Paria River Exotic Removal Phase I
Task 7 – Final Report

AWPF Grant Number 08-157
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Prepared by:
Grand Canyon Trust

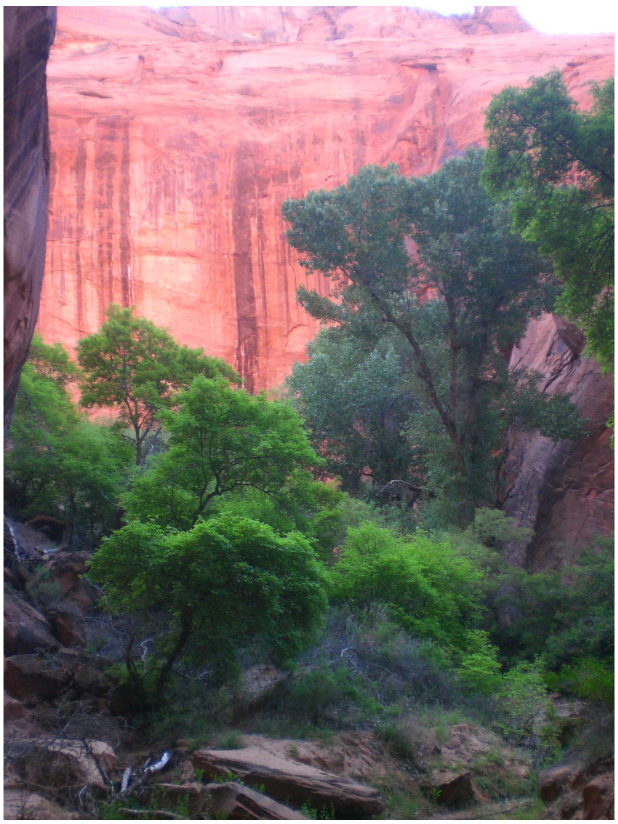


Table of Contents

Executive Summary

The Paria River originates in Bryce Canyon National Park and traverses the westerly edge of the Grand Staircase before entering Paria Canyon in Vermilion Cliffs National Monument, and ultimately, Glen Canyon National Recreation Area and the Colorado River at Lee's Ferry. The Paria Canyon is a designated wilderness area and is eligible for Wild and Scenic River designation due to its spectacular scenery, rugged terrain, and remoteness. It is also an area well known to hikers and backpackers and includes such places as the "narrows" and Buckskin Gulch, indisputably the two most popular slot canyons in the Grand Canyon region.

Many of the floodplains and terraces along the Paria River have become invaded by non-native tamarisk (*Tamarix ramosissima*) and Russian olive (*Elaeganus angustifoli*a) trees, and these species are becoming especially well established along the lower reaches of the river, near the confluence with the Colorado River. The highly invasive tamarisk and Russian olive were introduced into the southwestern United States in the late 19th century to help control stream bank erosion. Since that time, both plant species have spread throughout the west and caused major changes to rivers and streams. In the Paria River, their spread has been facilitated by historical land use, changes in climate, and by their ability to out-compete native species. The high competitive and reproductive success of tamarisk and Russian olive often results in dense stands, in some places choking out native vegetation to the point of creating a mono-cultural streamside habitat that reduces the diversity of other plants and wildlife species, increases fire hazard, and ultimately, results in the alteration of stream hydrology. The active removal of tamarisk and Russian olive from the Paria River has facilitated the recovery of native vegetation, restored critical habitat that supports a diversity of critical plant, bird and wildlife species.

In 2008, the Grand Canyon Trust's (GCT) well-established volunteer program received a grant from the Arizona Water Protection Fund (AWPF) to support a five-year effort to remove tamarisk and Russian olive from a 17 mile stretch of the Paria River in Arizona.[1] The objective of the Paria Exotic Removal Phase I project was to restore and preserve natural conditions in the Paria River Canyon by decreasing the negative impacts of non-native trees such as tamarisk and Russian olive and to enhance wildlife habitat by protecting and restoring native riparian vegetation through natural recruitment following treatment. This project also provided an excellent opportunity for public outreach through volunteer stewardship facilitated by the GCT's volunteer program.

From March through May 2008, a site assessment and baseline monitoring transects were established over three one-week backpacking trips. Vegetation, soils, and active channel width measurements were collected at 32 transects in 2008 and 19 transects in 2013 and 2014. Ultimately, nine reference transects, seven treatment transects (tamarisk and/or Russian olive present) and three "beetle" transects (tamarisk and/or Russian olive present but not treated) were sampled post-treatment. Although the transects were originally further stratified according to whether the transect was located on a riparian terrace vs. the floodplain, we pooled these together for this analysis, since most (15) of the transects

[1] The original grant proposal stated that Phase I of the project included "17 miles from the Arizona state line to

that were sampled were on the terraces and there are too few floodplain transects to consider them separately in the statistical analysis. Transect locations are shown on the project map in Appendix 1. and GPS coordinates are listed in Appendix 2. In addition to the transect data, photopoints were installed in March 2008 and were retaken on a semi-annual to annual basis throughout the project period.

In total, GCT crews removed 28,030 tamarisk trees including 7532 seedlings, 16,049 saplings, and 4449 mature trees over the 5-year exotic removal phase of the project. Crews also removed 1601 Russian olive trees including 496 seedlings, 731 saplings and 374 mature trees (table 1). Crews removed 12,085 square meters of tamarisk canopy cover and 2430 square meters of Russian olive canopy cover for a total of 3.66 acres of exotic canopy. Crews removed 5877 exotic trees from the flood zone and 23,666 exotic trees from the terraces (figure 4), for a total of 92.47 riparian acres. The vast majority of trees – over 91 percent – were treated via the cut stump method (figure 5).

Overall, tamarisk was completely removed from 6 miles of the Paria River project area and intermittently from transects along an additional 3.5 miles of project area, and Russian olive has been removed from over 10.5 miles of the project area. Site monitoring and maintenance will continue on an as needed basis.

Exotic Removal Methods and Discussion of Treated Sites

Addressing Site Challenges

While we have incorporated lessons learned from four seasons of exotic removal work since the project began in 2008 to improve safety, efficiencies and effectiveness, the extreme remote nature of the work site continues to present multiple challenges. Volunteer and staff safety are the biggest challenges we faced with this project. In 2011 we reevaluated our entire risk management plan for the project and improved our fieldwork communication techniques and protocols. However, communication between office-based and field personnel still presented a significant challenge, especially over the course of an eight day backpacking trip. The major concern is that a reliable long-term weather forecast for this potentially-hazardous area is not available prior to each trip; changes in the weather that are not part of the forecast on day one of a trip must be communicated to field leaders, which is challenging in such a deep, narrow canyon. Volunteer crews hike 10 to 15 miles to camp the first day, through 5 miles of narrows that are not passable above flows approaching 100 cubic feet per second. As our crews progress further into the more remote segments of the project area, the narrows persist as a potential hazard as weather forecasts cannot accurately predict more than 5 days out. Thus, our 8-day trips without reliable communication expose employees and volunteers to a life-threatening environment. The current work area does, however, allow better satellite reception near Adams Trail, allowing for more regular weather updates.

Another challenge we continued to face during 2012 was getting all tools, equipment, herbicide and food to our base camp safely and efficiently. For our spring re-treatment trip we were able to utilize pack horses to carry most food, gear and herbicide into the canyon to our base camp at Big Spring. The fall retreatment trip was unable to procure horse packing support, so four additional volunteers were needed to help haul gear into the canyon on the first day. For logistical reasons, these additional "sherpas" had to hike out on day two, and it was necessary for the remaining crew to haul about 200 pounds of gear from the drop site to base camp at Wooded Terrace (3 miles). This was time consuming, and the added weight to already heavy volunteer packs added further risk of injury before the work even began. Despite efforts to utilize pack horses and cut down on tools and gear, horse support can't be guaranteed due to changing conditions in the canyon and scheduling reasons. Field crew leaders, BLM fire crews and volunteers must carry extremely heavy backpacks loaded with food, tools, gear, gasoline, drip torches and herbicide into this remote project area. GCT crews practice "leave no trace" when in the Paria Canyon, which involves carrying out all human waste. This also adds to the pack weight.

Again, while our spring crew was able to base camp at Big Spring (12 miles from White House trailhead), the fall crew base camped at Wooded Terrace, which is about three miles downstream of Big Spring, which is a source of reliable, clean drinking water.

Wooded Terrace is still prohibitively far upstream from the next source of spring water, Wrather Canyon (5 miles). This necessitates using the heavily clay and silt-laden Paria River itself as our source of drinking water. Although we have devised a satisfactory system of settling and filtering river water for drinking, this still presents a challenge to fieldwork.

Exotic Removal Methods

At each site in the project area, field crew leaders analyzed the site and determined which removal method would be most appropriate. The primary removal method utilized for retreatment trips was the cut stump method. 99.8% of all trees retreated in 2012 were cut using this method. Other methods are outlined in the GCT Exotic Removal Plan. The cut-stump method is documented as being most effective and in most cases was the preferred method as it requires the least amount of herbicide. Where it was possible, crews pulled the younger trees in order to cut down on the use of herbicide. However, even the young trees have well-established root systems, so this method is only effective when the entire root below the crown can be removed. The basal bark method was used in only a few instances. Since crews are limited in the amount of herbicide they can carry, they used it as sparingly as possible. Girdling trees, by cutting into the cambium layer while leaving the tree standing, saves time, energy and herbicide and leaves some vertical structure on site for wildlife use. However, because no initial treatment occurred in 2012, there were no large mature trees to cut, and girdling was not ever an appropriate method.

