and 65 km wide. On the eastern edge of the Swell is a steep monocline called the San Rafael Reef. From the confluence of the three streams at 1,676 m (5,498 ft), the river cuts through the Swell and flows through an alluvial valley to its confluence with the Green River (1,212 m, 3976 ft). In total, the river extends approximately 174 km in length and the drainage encompasses almost 6,299 km². The San Rafael River is the last major tributary of the Green River before it joins the Colorado River in Canyonlands National Park. In an average year, the upper elevations receive approximately 1 m of precipitation, mostly in the form of snow.

The focus of this study is the lower 64 km of the river between Hatt's Ranch and the confluence with the Green River. Tamarisk has widely colonized the lower San Rafael River forming dense stands, however some areas still maintain a healthy variety of native vegetation. Dense tamarisk

stands increase channel roughness, which in turn slows water velocity during a flood and leads to vertical and lateral accretion of floodplains, thereby promoting channel narrowing (Graf, 1978, Birken and Cooper, 2006) In the San Rafael River, the invasion of tamarisk has occurred along with changes to the hydrologic regime as a result of water development in the headwaters.

Methods

Fish abundance

In 2011 electrofishing surveys were conducted at 10, 300 m long sites, and physical habitat data was collected at 9 of these sites. A total of four sites were surveyed above and six below the Hatt's Ranch diversion which is the division between the upper and lower San Rafael River. The lower river was divided into 300 m sections; therefore, section 8 refers to the reach 2,400 m (8 reaches) below the Hatt's Ranch diversion (Figure 4). Fish were collected with a two anode Smith-Root 2.5 generator powered pulsator (GPP) electrofishing canoe used as a barge moving upstream. The GPP was typically set at 30 pulses per second D.C., and 40 – 60 percent of maximum range. The crew consisted of two people with an anode and a net, with one additional person pulling the canoe upstream while netting fish. Multiple passes were not attempted as population estimates were not an objective of the survey. ‘Three species’ were the primary target, however all fish netted were measured to the nearest millimeter (mm) and weighed to the nearest gram (g) and released. Surveys were completed between 9 August and 30 September 2011. We calculated native and non-native fish density by summing the species-specific fish catch for each site and dividing by the total effort of each reach. In order to assign each species an abundance rank, designations were assigned based on catch per unit effort (CPUE, fish/hr) These rankings were established by the Utah Three Species Team and were based on past results of statewide ‘three species’ monitoring. The abundance rankings were set as follows: Absent = no fish captured; Low = CPUE < 5 fish; Medium = CPUE 5-10 fish; High = CPUE > 10 fish.

Habitat Assessment

Ground based habitat assessment

Habitat parameters recorded at the 9 sites included: percent pool, riffle, and backwater, and water depth. Pools were identified as concave depressions (laterally and longitudinally), which spanned the thalweg (i.e., the line defining the lowest points along the length of a river bed or valley) and had a maximum depth of at least 1.5 times the pool tail depth. We flagged both the upstream and downstream ends of each pool and calculated pool area after measuring pool width (measured at its widest point). Riffles were identified as fast water areas with surface turbulence and relatively large substrate sizes (Hawkins 1993). We identified backwaters as near-shore areas with currents that typically flow counter to the prevailing current (Hawkins 1993). The percent of complex habitat by reach was calculated by summing the area of pools, riffles, and backwaters and dividing by the total area of each reach.

Collecting electrofishing and habitat data at nine sites was sufficient to document the importance of complex habitat to the ‘three species’ however we could not accurately assess the effects of the 2011 flood with our small data set. Due to our desire to assess large scale habitat change we decided to use remote sensing and GIS to evaluate changes to the river post flood and evaluate these changes in relation to our tamarisk removal project.

Post flood habitat assessment using aerial imagery

In order to test the effectiveness of our tamarisk removal project we developed the following study question:

Did the 2011 flood result in more change within our tamarisk removal site compared to an untreated site? To test this question we identified an untreated site and treatment site that satisfied the following criteria:

- (1) Tamarisk removal within the treatment site must have been completed before March 1, 2011 (prior to spring flood event).
- (2) The untreated site must be neighboring our treatment site and be comparable in size.

(3) As the quality of the imagery varies along the flight line, the imagery of the selected untreated site and treatment sites must be similar in quality to ensure our ability to accurately delineate changes in the river.

Based on the criteria listed above our Hatt's Ranch tamarisk removal site was selected for our treatment site and an equally sized area on BLM property immediately downstream from the treatment where tamarisk has not been removed was selected as our untreated site (Figure 5). Having the sites in close proximity to each other avoids evaluating habitat changes in response to tamarisk removal when the areas might have dissimilar fluvial geomorphologic processes. Both sites are below Hatt's Ranch diversion.

In August 2010, the Bureau of Reclamation (BOR) in collaboration with BLM and USU photographed the entire length of the San Rafael River from a helicopter at approximately 450 meters above ground level. In 2011 we contracted a second flight of the San Rafael River using an unmanned aerial system called Aggie Air. The 2010 (pre-flood) imagery was compared to the 2011 (post-flood) imagery to assess habitat changes attributable to the flood. ArcGIS was first used to delineate the active channel in the 2010 imagery. This 2010 active channel was then layered over the 2011 imagery so areas of change, specifically lateral movement of the river could be identified. Lateral movement of the river often results in more complex habitat such as backwaters.

After identifying areas of lateral movement (Figure 6) within both the untreated site and treatment site these areas were digitized using ArcGIS. Total area (m²) was then calculated for each individual lateral movement site (Figure 7). After calculating the area for each site, a mean was generated representing the average area changed by the 2011 flood. The mean was generated for both the treatment site and untreated site and tested for statistical significance using a Student's *t*-test ($\alpha = 0.05$).

Investigations into the importance of large woody debris

In 2010 USU recorded UTM coordinates for each individual pool, riffle, and backwater on the lower San Rafael River; the surface area of each habitat feature, as well as the presence of beaver activity within the section was also recorded. Beaver activity was noted if the section contained beaver dams which were separated from natural log jams by looking for wood material cut by

beaver. Inspection of high resolution imagery coupled with the spatial location of each complex habitat feature recorded on the ground provided the required data to evaluate spatial correlation between complex habitat and LWD piles.

The 2010 imagery was used to count each LWD pile along the lower San Rafael River. Buffers of 60-m (30 meters upstream and downstream) were created around each LWD pile (n=40) and at an equal number of random points generated using a random point GIS function (Figure 8). Using GIS, each complex habitat feature was clipped from within the buffers to determine the number, type, and area of habitat features associated with each LWD pile and random point (Figure 9). After generating a mean number of complex habitat features within both the LWD buffers and the random point buffers the means were tested for statistical difference (T-test). Mean area (m²) was also generated for each habitat type (pool, riffle, backwater) associated with the two buffer types and tested for statistical difference using a Student's *t*-test. All *t*-tests were performed at the 0.05 significance level.

In order to maintain consistency on how piles were selected the following criteria was followed:

- 1) The debris pile must span approximately 50 percent or more of the active river channel.
- 2) When multiple piles are located within 60 meters of each other (30 meters upstream or downstream) only one point was selected in a centralized location between the piles.
- 3) Woody debris piles formed near braided channels or islands were excluded from the analysis to avoid biasing the results. In this situation it would be unclear if the island or the resulting collection of woody debris at the top end of the island is having more influence on the hydraulic processes and the localized formation of complex habitat.

Results and Discussion

Fish abundance

Native fish were found in greater abundance in the upper San Rafael River. Native fish catch rates at the Fuller Bottom and Buckhorn sites were much greater than any other sites sampled, 21 (fish/hr) and 36.8 (fish/hr) respectively. Few native fish were captured in the lower San Rafael River below Hatt's diversion. Low densities of bluehead sucker (1.7 fish/hr) were found at sample site 8, approximately 2.4 km below Hatt's diversion. Low densities of flannemouth sucker (3.4 fish/hr) were found at sample site 15, approximately 4.5 km below Hatt's diversion. We did not find roundtail chub in the lower San Rafael River. Roundtail chub were found to be most abundant at the Buckhorn site in the upper San Rafael River (8.4 fish/hr). Native fish were absent from all four sites below site 15 (Figure 10). At the lower sites, common carp and channel catfish dominated the fish assemblage, while native fish comprised the majority of the catch in the upper river (Figure 11). Based on the abundance ranking defined in the methods, flannemouth sucker are the only native fish with a 'high' abundance ranking and that only occurred at the Buckhorn site. The greatest catch of bluehead sucker was at the Fuller Bottom site (5.3 fish/hr) which is considered 'moderate' abundance.

Habitat assessment

The 2011 flood provided a unique chance to investigate formation of complex habitat within our tamarisk removal project, furthermore we also have an opportunity to use our two image sets (before flood and post flood) to study how a large flood influences incorporation and distribution of LWD into the river. At the turn of the 20th century, the San Rafael River on the Hatt's Ranch was characterized by multiple threads, numerous bars, and a low width-to-depth ratio. The gentle sloping, non-cohesive banks as shown in a historic photo taken at the turn of the century (Figure 12-A) were easily reset during floods. Figure 12-B illustrates how dramatically the current active river channel has been reduced. The historic connection between the mainstem and floodplain provided opportunities for native fish to access food resources and refugia during floods. The highly mobile river also provided opportunity for LWD to fall or wash into the channel. Annual floods reorganized the template of the river.

Ground based habitat assessment

Sample sites in the upper San Rafael River were found to have a greater proportion of pool and riffle habitats. The Fuller Bottom site was comprised of 16.2 percent pool and 16.8 percent riffle habitat (Figure 13). The Buckhorn Draw site was comprised of 16.2 percent pool and 29.6 percent riffle habitat. Complex habitat is less available in the lower San Rafael River; however there are exceptions such as site 15 that was dominated by riffle habitat at 44.7 percent. Pools and backwaters were also present in site 15 (Figure 13). When comparing the percent habitat measured at our sites in 2011 to the data collected in years previous, we found that some sites changed very little while others, such as site 15, changed dramatically. Prior to the 2011 flood site 15 was devoid of both backwaters and riffles and held less than 1 percent pool habitat. After the 2011 flood this site shifted to predominately riffle habitat. Post flood, this site also provided pool and backwater habitat. Backwater habitat is the most limited complex habitat type in the lower San Rafael River. Backwater habitat was only found in two (sites 27, 173) of the 22 sites sampled by USU between 2007 and 2008 (Budy 2009). Due to the high run-off in 2011, backwaters were formed in sites 8 and 15 where they were not present before. Both sites 8 and 15 are within our tamarisk removal area.

Post flood habitat assessment using aerial imagery

After digitizing the 2010 active stream channel and layering this image on the 2011 channel, areas were identified where the river departed from its previous course, changing the shape of the river. Visually identifying these areas is relatively easy and was used as a metric to evaluate changes in the treatment site compared to the untreated site. A total of 15 areas were identified in the untreated site and 18 within the treatment. While the number of sites were similar, the magnitude of change was significantly greater in the treatment (mean = 408 m², SE =66.7) compared to the untreated site (mean = 153 m², SE = 42.9, T-test $P = 0.003$) (Figure 14). One affected area below highway 24, within the study treatment was as large as 1,256 m², while the majority (12 of 15) of the sites within the untreated area were less than 200 m² (Figure 14). On the ground inspection of these "areas of change" (lateral movement sites) have confirmed that many of these areas will provide increased backwater and pool habitat at certain flows (Figure 15). Our tamarisk removal project appears to have increased the potential for spring floods to diversify river habitat.

Investigations into the importance of large woody debris

The *t*-test indicates that the mean number of complex features within the LWD buffers (mean = 2.45, SE = 0.195) is statistically different from the mean within the random buffers (mean = 1.05, SE = 0.171) ($P < 0.0001$) (Figure 16). There were slightly, more backwaters associated with the LWD than random sites, however, there were many more pools and riffle habitats formed near LWD piles (Figure 17). Also, the pools inside the LWD buffers were significantly larger than those associated with the random buffers (T-test $P = 0.002$). The mean size of riffle and backwater habitat was not significantly different between LWD and random sites (T-test $P = 0.14$, $P = 0.94$ respectively) (Figure 18).

Inspection of imagery on the San Rafael River clearly shows how deflection of flow can alter the morphology of the river and create backwater habitat (Figure 19-A). The deflection of flow around LWD is a key mechanism for that facilitates the creation of back water habitats that is very limited on the San Rafael River. Figure 19-B shows a large scour pool below a LWD pile within the Tidwell Bottom sample reach. When sampled during 2010 this pool held comparatively higher densities of all 'three species', especially roundtail chub (Budy 2011).