Site Assessment

We conducted a site assessment to inform the development of exotic removal and monitoring plans that will ultimately guide the implementation of the project. We completed the site assessment with the following objectives in mind:

1) Characterize stream hydrology, channel morphology and riparian vegetation and identify reference conditions.
2) Characterize the extent and locations of treatment areas.
3) Determine appropriate number and placement of photopoints.
4) Determine suitable locations for vegetation transects.
5) Evaluate the project area for safety and logistical considerations such as campsite. location, water sources, escape routes, and high-water safety locations.

Methodologies and Activities

We conducted the site assessment over three one-week trips that occurred prior to the AWPF grant contract. Based on the objectives of the site assessment, we created a series of products to inform the development of the exotic removal and monitoring plans. These products include: 1) estimates of tamarisk and Russian olive abundance across different sections of the project area, 2) a list of plant species that are found in the project area, 3) a risk management plan that contains cautions and safety procedures relevant to the project, and 4) a high-resolution aerial imagery map that details photopoint and transect locations, campsites, water sources, and safety and evacuation sites. These products, along with some representative photos of site assessment activities are included as appendices to this report.

Characterizing Project Area Hydrology, Channel Morphology and Riparian Vegetation

In this report, we include pictures and a narrative description of channel hydrology, morphology, and riparian vegetation. Quantitative measurements of channel shape, channel gradient, and composition of riparian vegetation will be collected on the first two monitoring trips, according to methods laid out in the monitoring plan. These data will quantify baseline conditions to which post-treatment data will be compared.

Hydrology

The Paria River begins its course from the high elevations of the Table Cliffs and extends down to the Colorado River, entering just below Glen Canyon Dam. Buckskin Gulch meets the Paria River at the Arizona-Utah state line. Both streams have intermittent flows above their confluence, but the Paria becomes perennial just below this point. The Paria River exhibits a seasonally flashy flow regime. Peak flows typically occur in the early Fall, when large, short duration floods are initiated by monsoonal weather patterns. Elevated flows also tend to occur during snowmelt runoff and rain events in the early spring. Perennial baseflows are maintained throughout the project area by numerous springs and seeps coming from the surrounding Navajo sandstone formation. Daily mean streamflow has ranged from 11 to 48 cubic feet per second (cfs) at the USGS gate at Lees Ferry over the period of record (1924 – present). Daily streamflow for the past 5 years is illustrated in Figure 1. Peak flows of up to 15,000 cfs have been recorded at Lees Ferry, however peak flows have not exceeded 5000 cfs in the past five years (see Figure 2).

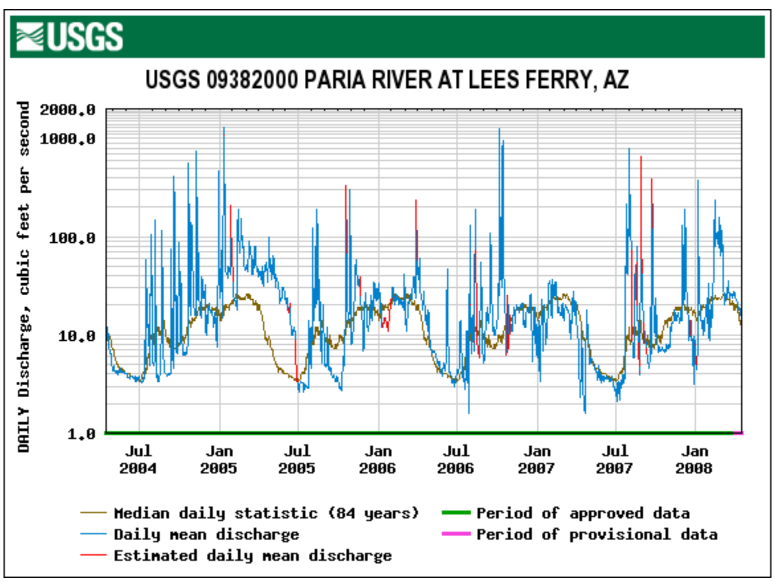


Figure 1. Daily streamflow statistics for the Paria River at Lees Ferry, April 2004-2008.

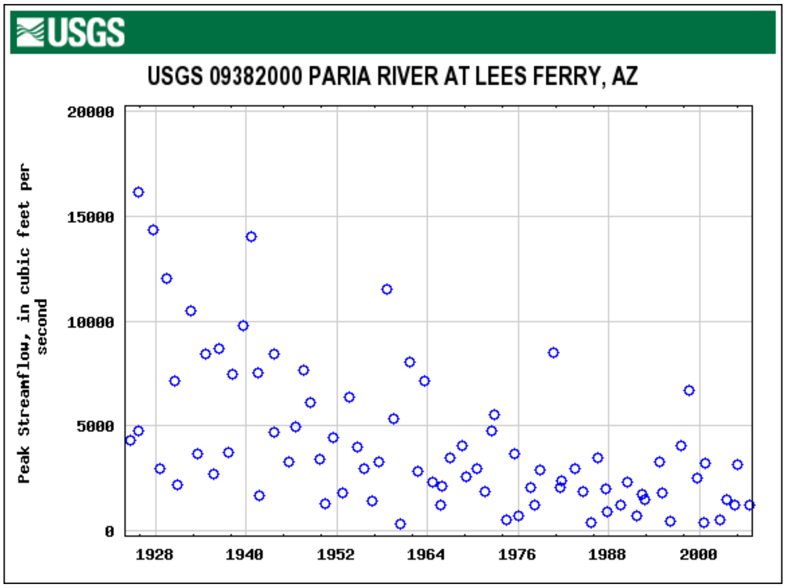
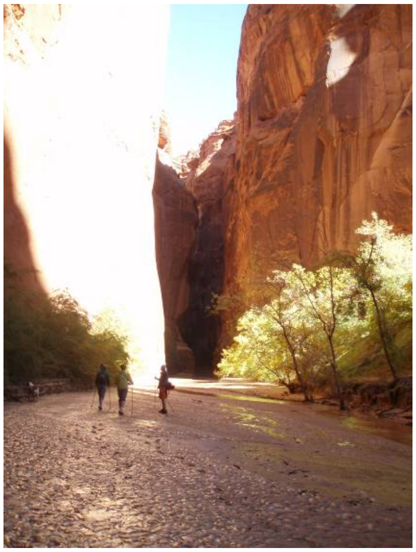


Figure 2. Peak streamflows in Paria River at Lees Ferry over the period of record, 1924 – 2007.

Channel Morphology and Riparian Vegetation

Channel morphology varies widely across the extent of the project area. The uppermost 5 mile section is a confined (valley width is less than two times active channel width) bedrock canyon, and supports small, intermittent patches of vegetation. Stream power is high, resistance and roughness are low, and sunlight is limited by the high canyon walls.



Representative photos of the uppermost 5 miles of the project area.

As the valley widens downstream, riparian vegetation increases and significant floodplain zonation occurs here. This zonation supports a wide diversity of riparian vegetation ranging from mesic to upland species. Patches of riparian vegetation range in size from

<0.5 to 2 acres. In the lowest 5 miles of the project area, the canyon widens and vegetation patches range from 1 to 10 acres in size.

Representative photos of the middle (left) and lower (right) section of the project area.

Dominant geomorphic surface types (See figure 3) that exist in the project area include the channel bed, depositional bars, the active channel shelf, the floodplain, and riparian and upland terraces. The channel bed and depositional bars do not typically support vegetation. The active channel shelf is frequently inundated, and supports mesic herbaceous species such as rushes (*Juncus* spp.), horsetail (*Equisetum* spp.), and tamarisk (*Tamarix ramosissima*), cottonwood (*Populus fremontii*), seep-willow (*Baccharis salicifolia*), and coyote willow (*Salix exigua*) seedlings and saplings. The floodplains are inundated at high flows and support a mix of woody and herbaceous vegetation, including saplings and mature cottonwood, willow, Russian olive, and tamarisk. Higher elevation riparian terraces also exist throughout the lower portion of the project area. These surfaces are rarely inundated and contain a mix of legacy cottonwood trees, grasses, shrubs, and mature tamarisk and Russian olive.

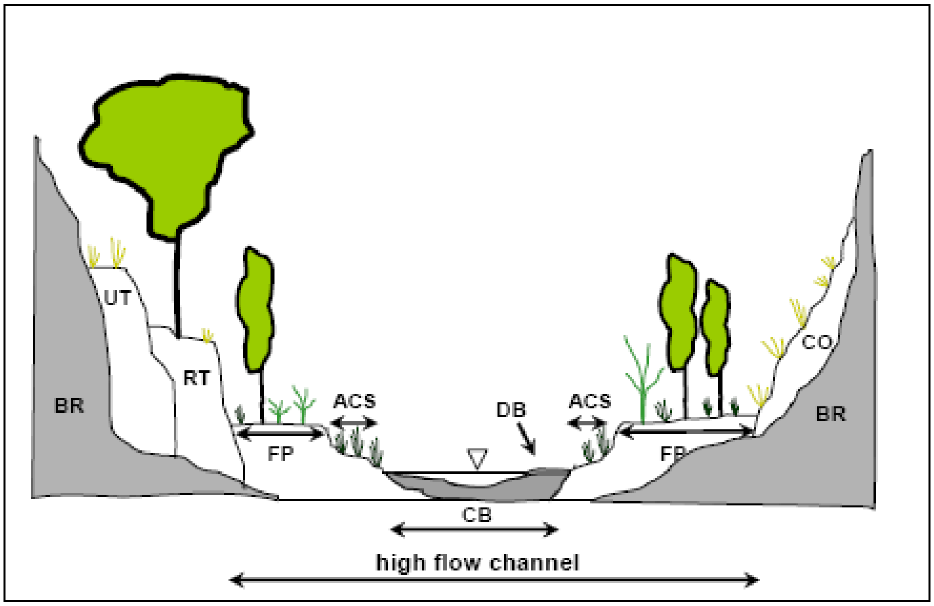
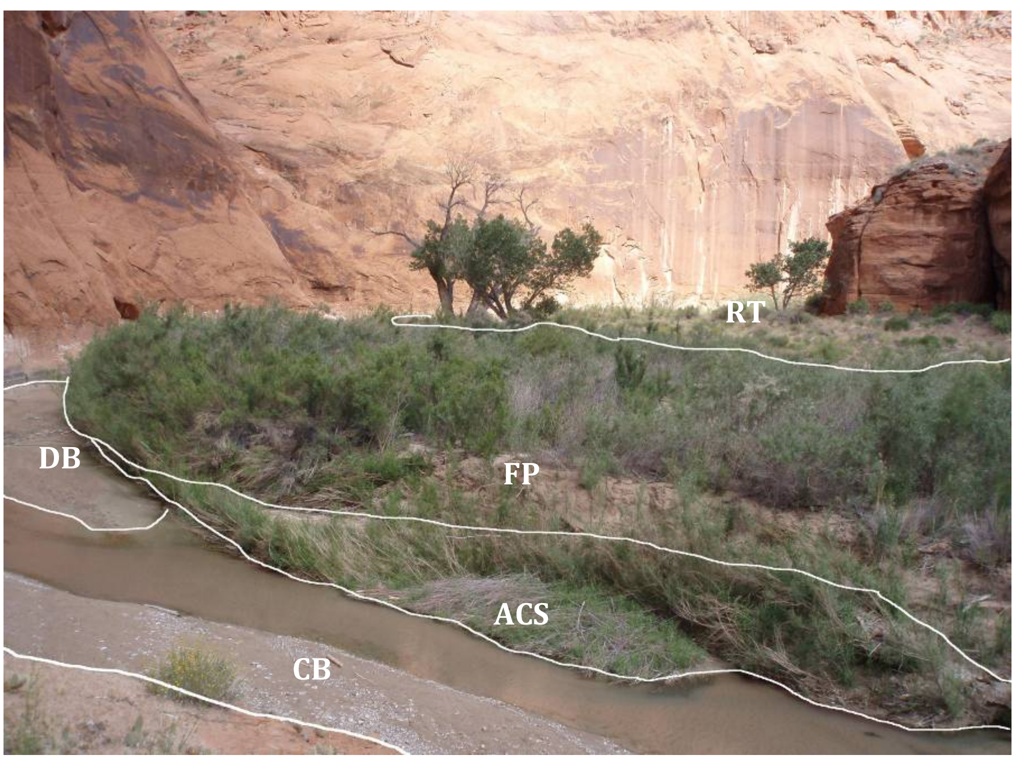


Figure 3. Geomorphic surface classification used for characterizing channel morphology (Scott and Reynolds 2007). Symbols represent the following geomorphic surfaces: BR=bedrock, CO=colluvium, UT=upland terrace, RT=riparian terrace, FP=flood plain, CB=channel bed, DB=depositional bar, and ACS=active channel shelf. Physiographic descriptions of surfaces based on Hupp and Osterkamp (1985), Graff (1987), Hupp (1988), Everett (1995), and Birkeland (1996). It should be noted that at any particular channel cross section, not all features would be expected to occur.



Example of floodplain zonation in lower project area. SeeFigure 3 for abbreviations of geomorphic surface types.

Description of Reference Conditions

Reference conditions exist throughout the project area, however they do not persist over a broad segment of stream, and could only be found intermingled among infested areas in the project and surrounding areas. There are two main types of riparian vegetation communities in the project area that can serve as reference conditions. More frequently inundated geomorphic surfaces such as the floodplain and active channel shelf are typified by dense stands of by dense stands of coyote willow and seep-willow, while reference conditions for riparian terraces may be characterized as open cottonwood gallery forests, containing herbaceous or upland understory species. Quantitative measurements of channel morphology will be collected as part of the monitoring plan to further characterize reference conditions.

Example of reference conditions for the active channel shelf and floodplain, consisting of dense monotypic willow stands.

Overstory is composed of mature Cottonwood while understory is composed of seep-willow, coyote willow, common reed (Phragmites australis), and a mixture of upland shrubs and grasses, such as four-wing saltbush (Atriplex canescens), and Indian ricegrass (Achnatherum hymenoides). Please ignore the Russian olive tree in the upper righthand photograph. ☺

Characterizing the Extent and Location of Treatment Areas

Tamarisk and Russian olive were enumerated in sections delineated by major geographic features that were identifiable on 1-m resolution aerial imagery. Each section was described in terms of the number of exotics by age class, campsite and water availability, and in some cases information regarding the type of herbicide that would be needed to accomplish the work was included. A

It is important to note that the site assessment rip was conducted approximately one week following a major flash flood, and thus most seedlings and saplings were completely buried and many of the adults were partially buried at the time. In addition, some areas were not surveyed completely due to time constraints. Thus, these preliminary counts are most certainly an underestimation of the actual number of exotics present in the project area, but accurately represent the extent and location of treatment areas and also characterize the relative degree of infestation across the project area. The number of exotics in the treatment area will be accounted for during exotic removal activities.

Determining the Number and Placement of Photopoints

In order to be consistent with other tamarisk mapping and removal projects in the area, we chose to delineate 500 m stream segments and install one photopoint in a representative treatment area in each segment. This frequency of photopoints was also consistent with exotic removal data collection, which was documented for the same 500 m segments. Photopoints were placed to capture an overview of vegetation composition and structure in areas that contain an average level of exotic infestation for the segment.

Determining Transect Locations

Vegetation transects were placed in treatment and reference areas located inside the project area and in a 4.5 mile 'control' segment downstream of the project area where exotic species are present, but not removed. Channel morphology changes significantly over the course of the project area, with sparse vegetation and little floodplain zonation in the uppermost reaches and the channel becoming increasingly less confined in the downstream direction. Abundance of all vegetation, including exotics, also increases significantly in the downstream direction. Due to the high variation in channel morphology and riparian vegetation across the project area, we decided to confine our treatment monitoring locations to the lowest five miles of the project area. We chose the most downstream section to conduct transect monitoring for several reasons. First, we believed that this was where the majority of the work would occur, given the number of exotics that were documented in the site assessment. We also expected to see the largest changes in the vegetation community and channel width in this section of stream following treatment. Second, we identified a 4.5 mile stretch of stream below the project area that is similar in channel morphology, floodplain zonation, and riparian vegetation composition to the lowest five miles of the project area, and we believe that this section of stream was suitable for placing our control (exotics present, but not removed) transects. Third, we believed that keeping the monitoring sites in relatively close proximity to each other would result in a significant gain in monitoring efficiency and effectiveness (as opposed to spreading across the entire 15 mile project area and 5 mile control segment) and would allow us to complete the monitoring over the two week period we have allocated for in the budget. Approximate locations for monitoring transects are indicated in the map in Appendix 1.

Locating Campsites, Evacuation routes, Water Sources, and High-Water Safety Zones.

During all site visits, campsites, water sources, high-water safety zones and evacuation routes were mapped and incorporated into GIS to maintain a permanent record of these locations. These features are identified on the project area map included in Appendix 1. We also developed a comprehensive risk management strategy (Appendix D) for the project using information gathered on site visits and background research.

To develop this plan, we hired an individual contractor with risk management experience to make several excursions into the canyon to evaluate and identify objective hazards.

This same individual then completed a survey of existing risk management literature pertinent to the landscape in which the Trust would work and began crafting protocols and procedures that the Grand Canyon Trust could implement in the field.

This individual engaged local, county, and federal land management and public safety authorities throughout the process in order to inform and strengthen the validity of his recommendations. These recommendations included the identification of possible evacuation routes out of the canyon, probable emergency helicopter landing zones in the canyon, and the development of field emergency protocol.

While we strived to complete this project without serious injury to any participant, the landscape of Paria Canyon is remote and inaccessible. It was, therefore, determined by the leadership of the Grand Canyon Trust to be both prudent and legally necessary to develop an extensive risk management strategy through which project leaders can reduce the risk to participants, and, should an individual become seriously injured, provide those project leaders with an emergency response framework.