An interesting pattern in LWD distribution is revealed when the piles are displayed on a map. Thirty-seven of the total 40 piles are found grouped together within a 19 km stretch around Hatt's Ranch (Figure 20). The 45 km below this aggregation is relatively devoid of LWD piles. Hatt's Ranch was the initial site selected for tamarisk removal in 2008 with removal being completed in 2009. Figure 21 shows a large quantity of wood piles stacked within the Hatt's Ranch during tamarisk removal. One explanation for the large concentration of woody debris around the Hatt's Ranch area is that tamarisk piles stacked within the floodplain were washed into the river during monsoonal flooding that occurred in the summer and fall of 2009. Figure 22 shows a lateral movement with tamarisk piles falling into the river as the banks erode around them. The imagery used to count the piles was captured during the summer of 2010, potentially detecting the washed in debris from the previous year.

During 2010 when USU quantified the habitat within the lower San Rafael River they also noted if beaver activity was present within each sample reach. Only 8 sites within the lower 64 km of

river were noted to have beaver activity. Six of the 8 sites noted with beaver dams were between section 5 and 79, which completely overlaps the LWD concentration (Figure 20).

To further investigate the idea that flooding had washed woody debris into the river, especially within our tamarisk removal sites, the 2011 Aggie Air imagery (post flood) was used to count and map the distribution of LWD piles. It was discovered that the 2011 flood flushed most LWD out of the river. Only four LWD piles were counted in the 2011 imagery. It should be noted that due to weather conditions the 2011 imagery is darker than and not as clear as the 2010 imagery. Also, some gaps occur in the 2011 imagery not allowing for complete survey of LWD piles. Even after accounting for these factors a decrease from 40 piles to 4 indicates a significant flush of LWD. A moderate flood might result in a different outcome as the flood would be great enough to wash in LWD but not so powerful that everything completely flushes out the system.

Recommendations

The electrofishing data collected for this report was limited in scope. We already have an abundant amount of information on the limiting factors, movement, and life histories for the native fish of the San Rafael River. A summary of the data collected by USU between 2007 and 2010 does however add greatly to the importance of the investigations into habitat change and LWD presented in this report. Because the USU research conducted on the San Rafael River has been so thorough the following discussion heavily cites the USU work while relating it to the importance of the new findings described in this report.

The greater abundance of native fish in the upper San Rafael River was expected as others have reported on the disparity in fish assemblage between the upper and lower San Rafael River (Budy 2011). While our surveys did not detect roundtail chub in the lower river we know a population does exist and not finding them in 2011 is likely due to the limited number of sites sampled. We know that populations of the ‘three species’ appear to be controlled through source-sink dynamics (Bottcher 2009), with the populations in the upper San Rafael River providing a source to the downstream sink populations. The main stem of the Green River also acts as a source for adult ‘three species’ that colonize the lower San Rafael River. Assessment of the available habitat provides insight into why native fish populations in the upper San Rafael

River are more robust. The Buckhorn Draw and Fuller Bottom sites held some of the highest proportions of pool and riffle habitat, these sites also have consistently provided higher catch rates of ‘three species’

Occurrence of age-0 and juvenile roundtail chub below the Hatt's diversion suggests the presence of upstream adults that are successfully spawning (Budy 2011). The shortage of complex habitat in the lower San Rafael River (Bottcher 2009) concentrates spawning activity, egg distribution, and rearing areas increasing the vulnerability of eggs and larval fishes to predation (Budy 2011). The loss of complex habitat can lead to increased predation pressure on native fishes. This occurs as non-native fish will also concentrate near these productive areas and prey upon the early life stages of native fish. Riffle, pool, and backwater habitats are sparsely distributed within the lower San Rafael River, and often separated by several km of shallow, sandy run habitat (Bottcher 2009). These sandy runs do not provide the appropriate substrate for primary and secondary production to establish (Death and Winterbourne 1995; Cardinale et al. 2002).

The presence of multiple year classes of flannelmouth sucker and roundtail chub during sampling conducted by USU upstream of the Hatt’s Ranch diversion, suggests these areas provide refugia, allowing these populations to endure despite no immigration since 1953. Removing the Hatt's diversion, and providing minimum in-stream flows, will allow fish to move into these refugia during low-flow conditions, likely improving survival and recruitment rates of the populations overall (Budy 2011). Removing the Hatt’s Ranch irrigation dam would aid in upstream dispersal of native fish allowing them to access the higher quality habitat in the upper San Rafael River. However, this would also allow non-native fish to colonize the upper San Rafael River where they are currently found in low abundance. The presence of non-native fishes in the lower San Rafael River has fundamentally altered the food web structure, increasing the length of the food chain and altering the potential for growth and maximum size of the native fishes (Walsworth 2011). Some non-native species, such as green sunfish, have escaped from upstream impoundments and colonized the upper San Rafael River. However, numerous non-natives that are found in the lower river have not established in the upper river due to the Hatt's diversion blocking upstream movement.

It would be feasible to chemically treat the lower 62 km of the river to remove all non-native fish from the Hatt's diversion to the confluence with the Green River. The economic feasibility and success of a chemical treatment would be greatly improved if the treatment could be scheduled during a drought year when large sections of the lower river dry up and fish are concentrated in isolated pools. Of course removing the non-native fish in the lower river would not be logical unless efforts were made to prevent the re-colonization of non-natives from the Green River. Discussions have been made on the possibility of installing a manned upstream barrier at the confluence that would prevent upstream passage of non-native fish while retaining the ability to move native fish into the San Rafael River. The cost or design of such a barrier is not known, however efforts have been made to secure funding to conduct initial engineering designs and cost estimates. A chemical renovation may be economically prohibitive; furthermore it may be too risky as its success hinges on the ability of the two sources (Green River and upper San Rafael) to repopulate the treated sections.

Future restoration efforts need to be focused on creation of complex habitat. Diversifying river habitat is a realistic goal as we have shown tamarisk removal can facilitate greater magnitude of change than untreated areas. Additionally, streams invaded by tamarisk have been shown to shift to poorer quality basal resources, which support a less plentiful and less diverse benthic invertebrate community (Kennedy and Hobbie 2004; Kennedy et al. 2005). Therefore, removal of tamarisk has the potential to support a more diverse benthic community as well as increase habitat complexity. The majority of the large pools in the lower San Rafael River are created by beaver dams or other large woody debris. In the future large woody debris or reintroduction of beaver into areas with adequate resources could facilitate the formation of pool habitat. Addition of dead tamarisk into the river as mechanical removal continues has also been discussed as an inexpensive alternative that would back up water and slow the incision process. Pool habitat in the San Rafael River also provides thermal refuge in the summer months when water temperatures can become extremely high. Addition of LWD into the river either by introduction of beaver or by mechanical means would encourage flooding that will support native vegetation as well promote pool and riffle habitat. Furthermore the deflection of flow created by LWD can create backwater habitat. It may be beneficial to add removed tamarisk directly to the river

rather than waiting for a flood event to wash it into the river as its important to have LWD piles set in place when high flows occur in order to redirect flow, creating backwaters and pools.

Establishment of native vegetation within tamarisk removal areas is critical to provide habitat for terrestrial wildlife as well as LWD for river habitat. Currently, the SRRC has used a water jet stinger to plant cottonwood poles throughout the 130 hectare (321 acre) Hatt's Ranch property. Plans are being made to plant willows and cottonwoods within the remaining 294.6 hectares (728 acres) where tamarisk has been removed. The water jet stinger drills the soil up to 3 m allowing for cottonwood cuttings to reach the water table increasing their survival and ability to compete with tamarisk. Ground water monitoring stations are being used to determine areas where water can be reached within 3 m of the soil surface. Water table monitoring needs to be expanded to determine suitable locations for future cottonwood pole plantings.

It's likely that the concentration of LWD around Hatt's Ranch could be attributed more to beaver activity than our tamarisk removal. The flood irrigation that has been in practice since 1953 might provide more abundant food resources (willow and cottonwood) in that area or there could be an attraction due to the hydrologic influences of the irrigation dam. Due to the importance of LWD on the San Rafael River and the concentration of beaver activity around Hatt's Ranch, if the diversion dam were removed to benefit native fish it would be important to monitor how beaver respond. It would be possible to release beaver marked in with PIT tags in unoccupied sections of the river and see if they eventually colonize Hatt's Ranch through the use of the existing PIT tag reader at Hatt's Ranch. Because beavers can travel overland a traditional radio-telemetry study might be necessary to track their movements and identify their preferred habitat on the San Rafael River.

Securing a minimum in-stream flow needs to be a top priority for agencies that oversee management of the San Rafael River. The exceptional water year in 2011 is currently being followed by one of the driest water years on record. This speaks to the unpredictability of desert streams in the American West. The long-lived fish of the Colorado River Basin have evolved ways to cope and survive in these harsh environments. However, the current inability to provide base flows to the lower San Rafael River hinders the persistence and population viability of the

native fish assemblage of the San Rafael River and tributary streams impacted by similar anthropogenic factors. Ideas for providing more stable flows in the Lower San Rafael River as well as how to deal with other factors limiting native fish populations are addressed in Part II.

Part II

Introduction

Past research and monitoring on the San Rafael River

Man-made modifications to both the channel and the floodplain have influenced the behavior of the channel and floodplain formation on the Hatt's Ranch. The Hatt's constructed levees in the 1970s to prevent the river from flooding their property. In addition, they straightened the river by filling the channel in two places, thereby cutting off two meander bends. The following excerpt from the USGS (1962) station analysis report describes the channel straightening on the Hatt's Ranch:

“During the period Nov 30 (1961) to May 15(1962) the owner of the land in the vicinity of the gage straightened the channel downstream from the gage by removing two large oxbows. This was accomplished by excavating a shallow channel across the gooseneck of one oxbow, then throwing a dike across the main channel just below it, and allowing the flow to erode the new channel down to grade. This was repeated on the second oxbow, the main channel being diked off on March 21. This caused the channel to scour down lower than it had ever been before, and made lowering of the gage necessary. Backwater at the gage caused by these operations resulted in some very large shifting-control adjustments during the period mentioned.”

This account provides anecdotal evidence that channel straightening may have facilitated incision of the river, thereby decreasing the ability of the main stem to connect with the floodplain and reducing the channel's capacity to contain large floods. Dendrogeomorphic results indicate that invasion of non-native vegetation increased the rate of both lateral and vertical accretion (Fortney et al. 2011). Previous studies have suggested tamarisk facilitates deposition of sediment by increasing the threshold of erosion and stabilizing an unconsolidated

fluvial surface (Dietz 1952; Pollen-bankhead et al 2009). River banks armored with non-native vegetation slow the water velocity during a flood increasing roughness (Griffin et al 2005). The reduced water velocities result in suspended sediment depositing on the floodplain surface.

Conducting annual monitoring on the San Rafael River is critical to our ability to gauge the long term success of restoration efforts and the status of native fish populations. In 2007 Utah State University established monitoring sites on the San Rafael River where electrofishing and habitat data were collected through 2010. At the conclusion of USU research projects on the San Rafael River, UDWR determined to continue annual monitoring efforts. In 2007 UDWR began systematic surveys of the river. These surveys coincided with additional work conducted by USU under contract with the Bureau of Reclamation. All bluehead sucker, flannelmouth sucker, and roundtail chub over 150 mm total length encountered during sampling by either the UDWR or USU were PIT (Passive Integrated Transponder) tagged and the location recorded. A stationary PIT tag reader was established by USU on UDWR property at Chaffin Ranch, approximately 4 km upstream from the Green River confluence. In April 2009, USU installed a second PIT-tag detector station approximately 60 km upstream from the Green River confluence, and 3.5 km downstream from the Hatt's diversion dam (Bottcher 2009).

From this PIT tag study we learned that downstream movement of flannelmouth sucker peaked in early May and accounted for 93 percent of all flannelmouth sucker detections from the PIT-tag antennae (Bottcher 2009). The PIT-tag antennae also detected significant movement from the endangered fishes of the Upper Colorado River Basin, including Colorado pikeminnow (*Ptychocheilus lucius*), razorback sucker (*Xyrauchen texanus*), and bonytail chub (*Gila elegans*). Between 2008 and 2010, 15 Colorado pikeminnow, 17 bonytail, 20 razorback sucker, and 4 “unidentified” fish (whose PIT-tag numbers indicate they are likely endangered species), were detected in the San Rafael River, this included 2 Colorado pikeminnow detected at the upper station. In addition to frequent use, the data shows that these fishes traveled great distances from initial tagging locations to the San Rafael River: one Colorado pikeminnow moved 282 km and one bonytail moved 333 km (Bottcher 2009). These findings demonstrate the frequent use and importance of small tributaries to the ‘three species’ as well as federally endangered fish.

The high runoff in 2011 damaged both the antenna arrays on the San Rafael River rendering them inoperable. In 2012 UDWR will be re-installing PIT-tag arrays at both sites. While some electrofishing will continue to evaluate population trends the utility of passively detecting fish makes it the preferred method for long term monitoring of the project. This technology should be used to: 1) investigate the role and importance of long-distance movement, 2) describe tributary and mainstream river usage among multiple species and life stages, 3) estimate survival and population size 4) reveal potential limiting factors, including the effects of dams and diversions (Budy 2011). Furthermore, use of a PIT tag array to monitor fish movements into the upper river after barrier removal would be a cost effective way to measure the effects of barrier removal on fish movement and utilization of the upper river. The first year after Hatt's diversion dam is removed the PIT-tag array could be moved up river to the Tidwell Bottom area approximately 16 river km from its current location to track movement of native fish into reaches upstream of the current fish barrier.

Genesis of the restoration project

Usually, a restoration project of this scale would be impossible simply due to the large number of landowners and other interests that would burden the process. This project is realistic because only four landowners are involved along the entire length of the river. The UDWR owns approximately 45 km of river. Two private landowners each own several km of river, and the remainder is managed by the Bureau of Land Management. Accruing \$1.2 million of funding from the Wildlife Habitat Enhancement Program initiated the project. The San Rafael River ranked high due to the potential to benefit multiple species and user groups. The restoration project was initially designed to be completed in multiple phases conducted over an estimated period of 10-15 years (San Rafael River Restoration Plan, UDWR 2008).

The basic objectives for restoration of the San Rafael River are to:

1. Manage for improved water quality and quantity sufficient to support a functioning ecological state and viable populations of native fish.
2. Re-establish connectivity throughout the San Rafael River by removing or modifying barriers to allow fish passage.
3. Restore connectivity between the stream channel and riparian zone.

4. Remove non-native fishes within the river and prevent further invasion through the use of fish screens on reservoirs, or migration barriers at the confluence of the Green River.

Discussion of past, present, and future of San Rafael River Restoration Project

The basic premise of restoration is active human intervention in nature, in order to initiate or accelerate the recovery of an ecosystem with respect to its health, integrity and sustainability. Managers need to be aware that restoration in terms of returning an ecosystem to its pre-disturbance condition is not always possible. When setting restoration goals a common technique is to look for evidence of how a system once functioned, or simply what it once looked like, and then working to return the system to this past reference state. The San Rafael River was once a wide, laterally unstable, multi-thread channel whose active bed was comprised of numerous bars. At present the river is confined by steep banks with a low width-to-depth ratio that prevents floodplain connectivity necessary to provide diverse habitat for native fish species. The driver of this change has been extensive water development coupled with decadal climate shifts (Fortney et al. 2011). In the early 20th century the median spring snowmelt flood lasted approximately 70 days and the peak was approximately $37.4 \text{ m}^3/\text{s}$ ($1,320 \text{ ft}^3/\text{s}$). In stark contrast, the median annual snowmelt flood for the period 2000-2008 lasted only 23 days, and the magnitude of the peak flow was approximately $9.8 \text{ m}^3/\text{s}$ ($345 \text{ ft}^3/\text{s}$), a respective 67 percent and 93 percent reduction from the early 1900's (Fortney et al. 2011). Restoration of the pre-disturbance flows in order to fully return the natural functioning of the river is not a realistic goal. However, re-establishment of some attributes of the ecosystem to a state that will provide increased benefit to native fish is certainly possible. In light of the increasing demands for water throughout the western states, rehabilitation of river habitat rather than restoration of historic flows is a more realistic way to approach habitat improvements on the San Rafael River. However, habitat improvements must be coupled with a minimum flow strategy as discussed below.

Working with water users to establish a minimum flow during drought periods, as well as periodically releasing water held in the upper storage reservoirs when feasible will not restore the

river to its pre disturbance state, however it will surely help enhance fish populations by preventing summer fish kills, creating river complexity, and maintaining native vegetation. Setting realistic goals for restoration of the San Rafael River is very important. Augmenting the current flow regime, reduction of non-native fish, and improvements to physical habitat are all achievable goals.

In the case of the San Rafael River, policy choices must be made to recognize which attributes can be at least partly restored. One logical place to start would be working with irrigation companies and reservoir managers within the drainage to coordinate spring time flushing flows. Even minor increases in the peak spring flows would enhance native fish habitat and survival. Furthermore, efforts to meet the first objective as stated above could be as simple as encouraging and seeking funding sources for efficient irrigation practices in the drainage. Currently, members of the SRRC are working directly with NRCS to identify water users in the San Rafael drainage that could benefit from improved irrigation practices. Shifting from flood irrigation to pressurized pipe can have considerable water savings allowing producers to irrigate more acreage with less water and return fewer salts and other dissolved solids to the river. For example, Hatt's Ranch which is the farthest downstream water user on the river can at times divert $0.21 \text{ m}^3/\text{s}$ ($7.5 \text{ ft}^3/\text{s}$) of water for irrigation. NRCS engineers estimate that converting to a pump irrigation system would save between $0.13\text{-}0.14 \text{ m}^3/\text{s}$ ($4.5 - 5 \text{ ft}^3/\text{s}$) of water that could then remain in stream for the benefit of native fish (Randy Bradbury, NRCS, *personal communication*). Water savings are especially critical in low water years such as the current year (2012) when flows in the lower river frequently drop below $0.42 \text{ m}^3/\text{s}$ ($15 \text{ ft}^3/\text{s}$). Furthermore, the recommended source of the water for a pressurized system would be shallow wells along the river. This system would eliminate the need for a diversion structure in the river itself. Therefore, installation of a pressurized irrigation system at Hatt's Ranch could potentially increase in stream flows as well eliminate the need for the Hatt's diversion. The Colorado River Salinity Control Program (CRSCP) administered by the NRCS has funding to install modern sprinkler irrigation systems that decrease salt loading by reducing over-irrigation and deep percolation that pulls salt to the surface.

Researchers have advised that removing barriers to upstream dispersal, diversifying habitat, and establishing minimum in-stream flows would likely increase the probability of persistence and population viability of the native fish assemblage of the San Rafael River (Budy 2011). The persistence of flannelmouth sucker and roundtail chub in the upper San Rafael River indicates that patches above the Hatt's Ranch diversion provide refugia, and population protection despite the lack of immigration since 1953. Removing this barrier and providing minimum in-stream flows will allow native fish to utilize the upper river and take full advantage of the more suitable spawning and rearing habitat (Budy 2011). Removing the irrigation dam or providing fish movement around the structure is feasible in the near future. Engineering will be required to determine the most cost effective and environmentally sound method for removal of the dam. While the dam currently provides the benefit of excluding non-native fish from colonizing the upper river it's likely that the benefits of restoring connectivity between the lower and upper San Rafael River would outweigh the costs. Increasing flows in the San Rafael River for the benefit of native fish will be highly political, therefore we should expect results to occur slowly and take considerable time.

In contrast, other improvements can be accomplished in the near future with high potential to improve conditions of the river by reversing down cutting at Hatt's Ranch and increasing connectivity of the mainstem to the floodplain. Some of these options are listed below:

1. Re-shape stream banks as necessary to create a more natural stream profile.
 - Mechanically reshaping the stream banks will likely become part of the project within the next five years. Strategically constructing backwaters along the river should be considered when finalizing design. Cutting banks down closer to river level will encourage flooding and formation of backwaters. Cottonwood poles and willow cuttings will need to be planted along these re-shaped areas to avoid invasion of weeds and promote a healthy riparian zone.

2. Construct grade control structures to mitigate the impact of prior channel down cutting.
 - A system of cross weirs placed in the channel to gradually increase the river channel approximately 2 meters through the lower end of Hatt's Ranch could be used to flood the two oxbow cutoffs by past modifications. This will allow the channel to reconnect with the historic floodplain and also reactivate the oxbows present on the property.
 - The flooding created by the grade control structures would assist the establishment of native willows and cottonwoods within our treatment area as the tamarisk removal surrounding these oxbows has already been completed. These oxbows have the potential to provide wetland areas for terrestrial and avian wildlife as well as rearing areas for native fish.

3. Introduction of beavers.
 - Section 1 of this report discussed the importance of LWD in providing complex habitat and refuge pools in the San Rafael River. Beaver activity has been cited as a major contributor of LWD to the San Rafael River. Promoting the introduction of beavers in the lower San Rafael River has the potential to slow down channel incision and encourage stream bank flooding that will further rejuvenate native vegetation in our tamarisk removal areas. Beaver introductions in many areas is controversial, especially when conflicts arise from beavers plugging up irrigation structures, or creating unwanted flooding in residential or recreation areas. One advantage the San Rafael River has in this regard is the lack of private ownership and irrigation needs below Hatt's Ranch. The live trapping and release of beavers in Utah is regulated by the UDWR and follows a management plan developed by multiple government agencies and stakeholders (Beaver Advisory Committee 2010). The stated goal of the plan is to maintain healthy, functional beaver populations in ecological balance with available habitat, human needs, and associated species. The

plan includes a list of approved sources, relocation sites, and outlines the process for translocation approval. We have initiated the process of receiving approval to introduce beavers to unoccupied sections of the San Rafael River if this action is deemed appropriate by the SRRC. The location of release sites should be focused on areas that will benefit the most from creation of pool habitat. For example, random forest modeling conducted by USU suggests that roundtail chub are predicted to gain the greatest benefit of pool enhancement if the reach 40 km below the diversion is restored and the least benefit if the reach 2 km below the diversion is restored (Walsworth 2011).

4. Work with land management agencies and Utah Department of Agriculture and Food to identify and implement best management grazing practices to improve the health of the riparian zone. Grazing is mentioned here because with any vegetation manipulation (i.e. removal of tamarisk and establish of native vegetation) management of grazing practices is a key factor in achieving project goals.
 - UDWR is currently working with the BLM to create a grazing management plan for the Lower San Rafael River. This plan will focus on implementing modern grazing practices such as establishing rest/rotation pastures, excluding cattle from sensitive riparian areas, and deferring grazing from tamarisk removal areas recently reseeded with upland vegetation. These changes in grazing practices will help maintain native vegetation where it currently exists and encourage re-establishment of native vegetation within our tamarisk removal sites.

Since the inception of the restoration project much progress has been made towards implementing the above strategies. In 2009 a private engineer company was contracted to conduct geological surveys around the Hatt's diversion. Information was gathered on the depth of siltation behind the dam, the location of bedrock beneath the dam, the condition and type of

bedrock, and the continuity of the bedrock (Professional Service Industries 2009). This information was desired to assist the UDWR in designing a fish passage or modifications to the dam. While more engineering is required, this report laid the ground work for the eventual removal of the dam or its modification to allow fish passage. While modification of the structure to allow selective passage of native fish while excluding non-natives would be ideal, the design for such a system is unknown. The SRRC has discussed the use of a fish weir that when manned could allow physically moving the native fish past the weir and removal of trapped non-natives.

The SRRC has also been working with Emery County to fund and implement a minimum flow study. Water users in Emery County are interested in identifying how much water needs to be provided to the lower San Rafael River in order maintain fish populations and help prevent listing the ‘three species’ under the endangered species act. The County Impact Board is currently funding Physical Habitat Simulation Modeling (PHABSIM) on the San Rafael River to evaluate changes in available fish habitat at different flows. Combined with the biological data, we will be able to estimate overall impact to fish populations as a result of changing flow regimes. The conclusion of this project will be an ideal time to work with the Emery County water users to develop a minimum flow recommendation as well as work towards establishment of an annual spring time release to simulate spring flooding.

Extensive removal of tamarisk has been completed on approximately 424.5 hectares (1,049 acres) of UDWR property on the lower San Rafael River. Initially UDWR contracted with NRCS to completely remove tamarisk within the boundary of UDWR property without knowledge of the areas where removal would be most successful. Using past imagery of the river at different flows we have been able to identify areas that have become inundated at various flow regimes of the past. In the future we can use this floodplain mapping to identify areas that have a higher potential for maintaining native vegetation after tamarisk removal. Furthermore, using imagery to map the current extent of native vegetation will allow us more strategically plan removal efforts in areas that can provide a seed source for natural regeneration of cottonwood. Removal efforts should not be attempted in areas that currently do not receive sufficient water to maintain native vegetation or are too far removed from sources of native seed (Figure 23). Prioritizing areas that can benefit the most from tamarisk removal is critical as we seek to maximize our project dollars in the future.