Exotic Vegetation Removal Results

Work Completed

Exotic removal activities began in fall 2008 with a 2-day field crew leader training session; the topics included a project overview, data collection updates, control methods, herbicide application and safety. Exotic removal work began in October and November, 2008 at the upstream end of the project area at segment 11.5 (in kilometers from White House Trailhead) and continued downstream to a central base camp in the middle of segment 15.5. Crews completed three backpacking trips and removed tamarisk and Russian olive from 8 stream segments, for a total of 2.8 miles of the project area.

The 2009 exotic removal work began where crews left off at the end of the 2008 at segment 16 and continued downstream to a central base camp in the middle of segment 20.5. Crews completed four 8 to 9-day backpacking trips in March/April and October/November and removed tamarisk and Russian olive from 10 stream segments, for a total of 6.25 miles of the project area.

In 2010, work consisted of retreatment of previously cut and sprayed trees, beginning at segment 12 and continuing downstream to a central base camp in the middle of segment 18.5. Crews completed 2 backpacking trips and removed tamarisk and Russian olive from 14 stream segments, for a total of 4 miles of the project area. Due to previously described unforeseen circumstances, progress in treatment implementation was slower than initially anticipated. Moreover, we recognized during 2010 that we would not be able to treat the entire project area with the funds allocated by AWPF. Due to the presence of the tamarisk leaf beetle (*Diorhabda carinulata*), which was actively defoliating tamarisk in the project area, we shifted our priority to initial treatment of Russian olive and focused tamarisk removal to our monitoring transects.

In 2011, initial treatment work began at segment 20.5 and continued downstream to a central base camp in the middle of segment 28.5. Crews completed three 8-day backpacking trips (one was cut short due to deteriorating weather) and removed tamarisk and Russian olive from 17 stream segments in total, over 5 miles of the project area. All Russian olive was treated from segment 20.5 through the end of segment 28.5. If tamarisk piles were present, Russian olive was mixed with existing burn piles. Otherwise, Russian olive branches were scattered on upper terraces. Tamarisk and Russian olive were removed from monitoring transects in segments 24.5, 25.5, 26.0 and 27.0. For all transects treated, tamarisk and Russian olive were removed within 5 meters of the 50 m transect line. Transects that were treated and completed include TF15, TF1, TRT4, TRT5, TRT15, TRT6, and TRT7. The entire bench around transect TRT6 in segment 26.0 and the majority of the bench around TRT15 in segment 26.0 was treated. We experienced setbacks in 2011 since we had planned two additional treatment trips in the spring with an AmeriCorps National Civilian Community Corps crew that had to be cancelled due to poor weather.

In 2012, re-treatment work began at segment 11.5 and continued downstream through segment 28.5. Crews completed two 8-day backpacking trips (one in March and one in October) and re-treated tamarisk and Russian olive from 35 stream segments in total, or 10.9 miles of the project area that had been previously treated in 2008-2011. All Russian olive was treated from segment 11.5 through the end of segment 28.5. All tamarisk was re-treated from segment 11.5 to 20.5. Monitoring transects in segments 19.0, 20.0, 24.5, 25.5, 26.0 and 27.0 were also re-treated. For all transects re-treated, tamarisk and Russian olive were removed within 5 meters of the 50 m transect line. Transects that were re-treated and completed include RRT1, TRT3, TF15, TF1, TRT4, TRT5, TRT15, TRT6, and TRT7. The entire bench around transect TRT6 in segment 26.0 and the majority of the bench around TRT15 in segment 26.0 was re-treated.

Between 2008-2012, Tamarisk and Russian olive in segments 11.5 through 18.5 received three treatments and segments 19.0 through 28.5 received two treatments. It should be noted that tamarisk has never been found in segments 22 through 24; only Russian olive was treated in these reaches. Overall, tamarisk and Russian olive were removed from 17 stream segments during the exotic removal phase of the project, over 10.5 miles of the project area.

Exotic Removal Totals

In 2008, GCT crews removed 5,039 tamarisk trees including 772 seedlings, 3292 saplings, and 975 mature trees. Crews also removed 53 Russian olive trees including 1 seedling, 35 saplings and 17 mature trees. Crews removed 4,031 square meters of tamarisk canopy cover and 338 square meters of Russian olive canopy cover for a total of 1.08 acres of exotic canopy within the 8 segments where work occurred this year. At each site in the project area, field crew leaders analyzed the site and determined which removal method would be most appropriate (Figure 4). GCT field crews recorded total tamarisk and Russian olive trees removed, distinguishing between the floodplain and riparian terrace. The floodplains are inundated at high flows and support a mix of woody and herbaceous vegetation, including seedlings, saplings and mature cottonwood, willow, Russian olive, and tamarisk. Higher elevation riparian terraces are rarely inundated and contain a mix of legacy cottonwood trees, grasses, shrubs, and mature tamarisk and Russian olive trees. Approximately 85% of all tamarisk and Russian olive removed were on riparian terraces and 15 % were found in the floodplain (see figure 4).

In 2009, GCT crews removed 13,024 tamarisk trees including 2348 seedlings, 8289 saplings, and 2387 mature trees. Crews also removed 391 Russian olive trees including 39 seedling, 231 saplings and 121 mature trees (See table 1). Crews removed 5127 square meters of tamarisk canopy cover and 768 square meters of Russian olive canopy cover for a total of 1.5 acres of exotic canopy within the 10 segments where work occurred this year.

In 2010, GCT crews removed 4,036 tamarisk trees including 1873 seedlings, 1739 saplings, and 424 mature trees. Crews also removed 122 Russian olive trees including 19 seedling, 86 saplings and 17 mature trees (See table 1). Crews removed 687 square meters of tamarisk canopy cover and 38 square meters of Russian olive canopy cover for a total of 0.18 acres of exotic canopy within the 14 segments where work occurred this year. 2010 work involved revisiting the project area from segment 12 to 18.5, so these totals represent a combination of initial (new trees) and retreated trees (i.e. regrowth on stumps). 2010 was the first year of retreatment for the project and results indicate that overall there was a reduction in the number of tamarisk and Russian olive that necessitated retreatment. In 2010 crews retreated 3,274 tamarisk trees. 1873 of these were seedlings that were likely wiped out in the most recent flood and 81 Russian olive trees.

In 2011, GCT crews removed 1679 tamarisk trees including 179 seedlings, 956 saplings, and 544 mature trees. Crews also removed 556 Russian olive trees including 67 seedling, 281 saplings and 208 mature trees (See table 1). Crews removed 1631 square meters of tamarisk canopy cover and 1211 square meters of Russian olive canopy cover for a total of 0.7 acres of exotic canopy within the 17 segments where work occurred this year.

In 2012, GCT crews removed 4,252 tamarisk trees including 2,360 seedlings, 1,773 saplings, and 119 mature trees. Crews also removed 479 Russian olive trees including 370 seedlings, 98 saplings and 11 mature trees (See table 1). Crews removed 609 square meters of tamarisk canopy cover and 75 square meters of Russian olive canopy cover for a total of 0.2 acres of exotic canopy within the 35 segments where work occurred this year.

In total, GCT crews removed 28,030 tamarisk trees including 7532 seedlings, 16,049 saplings, and 4449 mature trees over the 5 year exotic removal phase of the project. Crews also removed 1601 Russian olive trees including 496 seedlings, 731 saplings and 374 mature trees (table 1). Crews removed 12,085 square meters of tamarisk canopy cover and 2430 square meters of Russian olive canopy cover for a total of 3.66 acres of exotic canopy. Crews removed 5877 exotic trees from the flood zone and 23,666 exotic trees from the terraces (figure 4), for a total of 92.47 riparian acres. The vast majority of trees – over 91 percent – were treated via the cut stump method (figure 5).

Overall, tamarisk was completely removed from 6 miles of the Paria River project area and intermittently from transects along an additional 3.5 miles of project area, and Russian olive has been removed from over 10.5 miles of the project area.

Data from 5 years of exotic removal shows that in segments that received two treatments (19-28.5), there was a 78.1% relative decrease in total numbers of exotics removed from initial treatment to retreatment. In those segments that have received three treatments (11.5-18.5), there was an 86.9% relative decrease in total exotics removed from initial treatment to 2nd retreatment.