Currently, the cost of mechanical removal of tamarisk on the San Rafael River is approximately \$839 per hectare (\$339 per acre). In 2009 the cost was substantially less at \$690 per hectare (\$279 per acre). The price has increased due to rising cost of diesel fuel and heavy equipment operation. After initial removal, secondary treatments are necessary to control weeds, prepare soil for seeding, and purchase plant material or seed. The largest expense is planting cottonwoods and other native vegetation. Due to the high cost this work is only completed in specific areas where sources of native seed is inadequate, or in areas where cottonwood galleries are desirable for other wildlife. On the San Rafael River areas with a good mix of native vegetation prior to tamarisk removal have been allowed to reestablish naturally, greatly reducing costs. Ground water monitoring wells were also used to determine the proper depth to plant cottonwood poles. In most cases 3 m (10 ft) trees were planted 1.8-2.4 m (6-8 ft) deep to reach ground water. This deep planting method allows the young trees to reach water and establish their root system earlier giving them an advantage over any tamarisk re-sprouts on the surface. Table 1. summarizes the approximate cost for all treatments being conducted on the San Rafael River tamarisk removal project:

Table 1. Cost of tamarisk removal and post removal practices on the San Rafael River, Utah.

Treatment	Treatment Methods	Cost/Hectare	Cost/Acre
Archeological Survey	Contract with state archeologist	\$20	\$8
Mechanical Removal	320 CAT (or equivalent) with rotating grapple	\$839	\$339
Herbicide Application	Garlon 4, foliar and cut stump	\$171	\$69
Pile Burning	Pile/slash burning contracted out	\$111	\$45
Seed Purchase	Purchase of native seed mix	\$119	\$48
Harrow/Range Land Drill	Application of seed	\$67	\$27
Tree and Shrub Establishment	Cottonwood pole planting (10' plant stock) drilled ~ 8 ft to reach water table 15-20 trees/acre	\$3,834	\$1,549
Sub total (Without tree and shrub planting)	* Only specific areas are planted with cottonwoods	\$1,327	\$536
Total		\$5,161	\$2,085

While the cost of removal is high, tamarisk decreases the value of land in many ways. Tamarisk causes economic damage by consuming water resources that would otherwise have a higher economic value. While tamarisk occupies land, other land values such as livestock grazing,

wildlife habitat, and recreation can be reduced. Likewise, water used by tamarisk cannot be allocated to any other resource.

Tamarisk can be controlled using single or multiple methods, including chemical, mechanical, and biological techniques. The cost and success of tamarisk control techniques are variable based on local conditions; therefore it's important for the SRRC to research the most cost effective methods. Research into the most cost effective method for tamarisk removal on the San Rafael River resulted in the decision to use mechanical extraction methods. Extraction is a type of root crown removal technique which uses a large excavator (such as a CAT 320 or larger) to pluck individual trees from the ground (Figure 24). This mechanical process completely removes target trees and their root balls from the soil, along with a significant amount of their lateral roots. Using a tracked excavator allows access into the rough, rocky terrain present on the San Rafael. It also removes only the target species and does not require herbicide for the initial removal. An experienced operator can clear 1.2 to 3.2 hectares per day (three to eight acres). One drawback of this method is it can result in a significant level of soil disturbance and may require substantial re-vegetation efforts. The piles left after removal are also expensive to burn. One alternative to burning all tamarisk piles is to leave certain piles within the floodplain that will wash into the river during flood events. This method would reduce the cost of treatment and provide LWD for habitat formation. Considering the importance of LWD in creation of complex habitat discussed in Part I, allowing removed tamarisk to wash into the river would reduce the need of costly prescribed burns, and potentially create complex river habitat.

It is hoped that the release of the tamarisk beetle (*Diorhabda elongate*) on UDWR property will help control re-invasion of tamarisk after mechanical removal efforts are complete. Fuller Bottom was chosen as a tamarisk beetle release site by the Emery County Weed Department in 2005. Since 2005 tamarisk beetles have moved into the lower San Rafael naturally and have also been released at Hatt's Ranch. While the beetles have been seen aggressively attacking re-sprouts within the treatment area, it is not known if the beetles will effectively limit re-invasion. Further research into the density of tamarisk beetles required to control re-sprouts would be useful. The most appealing characteristic of the tamarisk beetle is that it inflicts no damage to

native plant populations. If biological control continues to progress, it could soon become a primary method for tamarisk control and post treatment maintenance. If this is the case, the economic and ecological advantages over other methods will be significant, including a reduced need for herbicide, no soil disturbance, and long term cost effectiveness. In some areas where beetles have been released native plant species seem to be thriving possibly due to improved light penetration to the understory and/or reduced competition for resources (personal observation).

While all biological control programs start with the hope of being successful this is not always the case. Failure in biological control can be attributed to the failure of an unsuccessful agent in which the density of the target weed has not declined. Agents fail when they do not become established, they become established but remain at low density or geographically restricted, or they become established and reach high density, but do not have a negative impact on the density of the target weed. An example of well established but ineffective agents are the gall flies (*Urophora quadrifasciata*) and (*U. affinis*) introduced to North America on diffuse knapweed, (*Centaurea diffusa*), which established and spread rapidly but did not reduce weed density (Harris 1980a; Harris 1980b; Myers *et al.* 1988). Cinnabar moth, (*Tyria jacobaea*) introduced as a control agent on tansy ragwort, (*Senecio jacobaeae*), also became common at many sites of introduction, but had little impact on the weed density (Myers 1980, McEvoy *et al.* 1993). In these cases the target are resilient to the type of damage caused by the biocontrol species released.

Since its release in 2004 the tamarisk beetle has reached high population densities and greatly expanded its geographical distribution (Meng *et al.* 2012). The tamarisk beetle has also been effective in defoliating large stands of tamarisk along entire river systems. What remains uncertain is if the tamarisk beetle will be able to kill the plant and significantly reduce their densities. To kill a tamarisk plant without chemicals or removal of the total plant and roots from the ground is difficult. However, repeated defoliation of the plant leads to a reduction in photosynthesis and food for the plant and root system. Each defoliation should result in a decrease or dying off of some of the root mass. As this happens repeatedly and the plant isn't allowed to grow new foliage and retain it for an extended length of time, it becomes possible to

kill the plant. Estimates on die off of the tamarisk due to defoliation via the beetle suggest 3 to 5 years, but this could be longer or shorter depending on the size of the plant and its root mass, how often it's defoliated and how limited the time is that the plant retains foliage (Myers 2000).

Another type of failure that can occur in biological control is the attack of non-target plants by the introduced species. In this situation the unwanted side effects associated with the attack of non-target hosts may counteract the environmental value of reducing density of the weed (Louda, et al. 1997). While the tamarisk beetle was studied for 20 years before its approval for release some still worry that the beetle could at some point switch from tamarisk to a native form of vegetation. Concerns exist that certain species of birds that have adapted to using tamarisk could be negatively impacted if tamarisk is significantly reduced and not replaced with native riparian vegetation (Sogge et al. 2008). As previously mentioned, the economic benefits of controlling tamarisk with a bio-control are great considering the high cost of chemical or mechanical treatment, however it's likely that successful control of tamarisk on the San Rafael River will need to continue the combination of chemical, mechanical, and biological control methods. It's also important to keep in mind that control of tamarisk could lead to unforeseen impacts. For this reason UDWR initiated a bird survey at Hatt's Ranch to monitor bird response to tamarisk removal (Wright 2010).

Recently researchers at USU have developed a model that will help prioritize tamarisk removal or other physical habitat improvement (Walsworth 2011). Implementing the results of this model in order to provide cost savings and ensure that habitat restoration is conducted in areas that will provide the most benefits to native fish is critical. Part I of this report provides evidence that removal of tamarisk can increase habitat diversity after a flood event, however, encouraging long term quantity and distribution of complex habitat will likely require a combination of: 1) the removal of non-native vegetation; 2) the restoration of channel-forming flows; and, 3) active (mechanical) channel reconfiguration.

Restoration of the channel and floodplain of the San Rafael River requires a sound scientific understanding of the geomorphic and ecological history of the river. With the knowledge gained since the implementation of the San Rafael River restoration we are close to obtaining all the pieces of the puzzle necessary to scientifically manage a large scale project that will have lasting

benefits for the unique assemblage of native fish of San Rafael River. Improper water development for agricultural and municipal use is a threat to populations of native fish in the San Rafael River. In order to improve conditions for native fish, or at least maintain their current populations, Emery County will need to incorporate native fish in their future water development plans and practices.

The United States Fish and Wildlife Service (USFWS) is responsible for administering the Endangered Species Act (ESA). The purpose of ESA is protect endangered and threatened species and the habitat on which they depend; as well as take steps to recover these species. Species at risk (i.e. drastic population declines) cannot receive protection under ESA until it is placed on a Federal list of endangered and threatened species. The listing process follows legal procedures and review of biological information to decide if a species warrants protection under the ESA.

A species can be added to the list when it is determined to be endangered (faces imminent extinction) or threatened (likely to become endangered in near future) due to any of the following factors:

- The present or threatened destruction, modification, or curtailment of the species habitat or range;
- Over utilization for commercial, recreational, scientific, or educational purposes;
- Disease or predation;
- The inadequacy of existing regulatory mechanisms; or
- Other natural or manmade factors affecting the species survival.

The USFWS often initiates listing proposals, however the listing process can start with a petition from any group with adequate biological data. The roundtail chub (*Gila robusta*) has been petitioned for listing under the Endangered Species Act in the Lower Colorado Basin. If roundtail chub were listed in the Upper Colorado Basin, the San Rafael River could be listed as critical habitat for recovery of the species. Federally listing one of the ‘three species’ under the Endangered Species Act has the potential to affect Emery County water users. Listing and critical habitat designation trigger the ESA provisions that may interfere with private

property use. Principal among these is Section 9, prohibiting specific acts in relation to endangered animals and plants. Section 9's prohibitions apply to both private and public land, regardless of whether critical habitat has been designated. For endangered animals, prohibited acts include (a) the "taking" of an animal, (b) possessing, selling or transporting an animal obtained by an unlawful "take," (c) transporting an animal interstate in the course of commercial activity, and (d) selling an animal interstate, or importing/exporting. While these restrictions would not affect Emery County directly as no one is in the business of taking, collecting, or selling 'three species', other definitions of "take" and "harm" could directly apply to Emery County.

The term "take" is a key ESA concept, and should not be confused with Fifth Amendment takings. It is defined by ESA statute to include a wide variety of acts that adversely affect the species. Of importance to the ESA's impact on private land owners, the USFWS defines "harm" to include indirect harm to listed species members through significant habitat modifications. This agency definition has been upheld by the Supreme Court as a reasonable interpretation of the statute (*Babbitt v. Sweet Home* 1995). Therefore, the dewatering of the San Rafael River during drought years could reasonably be viewed as "harm" to the species and the authority of the ESA could then regulate water management in the drainage. In fact, a very similar situation occurred in California and Oregon in 2001. During a drought in 2001, the U.S. Bureau of Reclamation terminated delivery of irrigation water from its Klamath Project in northern California and southern Oregon, to ensure lake levels and river flows sufficient to protect three fish species listed under the ESA. Thirteen agricultural landowners and 14 water, drainage, or irrigation districts in the Klamath River Basin, all had been receiving water from the Project.

While water allocation is always a contentious issue in the West, if providing water helps prevent the listing of the 'three species', local residents and governments would realize an important long-term benefit of conservation, namely the ability to maintain the levels of land use and recreational activity they currently enjoy. Other provisions exist under the ESA for land owners and water users to avoid listing such as the development of Candidate Conservation Agreements (CCA's) which may remove threats facing candidate species. Also, Safe Harbor Agreements (SHA's) provide regulatory assurances for landowners who voluntarily aid in the recovery of

species. Taking these proactive measures to protect ‘three species’ should be explored whenever feasible. In addition to the native fish benefits, this project has the likelihood of improving the human environment by reducing losses to flooding, improving grazing conditions on BLM properties, improving water quality, and increasing recreational use of the river.

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Figure 1. Aerial image of the Hatt's Ranch irrigation diversion (photo credit: Craig Walker) on the San Rafael River Utah. Most native fish occur above the diversion which is a complete barrier to upstream fish movement. The Diversion separates the lower and upper San Rafael River and prevents native fish from reaching higher quality habitat found in the upper San Rafael River; however, it has also kept non-native fish from colonizing the upper reaches where they would predate and compete with native fish. Providing passage around the diversion would benefit long migrating species such as flannelmouth sucker and Colorado pikeminnow, however this action would also open the upper river to invasion of non-native fish.

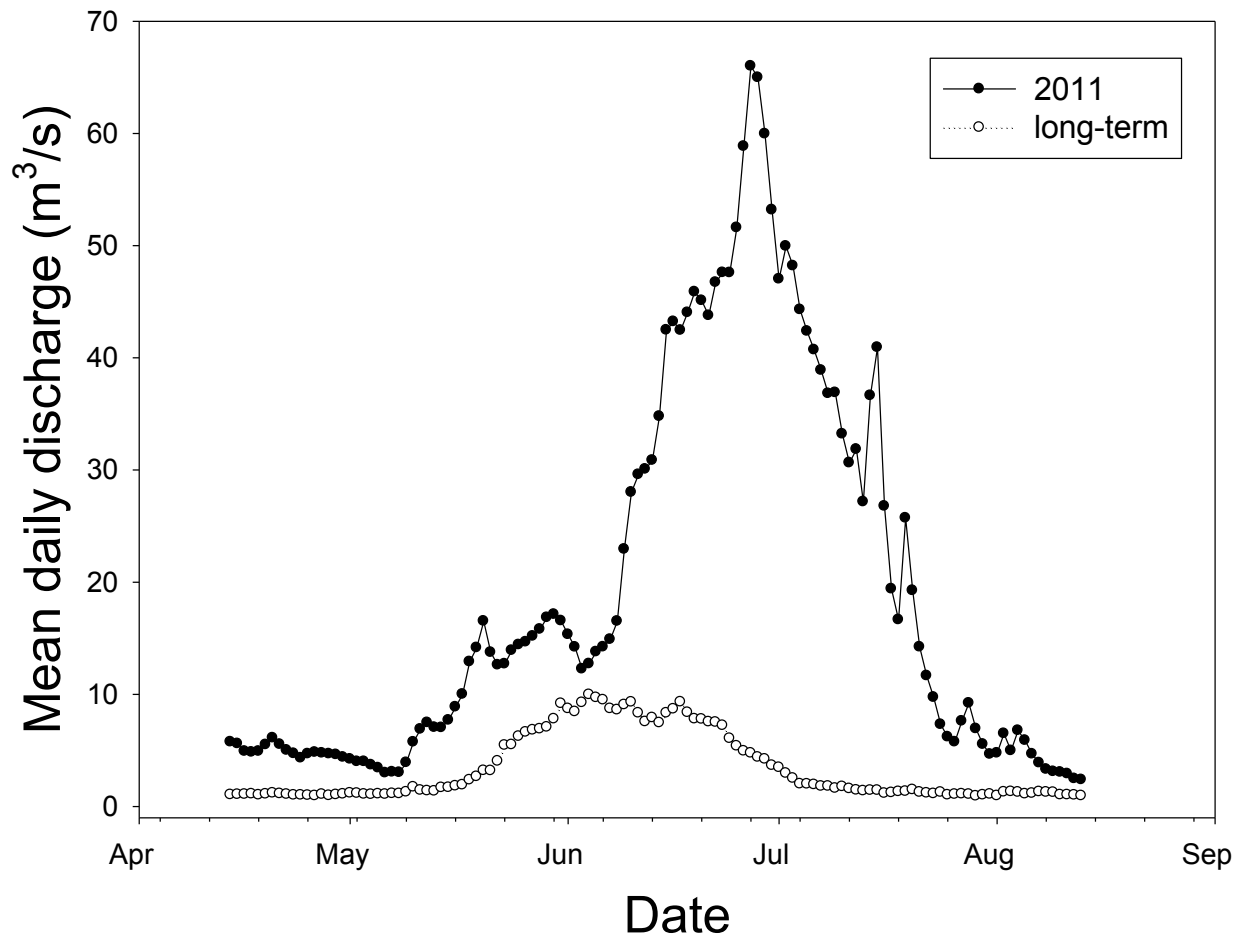


Figure 2. Measured discharge of the San Rafael River, Utah in 2011 (closed circles) compared to mean daily discharge over the period of record (1910-1918 and 1946-2012; open circles).

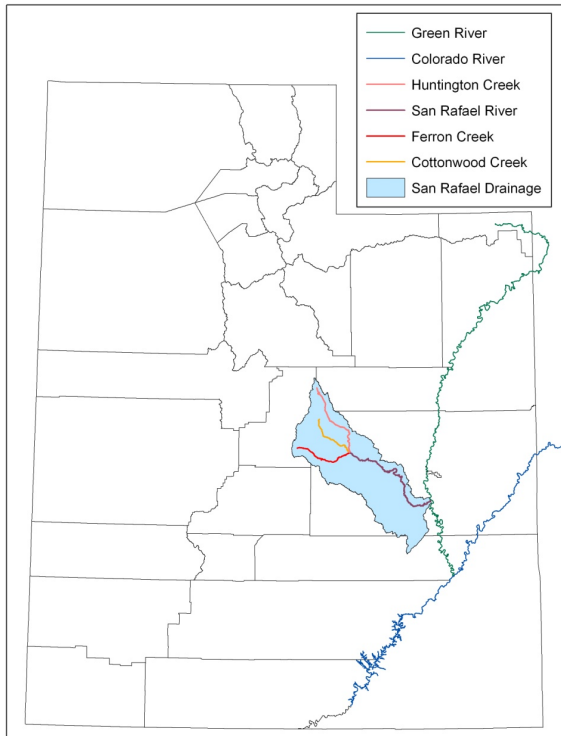


Figure 3. Map of the San Rafael Drainage. Map illustrates the merging of the three tributaries (Ferron Creek, Cottonwood Creek, Huntington Creek) to form the San Rafael River which joins with the Green River in Emery County, Utah.

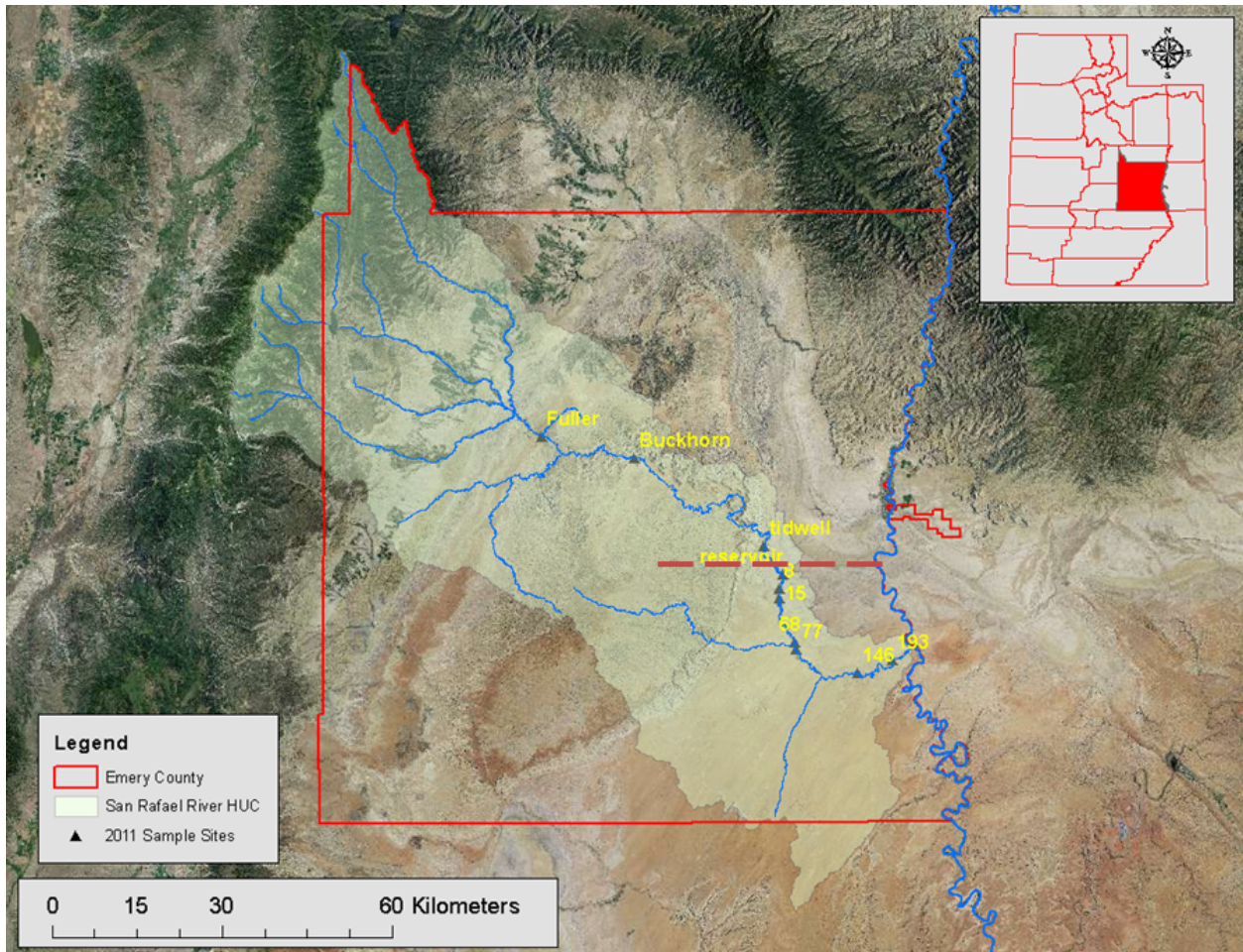


Figure 4. Location of 10 sample reaches surveyed in 2011 (black triangles). The red dashed line shows location of Hatt's Ranch diversion, and the division between the upper and lower San Rafael River. The lower river was divided into 300 m sections; therefore, section 8 refers to the reach 2,400 m (8 reaches) below the Hatt's Ranch diversion.

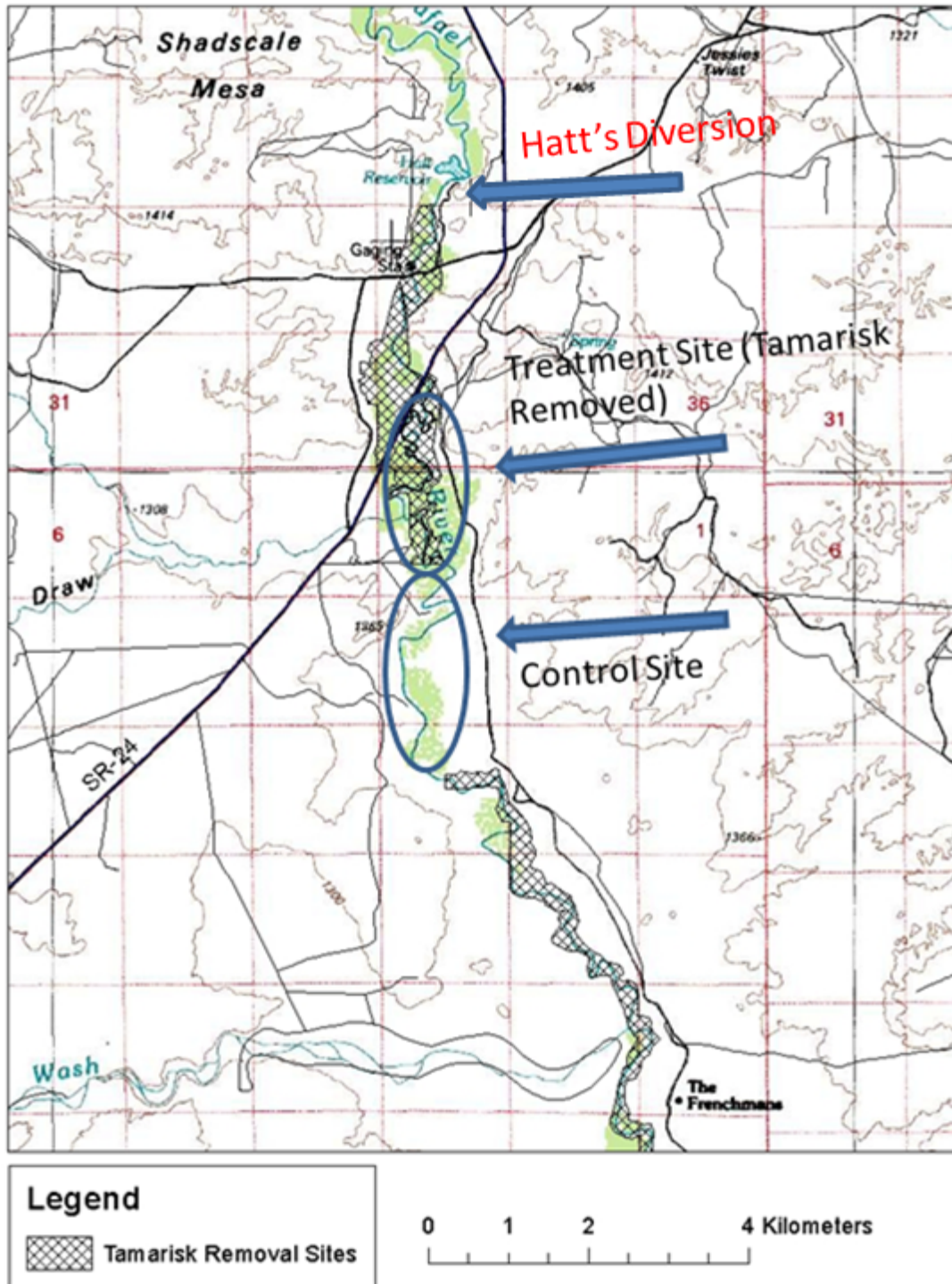


Figure 5. Location of the untreated site (control site) (blue oval) and treatment site (cross marked area inside blue oval), the untreated site is located between the Hatt's Ranch and Frenchman Ranch tamarisk removal projects.