Table 1. 2008-2012 Tamarisk and Russian Olive Removal Summary

Year	Tamarisk Seedlings	Tamarisk Saplings	Tamarisk Mature	Tamarisk Cover (sq m)	Russian Olive Seedlings	Russian Olive Saplings	Russian Olive Mature	Russian Olive Cover (sq m)
2008	772	3292	975	4031	1	35	17	338
2009	2348	8289	2387	5127	39	231	121	768
2010	1873	1739	424	687	19	86	17	38
2011	179	956	544	1631	67	281	208	1211
2012	2360	1773	119	609	370	98	11	75
Totals	**7532**	**16,049**	**4449**	**12,085**	**496**	**731**	**374**	**2430**

Figure 4. 2008-2012 Exotic Removal Summary by Geomorphic Surface Type

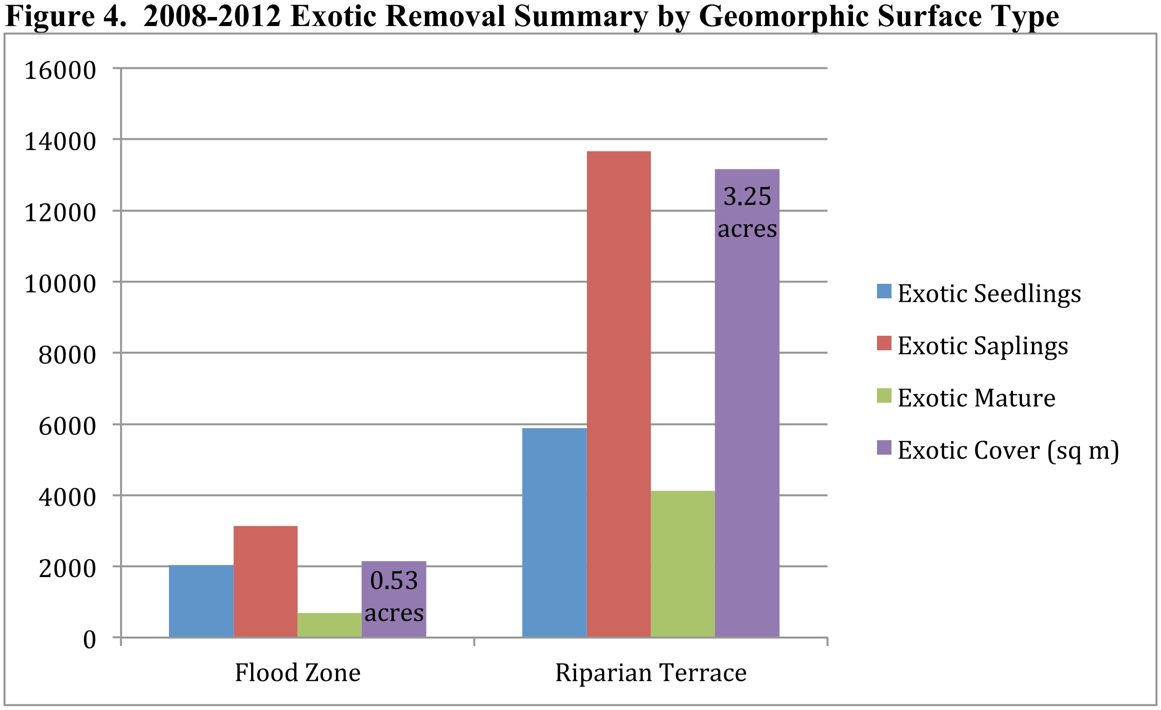
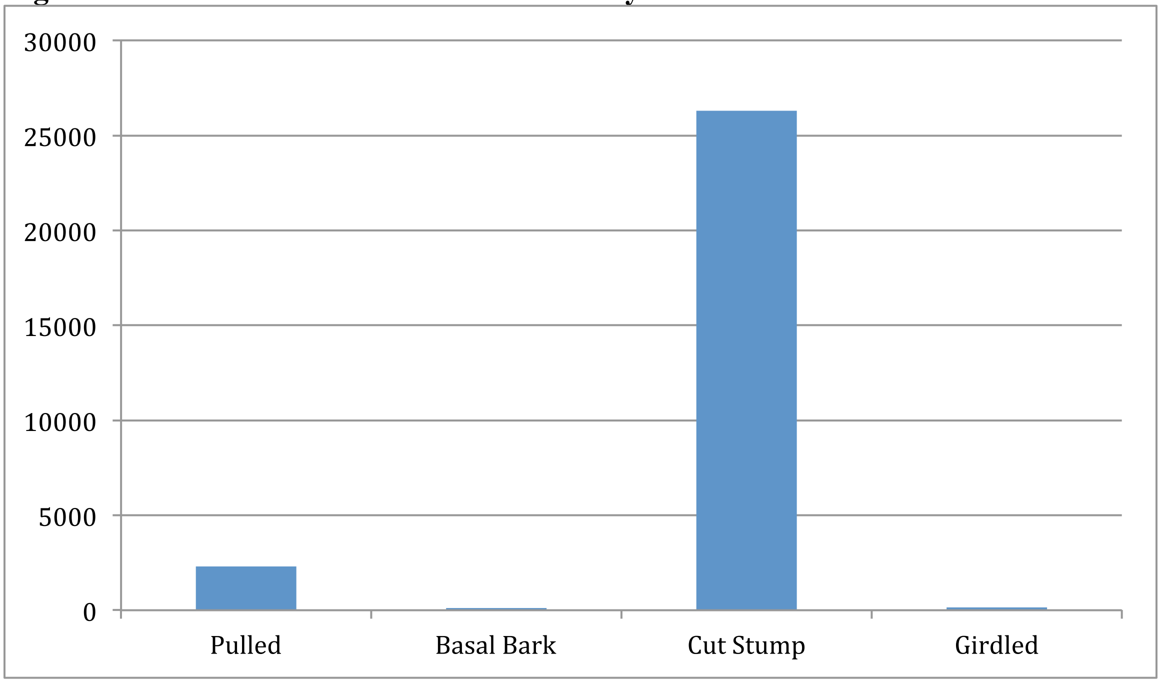


Figure 5. 2008-2012 Exotic Removal Totals by Method



Herbicide Use

The herbicides used for control were Triclopyr-based general use herbicides. We used Garlon® 4 Ultra in a mixture of 25% with 75% methylated soybean oil (a 1:3 ratio) on riparian terraces. We used Garlon® 3a mixed with 50% water (a 1:1 ratio) when removing trees in the floodplain due to the sensitivity of aquatic life to Garlon® 4 Ultra. Garlon® was mixed with blue marker dye that colored the treated stumps and faded with exposure to light over time. The use of dye ensured that cut stumps were not missed and hopefully increased the success rate. The herbicide application tool was a 32-ounce stainless steel sprayer, pressurized with bicycle pumps. These sprayers were mostly well-suited for the backcountry conditions in Paria Canyon as they were virtually indestructible and field repairable, although they were somewhat heavy. During the final two years of exotic removal, we switched to 32-ounce plastic Stihl® sprayers with built-n pumps, and Nalgene® polyethylene plastic squeeze bottles treated with thread tape. These latter two types of sprayers tended to clog less frequently, reduced pack weight, and were much easier to fill with herbicide, reducing the likelihood of spills.

In 2008, crews used a total of 8.9 gallons of mixed herbicide, equal to 3.2 gallons of actual herbicide concentrate in the project sites (table 2).

In 2009, crews used a total of 16.2 gallons of mixed herbicide, equal to 6.4 gallons of actual herbicide concentrate in the project sites (table 2). By fall 2009, tamarisk regrowth was evident in segments that were treated in 2008. Crew leaders increased the ratio of Garlon® 4 Ultra to methylated soybean oil from 1:3 to 1:1 on riparian terraces.

In 2010, crews used a total of 5.2 gallons of mixed herbicide, equal to 2.0 gallons of actual herbicide concentrate in the project sites (table 2). Tamarisk regrowth was evident in segments that were treated in 2008 and 2009, so we increased the ratio of Garlon 4 Ultra to methylated soybean oil (MSO) from 1:3 to 1:1 on riparian terraces, which is consistent with the product label. We continued to use Garlon 3A mixed with water at a 1:1 ratio when removing trees in the floodplain. In order to increase effectiveness of the Garlon 3A herbicide that is used in the floodplain, we decided to use this undiluted, which is consistent with the product label, to be more effective at limiting regrowth. Unfortunately, crews did not reach the segments that were treated in 2009 with 1:1 Garlon 4 to see if the stronger herbicide concentration was resulting in lower rates of regrowth.

We consulted extensively with other restoration practitioners in the region to determine if our rate of regrowth was consistent with their results. Many others were using Imazapyr (with the trade name Habitat) and finding good results; however, this herbicide is non-selective so there was danger of harming non-target species, which was why it was not analyzed in the EA, and was not used on our project. Dow chemical (manufacturers of Garlon) and other restoration literature (Nissen et al. 2009) state that cut stump treatments can be made almost any time of year, although it was best to avoid spring applications when tamarisk grows rapidly. Conversations with regional restoration practitioners who were monitoring the outcome of their work also suggested that cut stump treatments made during the spring were as effective as those made during other times of year. In a conversation with Curt Deuser, Supervisory Restoration Ecologist with the Lake Mead Exotic Plant Management Team, he brought to our attention that an improved JLB Oil Plus was 100% vegetable-based and facilitated penetration into the cambium more effectively than MSO, which could help us achieve better effectiveness on terraces. We switched to JLB Oil Plus the following year.

Table 2. Herbicide Use

Year	Garlon® 3a (mixed oz)	Actual Garlon ® 3a (oz)	Actual Garlon® 3a applied (gal)	Garlon® 4 Ultra (mixed oz)	Actual Garlon® 4 Ultra (oz)	Actual Garlon® 4 Ultra applied (gal)
2008	531	266	2.1	606	152	1.1
2009	1202	601	4.7	874	219	1.7
2010	320	160	1.3	348	87	0.7
2011	214	107	0.8	444	111	0.9
2012	231	116	0.9	267	67	0.5
Total Herbicide	**2594 oz**	**1250 oz**	**9.8 gallons**	**2443 oz**	**636 oz**	**5.7 gallons**

In 2011, crews used a total of 5.1 gallons of mixed herbicide, equal to 1.7 gallons of actual herbicide concentrate in the project sites (See table 2). We used a 1:3 ratio of Garlon 4 Ultra to JLB Oil Plus on riparian terraces. In order to increase effectiveness, we increased Garlon 3A mixed with water to a 3:1 ratio, which is consistent with the product label, when removing trees in the floodplain.