Figure 6. Before (above) and after imagery of the tamarisk removal treatment area. Yellow circles represent fixed coordinates, blue arrows indicate areas showing post-flooding lateral movement. Post-flood imagery shows the extensive tamarisk removal in this area (dark circles in bottom image are slash piles that were later burned).



Figure 7. Lateral movement (red hatched) of San Rafael River Utah from 2011 flood; grey cross marked section indicates the 2010 active channel. GIS was used to calculate the area of lateral movement sites. The river was flooding when this imagery was captured (2011, National Agricultural Imagery Program, NAIP), and is not the aggie air (post flood) imagery used to delineate the lateral movement as seen in Figure 6.

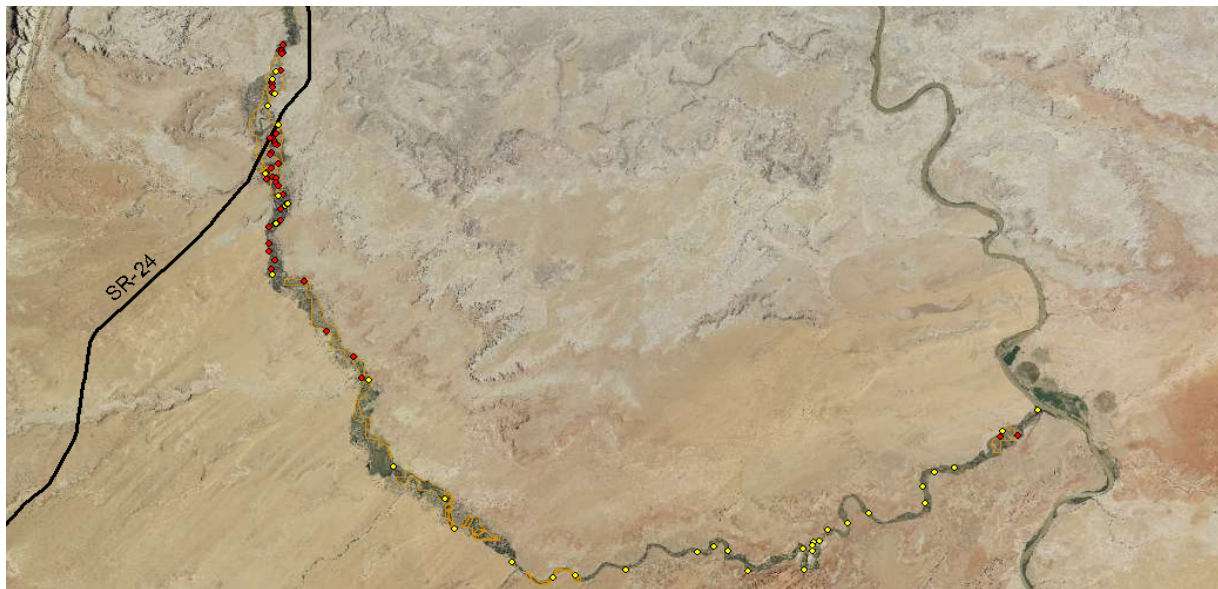


Figure 8. Location of LWD piles (red circles, n=40) and the random points (yellow circles, n=40) used to create random buffers along the lower San Rafael River Utah.

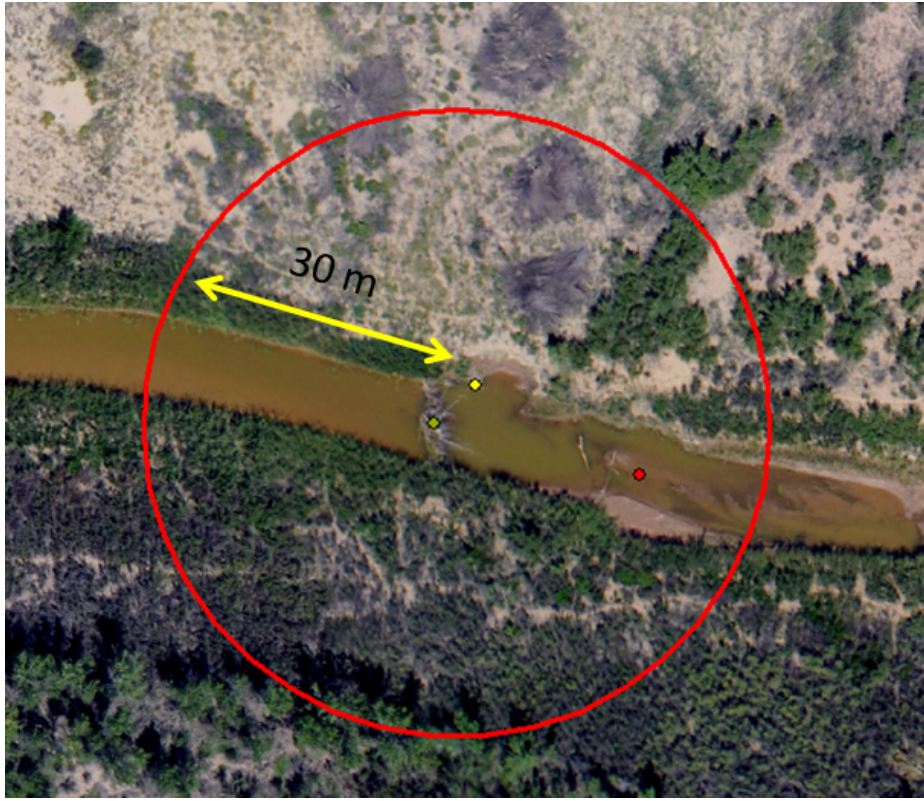


Figure 9. Close up view of a LWD pile buffer (red open circle) showing complex habitat features; yellow circle indicates a backwater, closed red circle is in riffle habitat and the green circle indicates the top of a pool. Buffers were used to select only the habitat near the large woody debris (LWD) pile (30 m upstream, and 30 m downstream) Type, number and area of features within buffers were summarized.

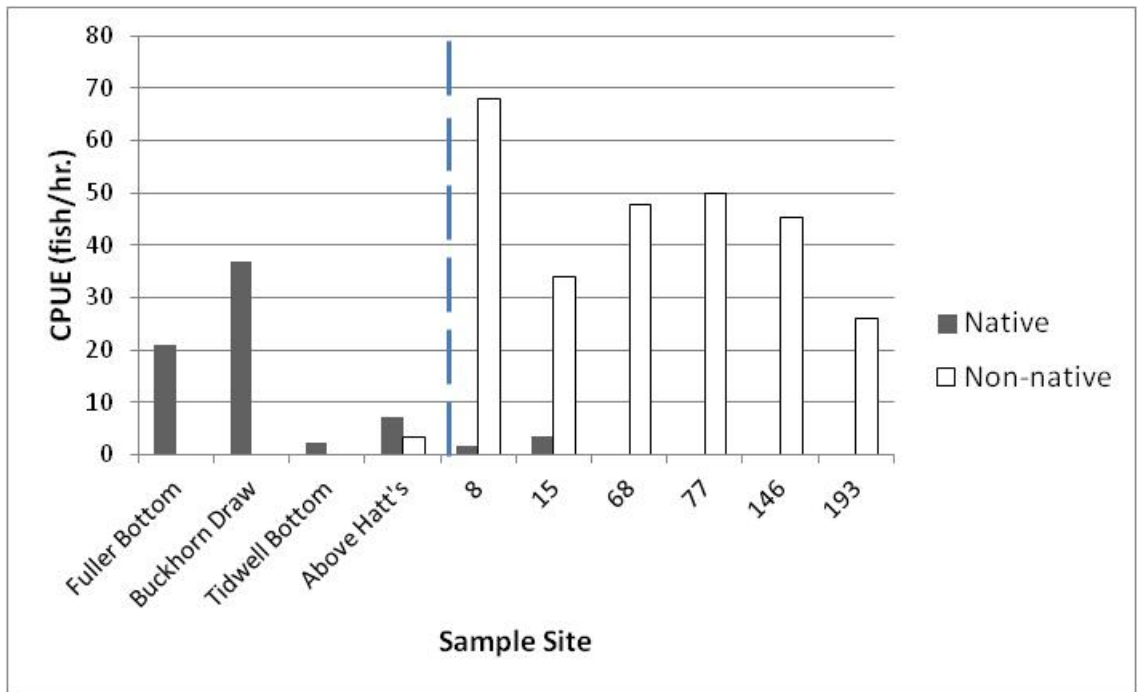


Figure 10. CPUE of fish captured during electrofishing surveys on the upper and lower San Rafael River Utah. The blue dotted line represents the location of the Hatt's diversion dam; upper San Rafael River sites are left of the line. Native fish were not captured below site 15.

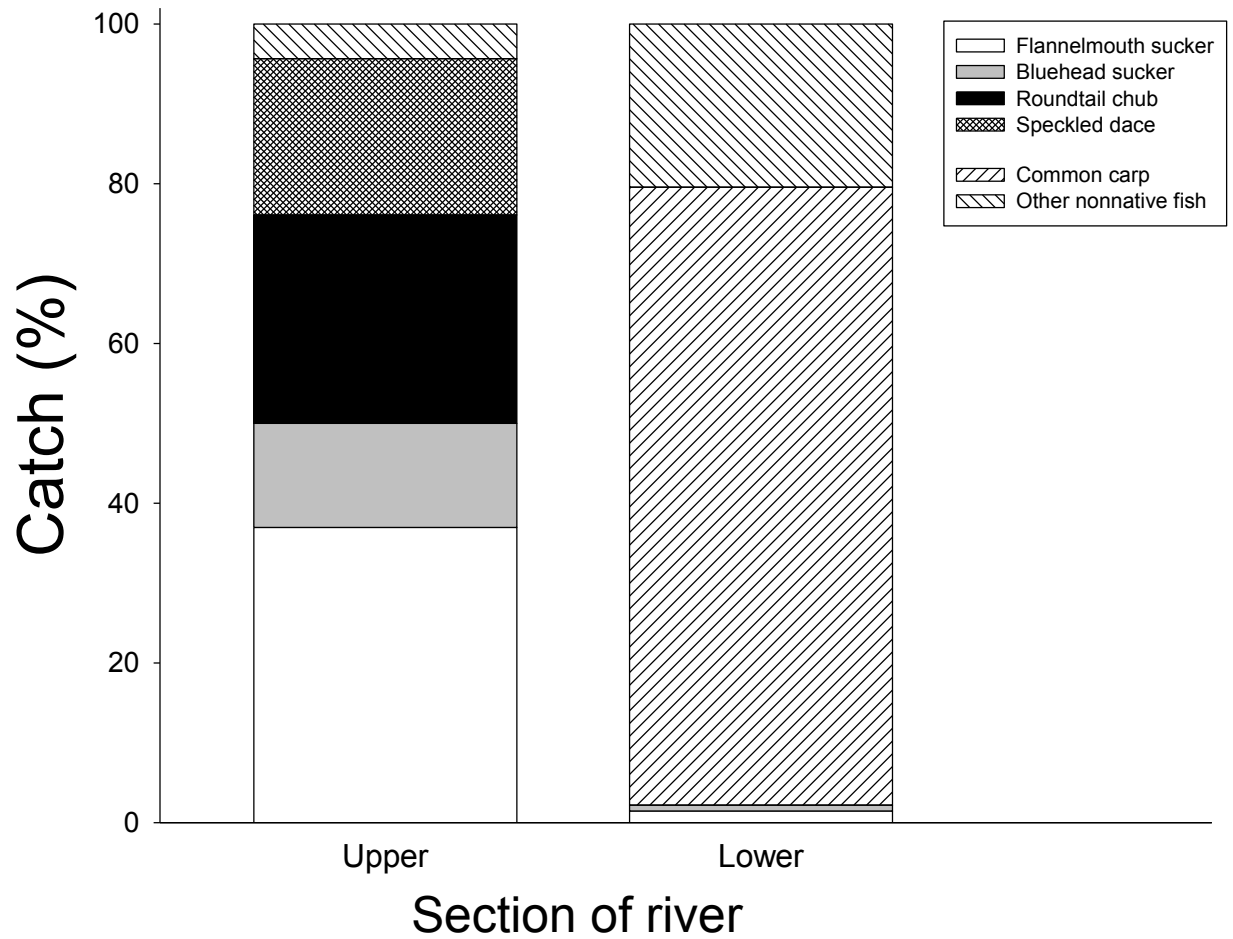


Figure 11. Percent catch of fish captured in the upper San Rafael River Utah (left) compared to the lower San Rafael River (right) during 2011 electrofishing surveys. The four native species: flannemouth sucker, bluehead sucker, roundtail chub, and speckled dace are shown individually. Non-native common carp are shown individually, and all other non-native fish are shown together.

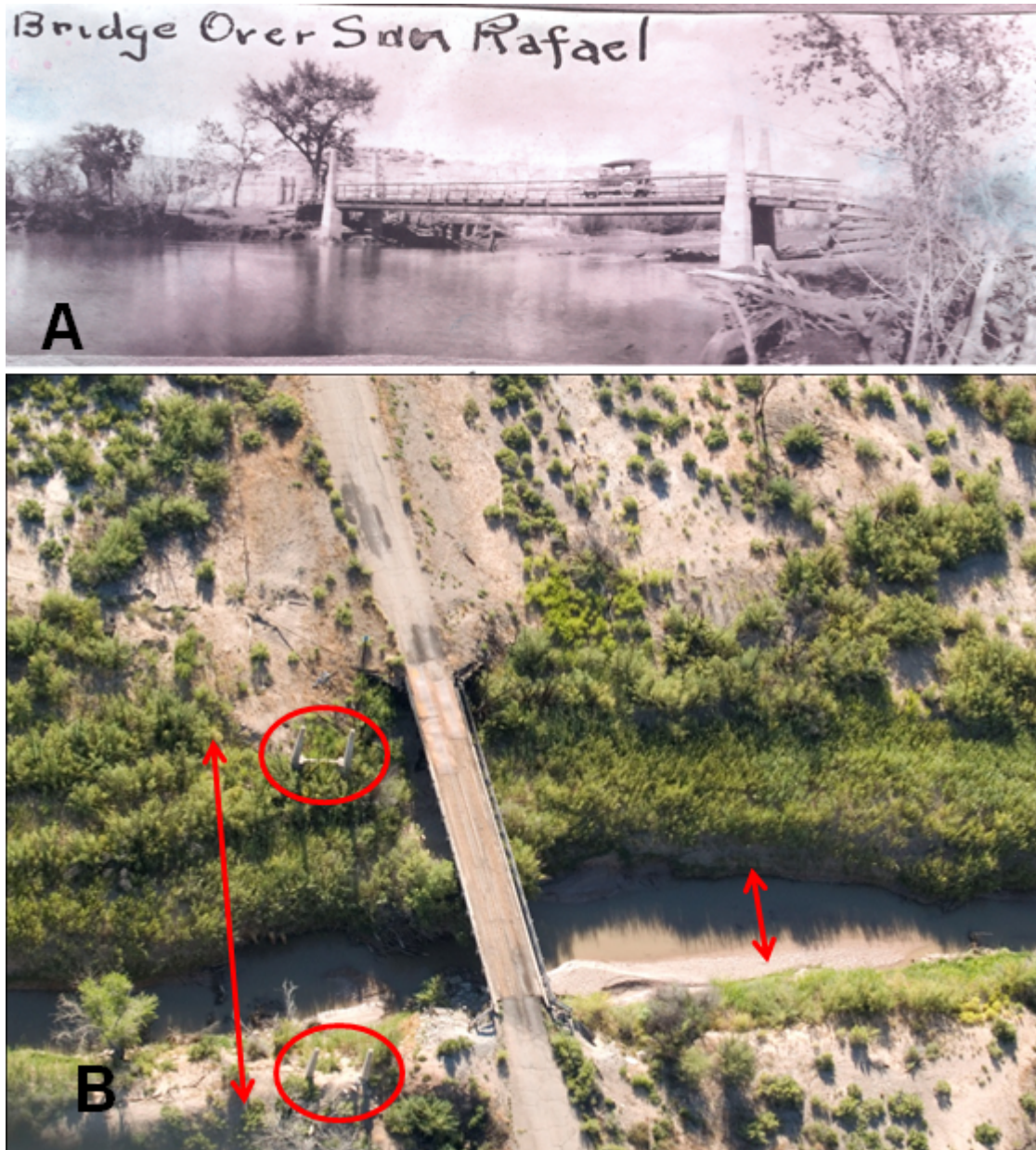


Figure 12. Photograph A. San Rafael River at the old Highway 24 bridge near Hatt's Ranch, depicting typical channel conditions in the early twentieth century (between 1921-1924, Credit: Floyd Kelly). This historical photo shows a wide and shallow channel with large woody debris collecting along the river bank. Photograph B. Illustrates the current river conditions on the San Rafael River. The red circles indicate the old vertical bridge supports that are present in photograph A. Notice that in photograph A the river extended out past these vertical supports. The red arrows indicate the historic (left) and current (right) active river channel.

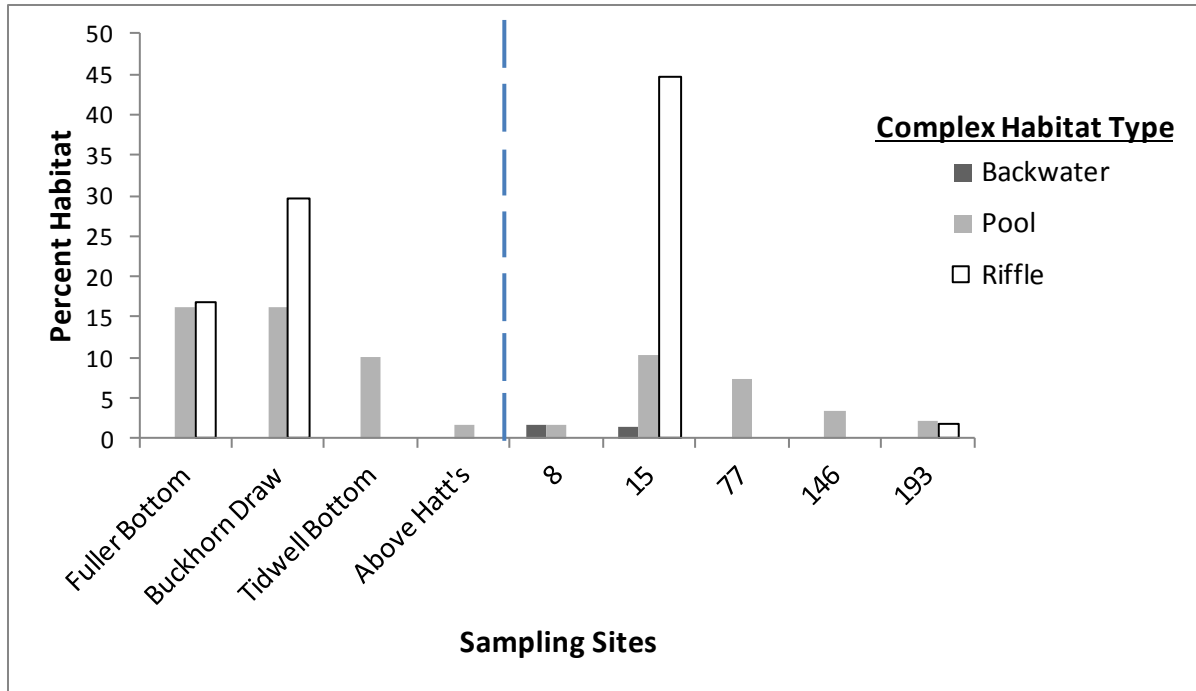


Figure 13. Complex habitat types at 9 sample sites on the San Rafael River Utah in 2011. Fuller Bottom is the furthest upstream site and 193 is the furthest downstream site, near the Green River. The blue line indicates location of Hatt's diversion dam and the division of the upper (left of the blue line) and lower river.

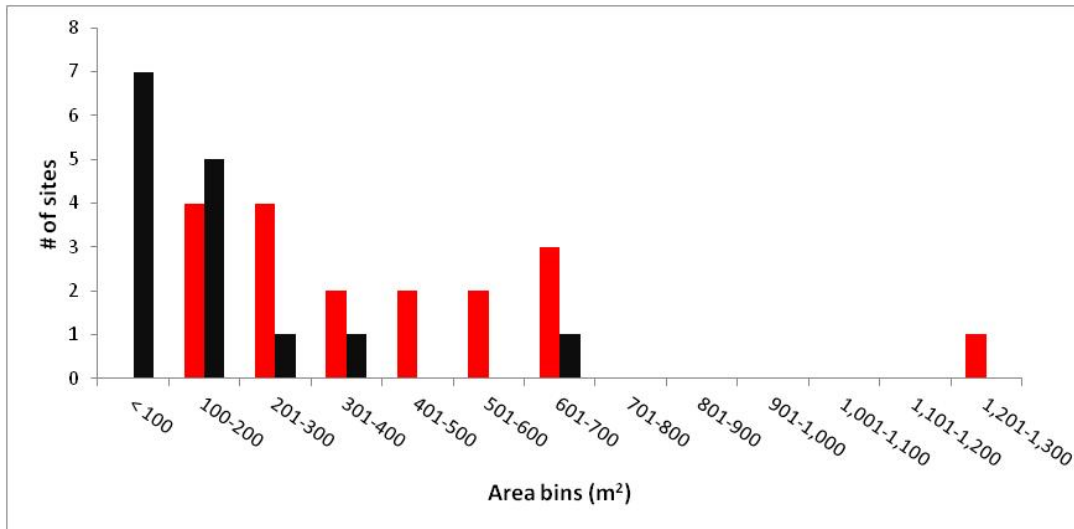


Figure 14. Sites showing lateral movement in response to 2011 flood on the San Rafael River Utah; red bars indicate treatment areas where tamarisk was removed, black bars indicate untreated areas. While the number of treated and untreated sites showing lateral movement were similar ($n=18$ treated, $n=15$ untreated) the area affected was significantly greater in the treatment (mean = 408 m^2 , SE = 66.7) compared to the untreated site (mean = 153 m^2 , SE = 42.9 , T-test $P = 0.003$).



Figure 15. Lateral movement within our tamarisk treatment site on the lower San Rafael River Utah. Photograph A. Shows the typical steep banks and narrow channel that forms a ditch like river lacking habitat complexity. Photograph B. Shows a lateral movement site within our tamarisk treatment area. The blue oval shows a tamarisk pile falling into the channel that was a considerable distance away before the channel migration. The red arrow shows the river edge at base flows; when the river rises slightly this area will flood creating habitat complexity.

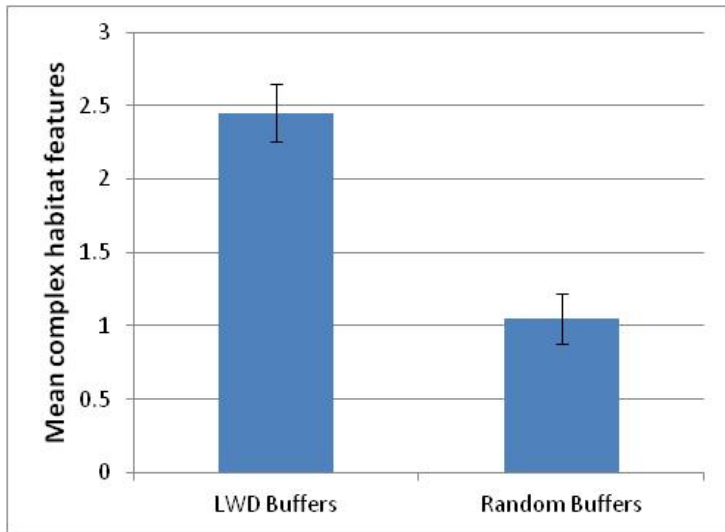


Figure 16. Mean number of complex habitat features (backwaters, riffles, pools) within LWD buffers (mean = 2.45, SE = 0.195) and random buffers (mean = 1.05, SE = 0.171). Standard error bars are displayed on graph (T-test, $P < 0.0001$).