In 2012, crews used a total of 3.9 gallons of mixed herbicide, equal to 1.4 gallons of actual herbicide concentrate in the project sites (See table 2). We used a 3:7 ratio of Garlon 4 Ultra to JLB Oil Plus on riparian terraces. We used a 3:1 ratio of Garlon 3A mixed with water when removing trees in the floodplain.

In total, GCT crews applied 9.8 gallons of actual Garlon® 3a and 5.7 gallons of Garlon® 4 Ultra (15.5 gallons of herbicide) over the 5 year exotic removal phase of the project.

The BLM required that one leader on the project site obtain certification through a week-long BLM Pesticide Applicator training. This training cost the project $1500 (including travel and lodging) to train a new herbicide applicator. Other supporting leaders obtained Arizona State pesticide certification and worked under the supervision of BLM certified GCT staff. To mitigate potential herbicide leaks and spills on backpacking trips all herbicide was packed for secondary containment. Herbicide was carried in heavy duty plastic dry bags designed for river trips which were then strapped to the outside of backpacks. When herbicide traveled on horseback, a sealed 5 gallon bucket served as additional secondary containment. All herbicide containers were leak and spill resistant and made with fluorinated high density polyethylene plastic. All application equipment and chemicals were stored in sealed ammunition cans during transport in vehicles and all storage containers had the product's specimen label and Material Safety Data Sheet (MSDS) clearly displayed underneath a waterproof plastic sheet. The MSDS contained fire and explosive hazard data, environmental and disposal information, health hazard data, handling precautions, and first aid information. All trip participants reviewed the MSDS with the project leader and understood the first aid instructions described on the MSDS.

Project participants understood and abided by the established Personal Protective Equipment (PPE) requirements and rules outlined in the risk management plan for the project. Rubber gloves, long sleeved shirts, long pants, and eye protection were part of the PPE necessary for this project. (See appendix 2 for photos of herbicide use and removal methods).

Pile Burning

Brush and debris from cut trees were scattered in those areas where only small amounts of material was removed. In areas of heavier concentrations, brush and debris were stacked in piles and subsequently burned by BLM fire crews. The reasons for pile burning were: to reduce impacts to recreational users, since slash left behind in piles or scattered would create unsightly impacts and reduce already-limited camping space in the area; to encourage nutrient replenishment in soils; and to prevent cut debris from washing downstream, where it could create hazards for hikers and potentially encourage the spread of the very species we had removed. Crews piled cut material along the banks of the Paria River (above high water mark) in the anticipation that piles would be moved to below the high water mark immediately prior to burning, and burned in accordance with the BLM approved pile burning plan. Patrick Flemming, BLM's Arizona Strip Fuels Manager, served as the project liaison and was be responsible for burning the piles. He was not able to join crews in the field until the second trip of 2008, but was able to give constructive feedback on the placement and structure of piles to make burning most effective and efficient. Due to his commitment to other BLM projects, he was not able to join crews in the inner reaches of the canyon while cutting was taking place, so piles were placed as close to his description as possible. There were many riparian terraces that were heavily infested with tamarisk in the narrows and sometimes very small amounts of space to make piles above the high water mark so they were not highly visible. The pile burning was planned for early spring 2009 to avoid the heavy recreational season and reduce negative impacts to recreational users. Many volunteers expressed interest in helping with this phase of the project, however due to BLM policy, only personnel with red cards were allowed to be involved in pile burning activities.

In 2009, the majority of the heavy tamarisk infestations were on riparian terraces where these large amounts of debris had to be piled and burned in accordance with the BLM approved pile burn plan. GCT crews worked closely on the ground with Mark Atwood, the BLM Fuels Crew representative who was responsible for implementing the pile burning. He was able to join crews in the field on the second trip of the season after the first burn was completed in March 2009. He worked with GCT field crew leaders and volunteers to give constructive feedback on the placement and structure of piles to make burning more effective and efficient. Effective pile construction techniques required volunteer crews to spend extra time and energy to cut the debris into smaller pieces, so crews of 10 people were absolutely necessary to make daily progress cutting trees and building quality burn piles.

Pile burning was completed again in October 2009, concurrently with exotic removal activities. The original burn plan analyzed in the EA involved stacking piles on the edges of the terraces above the high water mark after which they would be dragged down to the floodplain to be burned, avoiding long term impacts on the riparian terraces. However, this approach was modified due to the added effort to move the piles, as well as the loss of leaf litter that is necessary to ignite the piles once they cured. The pile burning that occurred on the riparian terraces had some unanticipated negative effects on the native vegetation on the riparian terraces that was not fire adapted (See Appendix 2.), which we feared would lead to longer-term damage to the vegetation and appearance of the area. The burn intensity may have also sterilized some soils, further postponing the recovery of native vegetation and possibly leading to increased colonization by other invasive species, such as cheatgrass. This was primarily due to the fact that green tamarisk tended to burn hotter than tamarisk that had been cured, and because piles were placed too closely together (due to significant biomass and lack of space) on some of the banks, which allowed fires to travel between piles into areas of native vegetation.

Kate Watters (GCT) and Mark Atwood (BLM) discussed some options for mitigating the hotter burns on the terraces subsequent to 2009, including stacking the piles in the floodplain and coordinating with BLM fire crews to burn directly after treatment trips, when piles were still green. The rationale for this decision was that burning in the floodplain would: prevent cut debris from washing downstream and creating hazards for hikers; prevent damage to long lived native shrubs on the terraces that were not fire adapted; and avoid leaving scars and disturbance on terraces where successional invasives could colonize. Where this approach was not possible due to narrow floodplain width, smaller piles were to be placed on top of cut stumps on the terraces and burned once they were cured properly. We also discussed the option of girdling larger trees, including some Russian olives which do not burn as well as tamarisk, to help reduce the size of burn piles on terraces.

There were some obstacles to overcome to get the desired results from pile burning, but we had further discussions with BLM and GCT staff to collectively develop some alternatives for fall 2010. Both BLM and GCT were interested in mitigating any unnecessary harm to this unique area as well as maintaining support for the project from recreational users and the general public, which could have been compromised by the visual impacts associated with burning.

Because the 2009 pile burning had some unanticipated negative effects on native vegetation, in 2010 the BLM and GCT created a plan to stack the piles in the floodplain and coordinate pile burning with BLM fire crews directly after treatment trips, when piles were still green. However, no pile burning was completed in 2010 due to an unusually large flood in October, which washed any new piles stacked in the floodplain downstream.

In 2011, there were approximately 47 burn piles from segments 20.5 – segment 27.0. Unfortunately, pile burning was not completed in 2011 due to stated budget and scheduling constraints by BLM. We secured a commitment from Lorraine Christian, AZ Strip BLM Field Manager, that BLM had funds allocated to burn the piles in 2012 and would be able to complete this task in late spring 2012.

In 2012, because no initial treatments occurred, there was substantially less brush and debris from cut trees. Therefore, in most areas debris was scattered on riparian terraces, unless burn piles were present and not already too large, in which case debris was added to existing piles. In some areas a few new burn piles had to be created. The majority of the heavy tamarisk infestations were on riparian terraces where the heavy concentrations of debris were piled and burned in accordance with the BLM approved pile burn plan. There were approximately 69 burn piles in the project area by the end of our spring re-treatment trip. This included all of the 2011 debris, since crews were not able to burn those piles. In May 2012, the BLM sent an 8 person fire crew through Paria Canyon to burn the existing piles. The crews managed and monitored the fires, and public access was not restricted during the prescribed burns. Smoke emissions were managed in accordance with the Arizona Department of Environmental Quality regulations.

Exotic Removal Discussion

The area of the Paria River associated with the exotic removal activities was difficult to access, containing intermittent dense patches of tamarisk and Russian olive trees scattered between healthy stands of native riparian vegetation. As the crews moved downstream access issues became more complex, with increased travel time and tamarisk and Russian olive densities. Lessons learned from the initial project implementation brought up several issues that became increasingly challenging as the project continued.

In 2008, crews made good progress, completing exotic removal in 9 of the 42 segments of the project area. Despite the challenges, in a short period of time crews were able to remove a significant number of exotic plants from a very remote place. By the end of the year, we had hopes that we would be able to cover the entire extent of the project area with AWPF funding during the remaining scheduled backpacking tripsover the life of the project.

Also in 2008, GCT applied for $35,000 in funding through the Conservation Alliance to complete exotic removal in the 5 miles of river in the Utah section of the Paria Canyon from the wilderness boundary to Buckskin Gulch that was outside the scope of AWPF funding. However, we were not awarded the grant, and throughout the project we were unable to secure additional funding to remove tamarisk from this section of the project area.

In 2009, crews completed exotic removal in an additional 10 of the 42 segments in the project area. While this was significant progress, we did, however, begin to have concerns that we would not be able to cover the entire extent of the project area on schedule with AWPF funding. Despite having completed 19 of the 42 segments in the project area, GCT crews were moving slower than anticipated, especially considering that tamarisk and Russian olive densities increased below segment 23, where the canyon opened up, riparian terraces widened, the distance from the trailhead increased, and deep pools and floods remained a concern. Also in 2009, we anticipated GCT volunteer coordinator staff changes, and the need for new field crew leaders to be trained for the project. We were also monitoring the effects of the tamarisk beetle *(Diorhabda elongata)* that had been recently observed in the project area for its possible effects as a long-term solution to tamarisk control in the area. We anticipated that we could use tamarisk beetle defoliation to shift our hand removal efforts to Russian olive and removal of tamarisk only from those segments where monitoring transects were located. We addressed tamarisk regrowth with higher concentrations of herbicide, and restricted cut stump methods to the fall season when it was documented to be more effective with the plant's phenology (Nissen et al. 2009). We led one spring 2010 retreatment trip (which also served as training for new staff) and three exotic removal trips in the fall of 2010.

In 2010, crews made good progress and retreated a majority of the project area. However, the year was also filled with new challenges that required us to reevaluate our methods and develop alternatives to be able to access the project area more safely and efficiently to maximize our effectiveness. Paramount among these challenges was a flash flood that not only cut a trip short, but necessitated an overland rescue by a Kane County Search and Rescue foot crew. While no one was injured, this event brought increased attention and urgency to the risk intensive nature of the project and the need for stronger safety protocols and measures. While we were able to remove a significant number of exotic plants in 2010, we continued to have concerns that we were not on track to complete the scope of work within the proposed time period and with remaining AWPF funding. We began discussing our options with the BLM and revising our plans so we could complete a reasonable portion of the project area and collect meaningful data. Although we had by this time completed initial exotic removal in 18 of the 42 segments in the project area, and retreated 14 of those segments, it was almost impossible to realistically predict how much work a crew of 10 people could complete during a weeklong trip, especially since tamarisk and Russian olive density increased dramatically below segment 23. We continued to watch the effects of the tamarisk beetle, although the defoliation process was progressing slowly and did not seem to be killing many trees as of 2010. GCT planned to lead two spring trips and three fall exotic removal trips in 2011.

In 2011, we continued to incorporate lessons learned and use adaptive management to increase our effectiveness, efficiency, and safety. However, the remote aspect of the project area and intense flash flood risk made for increasingly challenging field conditions. Crews made good progress in 2011, removing Russian olive from the majority of the project area and initially treating over half of our monitoring transects. However, we came to realize that we would not be able to complete the entire scope of work within the proposed time period with remaining AWPF funding. For 2012, pending a contract extension with AWPF, we planned to retreat the 4.5 mile area initially treated in 2011, ending our exotic removal activities associated with the AWPF grant.

We felt strongly that retreatment of the area should take priority over working on additional segments for two reasons. First, our monitoring data pointed to the fact that retreatment is necessary in order to achieve natural recovery of the native plant community. Second, moving further into the remote portions of the wilderness represented insurmountable safety risks to GCT employees and volunteers. Additionally, we felt that the inefficiencies associated with traveling two days one way by foot and carrying heavy backpacks with gear beyond where horses can safely pass was not a prudent use of AWPF funds. The retreatment approach, followed by monitoring treatment transects, would allow us to collect the best possible data on our effectiveness and then share this information with others attempting similar ventures.

Also in 2011, we continued to observe the effects of the tamarisk beetle, although defoliation continued to progress slowly and the beetle's value as an effective long-term biocontrol agent remained unknown.

In 2012, we implemented our plan to retreat the project area rather than begin initial treatments on additional segments. Crews made good progress toward this task, retreating tamarisk and Russian olive across 9.5 miles of the project area that had been previously treated in 2009-2011, including the remainder of the monitoring transects. We accomplished more in 2012 than we anticipated, and completed the exotic removal activities associated with the AWPF grant.

Our data suggested that multiple treatments (with a year in between) substantially reduced the numbers of trees that regenerated after each treatment. Segments that received one re-treatment saw a 78.1% relative decrease in total exotics. Segments that received two re-treatments saw an 86.9% relative decrease in total exotics from the first to the third treatment. It is important to note that re-growth after multiple treatments, while minimal, did still occur.

Suggestions to improve efficiency, effectiveness, safety, and ultimate success included addressing shortcomings of the EA light of progress made and lessons learned on the ground. These issues included restraints on trip length, the use of pack animals to transport supplies, and addressing the compliance necessary in order to store herbicide in the canyon for short periods between trips. Closer coordination with our BLM project liaison on burn pile placement was intended to help make the implementation of the burn plan easier for fire crews, clarify piling methods, and assure that piles were burned in a timely fashion to reduce visual impacts and use as firewood by recreational users. We also explored alternatives to mitigate the negative impacts of pile burning on the riparian terraces and native vegetation.

Throughout project implementation, GCT crews had very positive interactions with visitors while living and working in the Paria Canyon, although many users were not aware that the project was underway. Brochures and interpretive signs at Paria Canyon trailheads and visitor centers were crucial to inform both day and overnight visitors about the project and to educate the public about the importance of exotic removal for the health riparian ecosystems.

Monitoring

Monitoring Objectives

Monitoring data collection was focused on the following questions related to the Paria River Exotic Removal project.

Q1) **How effective are the methods used for exotic management?** – The number of exotics removed from 500 m segments of the stream by age class, removal method, time of year, and geomorphic feature type were measured. Following removal, stream segments were surveyed for exotic regrowth and seedling recruitment. Survey data was intended to provide insights into the success of individual methods, effects of timing of removal (e.g., fall vs. spring), and susceptibility of the overall project area and specific geomorphic surface types (e.g., floodplain vs. riparian terrace *sensu* Scott and Reynolds 2007) to regrowth or recruitment of exotics.

Q2) **How does vegetation recover following exotic removal?** Three $30m^2$ rectangular plots were established along a transect line parallel to the stream bank in 16 treatment and 16 reference areas. Prior to removal activities, vegetation cover, structure, and soil characteristics were measured inside each plot, and the geomorphic surface type (floodplain vs. riparian terrace) of the plot location was recorded. A subset (19) of the original transects were sampled post-treatment (see next section). Vegetation transect data were analyzed to examine recovery of vegetation following removal by comparing pre- and post- removal characteristics in reference and treatment plots.

Q3) **How do exotic removals affect channel form?** –The effect of exotic removal on channel form was assessed using active channel width measurements that were collected at each vegetation plot. Treatment and Reference transects were compared to provide some insight into the effects of exotic removal on bank erosion processes and channel widening. As part of the baseline monitoring, channel measurements were also collected at six locations using a second method intended to assess overall channel form and stability. Channel cross-sectional profiles were measured in riffles (the most stable sections of the stream) in reference (willow-dominated) and treatment areas. Post-treatment measurements of cross-sectional profiles are scheduled for the final year of monitoring (but see discussion of these measurements in the conclusion section of this document).

Q4) **Are tamarisk beetles present and are they affecting tamarisk in the project area?** We conducted five sweep net surveys at each treatment transect with tamarisk present and recorded the level of defoliation of tamarisk at these locations.

Methods

Following methods and procedures outlined in the Monitoring Plan, pre-treatment monitoring in the project area occurred on May 26- June 2, 2008 and June 8-15, 2008. The first post-treatment monitoring trip occurred on June 7-14, 2013, and the second post-treatment monitoring trip occurred June 1 to June 8, 2014. Vegetation, soils, and active channel width measurements were collected at 32 transects in 2008 and 19 transects in 2013 and 2014. Ultimately, nine reference transects, seven treatment transects (tamarisk and/or Russian olive present) and three "beetle" transects (tamarisk and/or Russian olive present but not treated) were sampled post-treatment. Although the transects were originally further stratified according to whether the transect was located on a riparian terrace vs. the floodplain, we pooled these together for this analysis, since most (15) of the transects that were sampled were on the terraces and there are too few floodplain transects to consider them separately in the statistical analysis. Transect locations are shown on the project map in Appendix 1. and GPS coordinates are listed in Appendix 2. In addition to the transect data, photopoints were installed in March, 2008 and were retaken on a semi-annual to annual basis throughout the project period.

Monitoring Plan Overview

To address the above objectives, four main types of data were collected. Figure 6 shows the layout of the project area and general locations where data will be collected. Exotic removal data was collected in 500 m stream segment increments across the entire project area during exotic removal activities to track progress toward our removal objectives.

Photopoints were also used to document changes in riparian vegetation in each 500 m segment. Vegetation, soils, and active channel width measurements were collected in reference and treatment areas in the lower end of the project area. Vegetation, soils and active channel width measurements were laid out as indicated in Figure 7. These measurements were used to compare pre- and post-removal vegetation and floodplain characteristics and track our progress toward restoring natural conditions and improving wildlife habitat in the Paria River. We established detailed channel cross-sectional and longitudinal profiles at 6-9 locations in the project area to determine the influence of treatments on channel stability, however, these were not measured post-removal (see discussion).