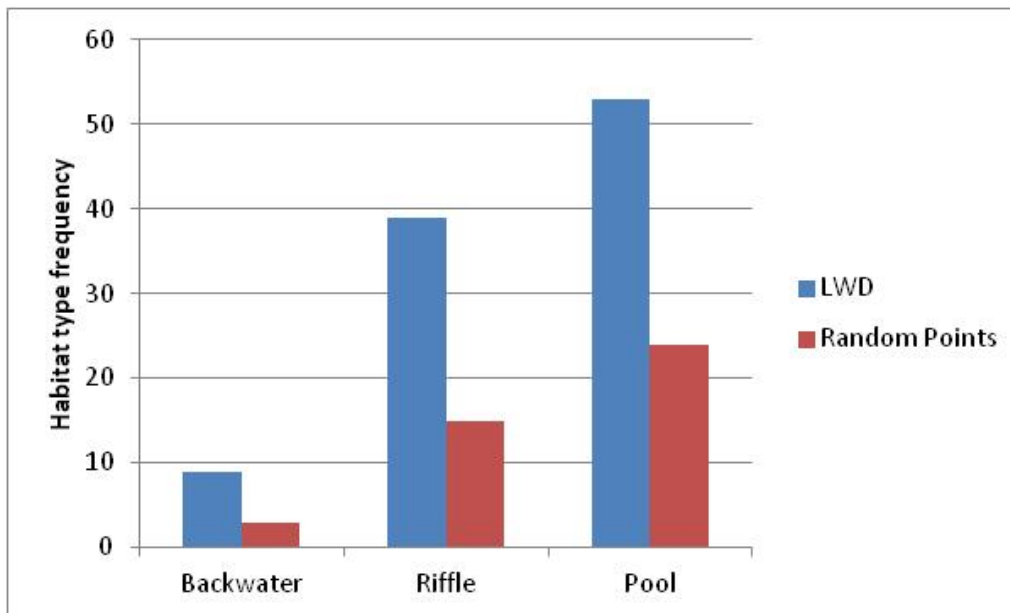


Figure 17. Number of complex habitat features sorted by type (backwater, riffle, pool) within LWD buffers (blue bars) and the random buffers (red bars) on the San Rafael River. All three habitat features occurred more frequently around LWD piles.

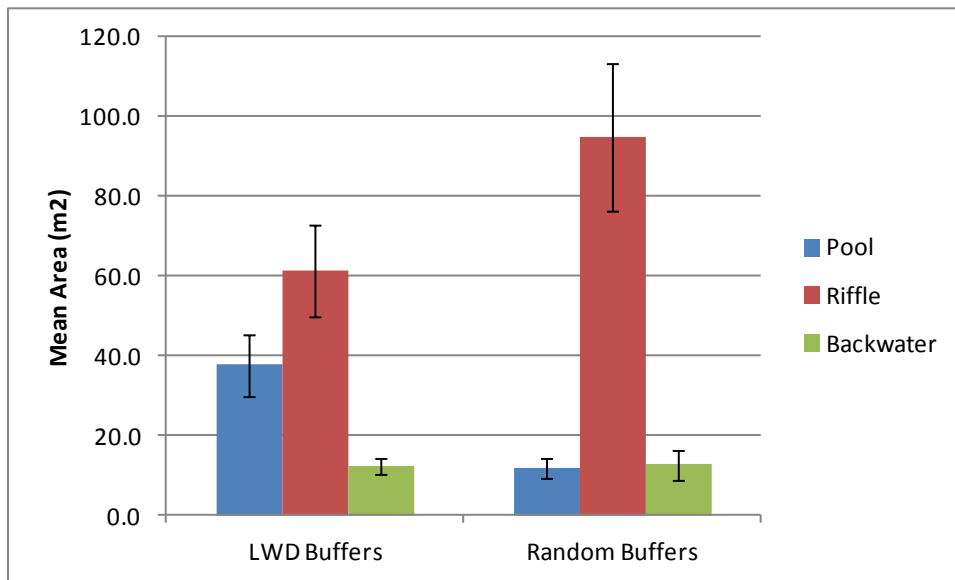


Figure 18. Mean area of complex habitat associated with LWD buffers and random buffers. The mean size of pools around LWD was significantly greater than at random sites (T-test $P = 0.002$). Mean size of riffle and backwater habitat was not significantly greater at random than LWD sites (T-test $P = 0.14$, $P = 0.94$ respectively). Standard error bars are displayed on graph.

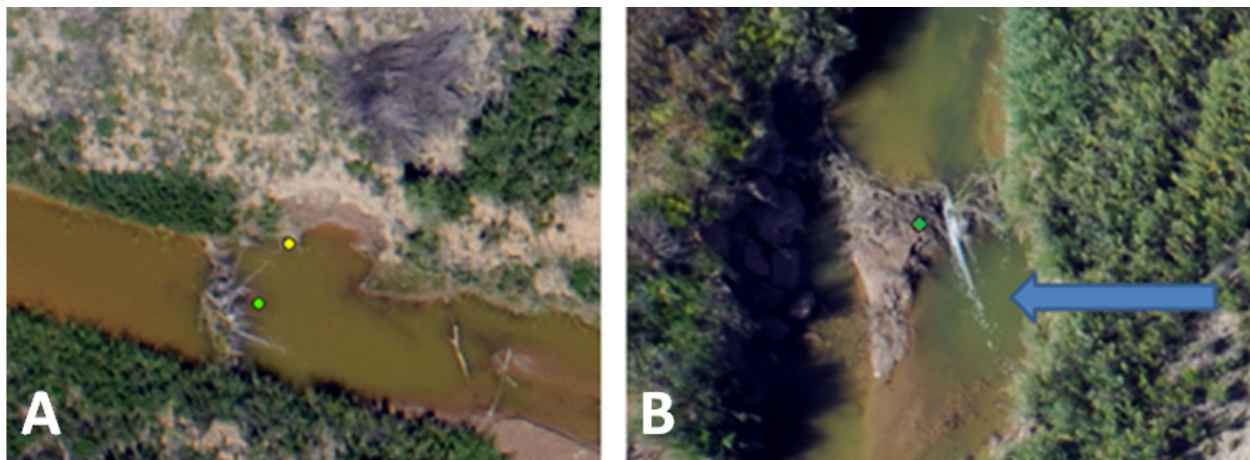


Figure 19. Creation of important fish habitat through the use of large woody debris (LWD) piles (green circles) on the San Rafael River, Utah. A. Demonstrates a backwater (yellow circle) created by a deflection of flow around a LWD pile (green circle). B. Illustrates a large scour pool (blue arrow) created by a LWD pile.

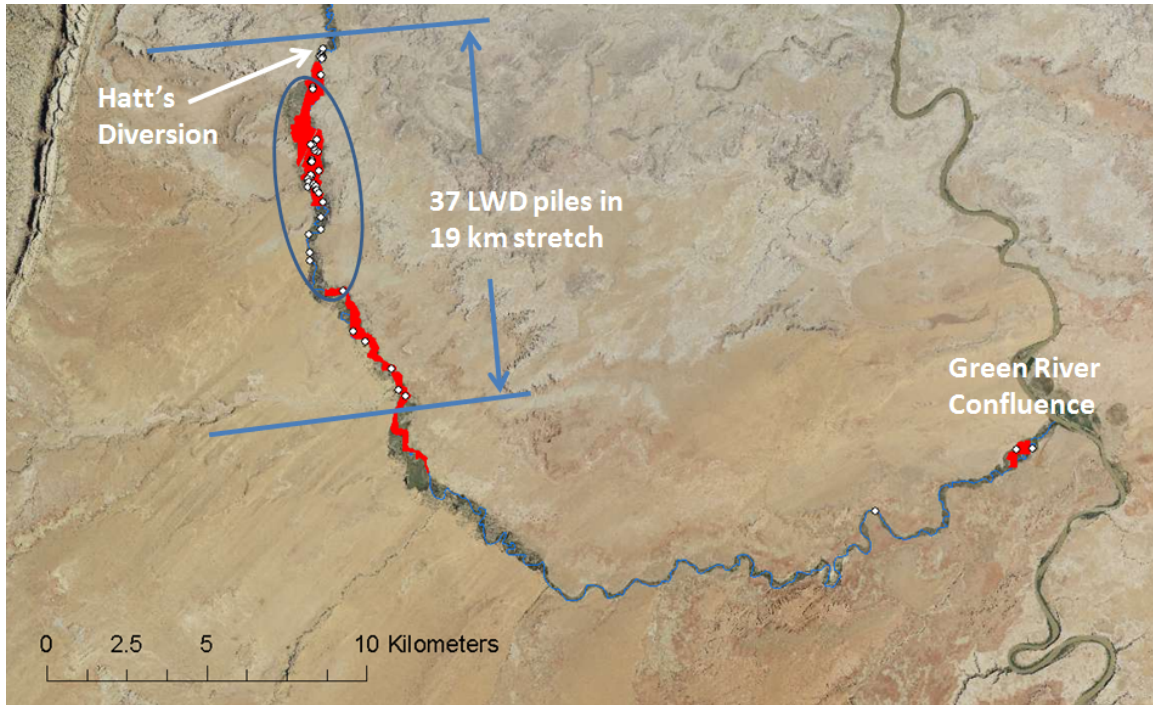


Figure 20. Distribution of LWD piles (white circles) on the lower San Rafael River Utah; the highest concentrations of LWD piles (37 of 40) occurred in a 19 km stretch below the Hatt's Ranch Diversion near tamarisk treatment areas (red) and high beaver activity (6 of 8 dams) found in 2010 (blue oval). The high concentration of LWD in 2011 was likely due to a combination of tamarisk piles flushing into the river and beaver activity.



Figure 21. Imagery showing extent of the tamarisk removal project. This photo is only showing 48.5 hectares (120 acres) of removal, currently we have removed approximately 424.5 hectares (1,049 acres) of tamarisk. Note the areas of flooding that contain tamarisk piles (blue arrows). Flooding within our tamarisk treatment areas likely have contributed beneficial LWD to the river system. Red arrow points out one of the many tamarisk slash piles.

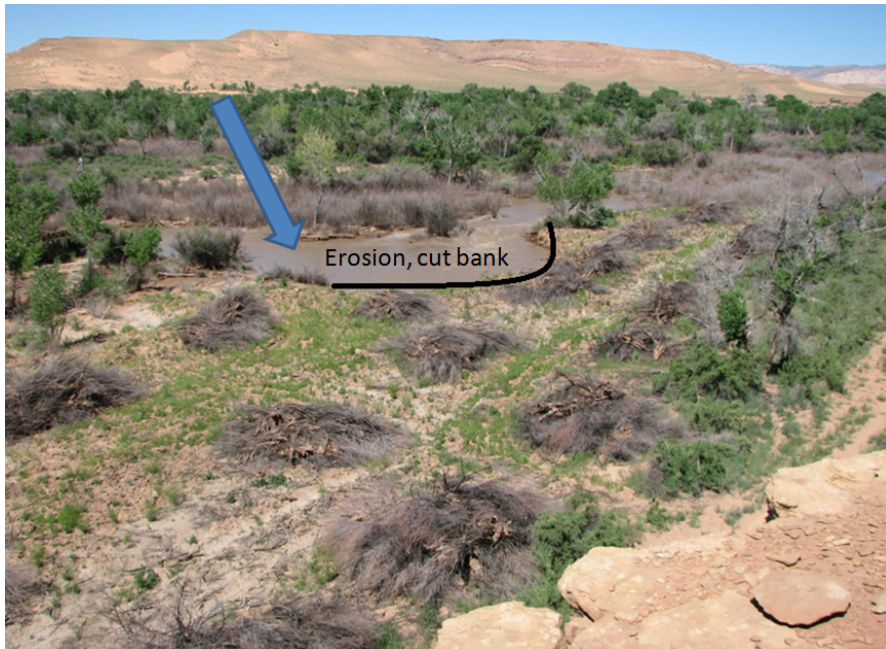


Figure 22. Photograph showing bank erosion and tamarisk piles (i.e., large woody debris) falling into the river (blue arrow); both are positive intended results of tamarisk treatments.



Figure 23. Example of the extent of 2011 flooding captured by the 2011 NAIP imagery. In this image the floodplain had been digitized (red lines).



Figure 24. 321C excavator with rotary grapple attachment working to remove tamarisk at Hatt's Ranch, October 2008. This method allows individual tamarisk plants to be plucked while minimizing disturbance to surrounding native vegetation. Removal of the root ball from the soil minimizes the need for costly herbicide treatments.