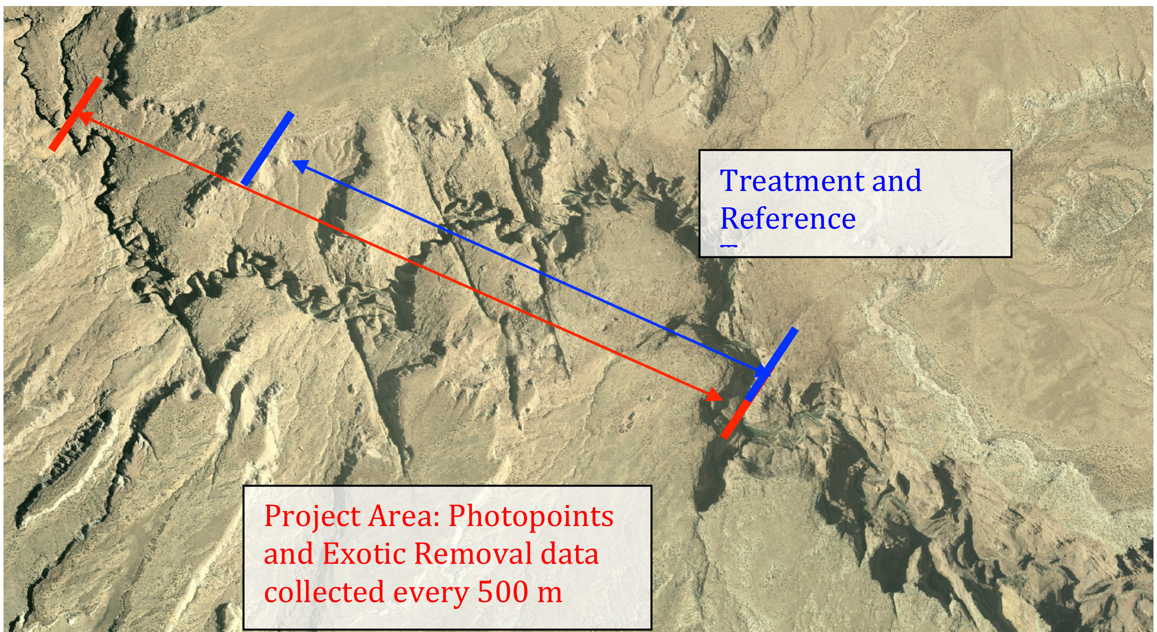


Figure 6. Project area and monitoring layout.

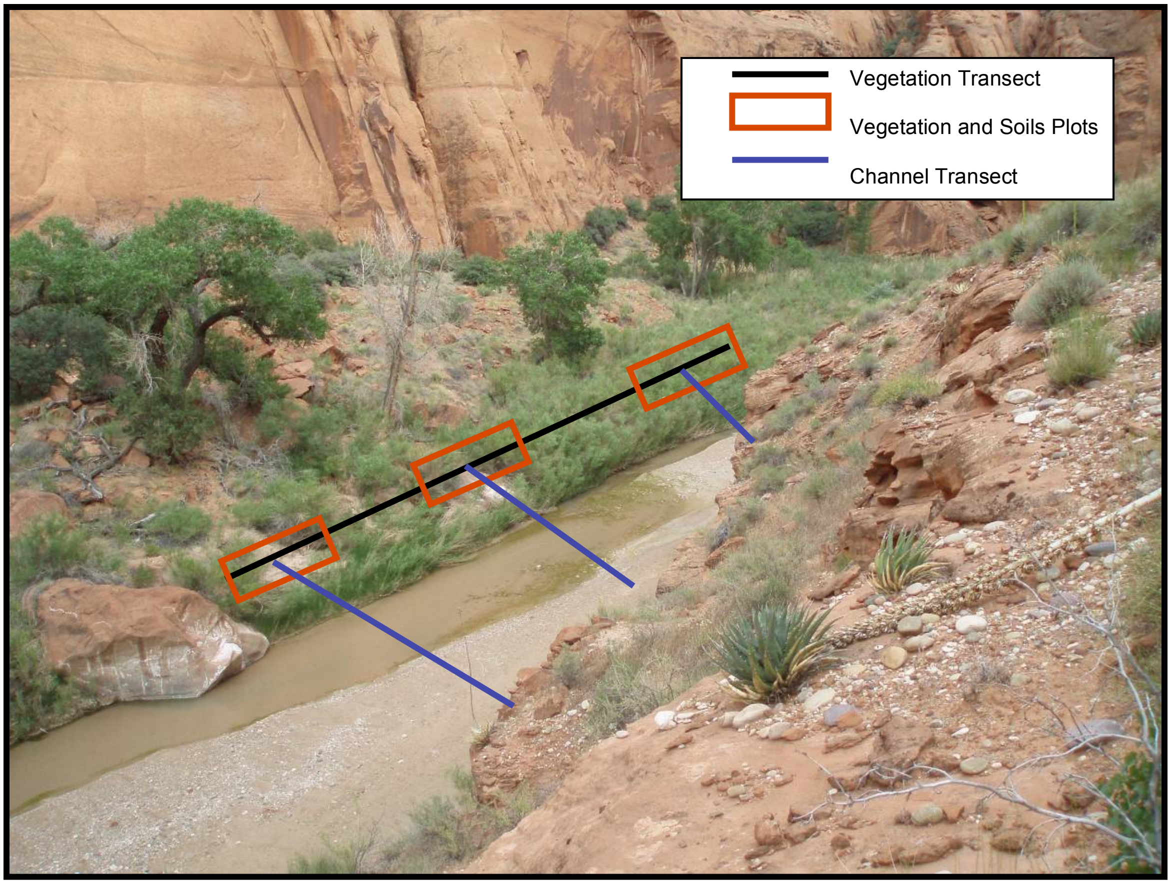


Figure 7. Sampling layout for vegetation and soils plots and active channel width measurements. Note: Figure is not to scale.

Monitoring Exotic Removal

Data Description

Exotic removal data collection occurred during initial exotic removal activities and was repeated during post-removal surveys to address Q1. Exotic removal monitoring data broadly characterized each 500 m stream segment in the project area in terms of channel flow, light exposure, degree of infestation, species composition, soil type, and invasive species cover, age class, and distribution across the geomorphic surfaces. Exotic removal data was collected in 43 500-m stream segments. Please see the Exotic Removal Plan for additional detail.

Data Analysis

Pre- and post- treatment exotic removal was analyzed to determine treatment success by comparing total cover exotic cover in each 500 m segment pre- and post- removal. Post-removal retreatment data was analyzed in relation to one or more of the following: removal method, age class, geomorphic surface type or timing of removal to extract patterns in treatment failures and successes. Pre- and post- treatment data and retreatment data will be analyzed using ANOVA and multivariate data analysis methods.

Monitoring Benchmarks

We expected to see tamarisk and Russian olive cover reduced to less than 5% across the entire project area. We expected all removal methods that are employed to be effective, and thus do not expect to see differences in effectiveness among removal methods.

Photopoints

Data Description

Photopoint documentation occurred in a representative treatment area in each 500 m segment of the stream. Photoplot IDs contained the name of the segment, and were indexed by views that are labeled as letters, as necessary. View A will always be a reference photo of a person standing at the photopoint, so that the point can be relocated. Photoplot locations were also marked on the map, and labeled as “PP” followed by the segment ID (e.g., PP13). A total of 53 photopoints were established; one in each 500-m stream segment. Photopoints will be used to qualitatively assess change in treated areas over time and help to address Q1, Q2 and Q3.

Photopoint locations were incorporated into GIS to maintain a permanent record of point locations. Photopoints were used on a continual basis to qualitatively monitor changes in vegetation following treatments. We hope our partners will continue this monitoring well past the project period, thus can be used to evaluate both short- and long-term changes in vegetation.

Monitoring Benchmarks

We expected to see a visually obvious reduction of tamarisk and Russian olive throughout the project area in the short term. We expected to see a noticeable increase in cover of native species as photopoint monitoring continues over the long-term (> 5 years).

Results and Discussion

Analyses of monitoring transect data compare the reference and treatment transects with respect to vegetation, soils, and active channel width. All transect and channel cross-section data are located in Appendix 3.

Only seven of the sixteen originally selected treatment areas were treated by the end of 2012, thus only a subset of the original transects were sampled post-treatment. This included a total of 19 transects: 9 reference, 7 treatment, and 3 untreated ‘treatment’ transects that we retained in order to assess effects of the tamarisk beetle on tamarisk-infested areas. See Appendix 1 for a visual overview of exotic removal competed to date in the project area and the 2012 Exotic Removal Report for more information about the exotic removal work completed.

Photopoints

Fifty-three photopoints were established for ongoing monitoring in March 2008, following protocols outlined in the Monitoring Plan. Photopoint photos and records are located in Appendix 3 (on DVD). Photopoint coordinates and accuracy information were collected in UTMZ12, NAD83 datum using a Garmin GPSMap 60cx. Generally, one photopoint was established in each 500 m segment, however multiple photopoints were established in some segments due to high abundances of tamarisk and Russian olive. See Appendix 2. for representative photos and interpretation of the more illustrative photopoints on the project.

Analysis of Vegetation Data

Vegetation data were collected to monitor the effectiveness of tamarisk removal and regrowth of native and non-native vegetation following removals. Percent cover of vegetation was measured in the three plots at each transect and averaged for the entire transect. Unknown plant species were documented on transects and in adjacent areas by collecting voucher specimens that were subsequently identified by professional botanists. To date, a total of 146 species have been observed on the transects.

Comparison of community metrics

Metrics that describe the vegetation community for each transect type are included in Figure 9.

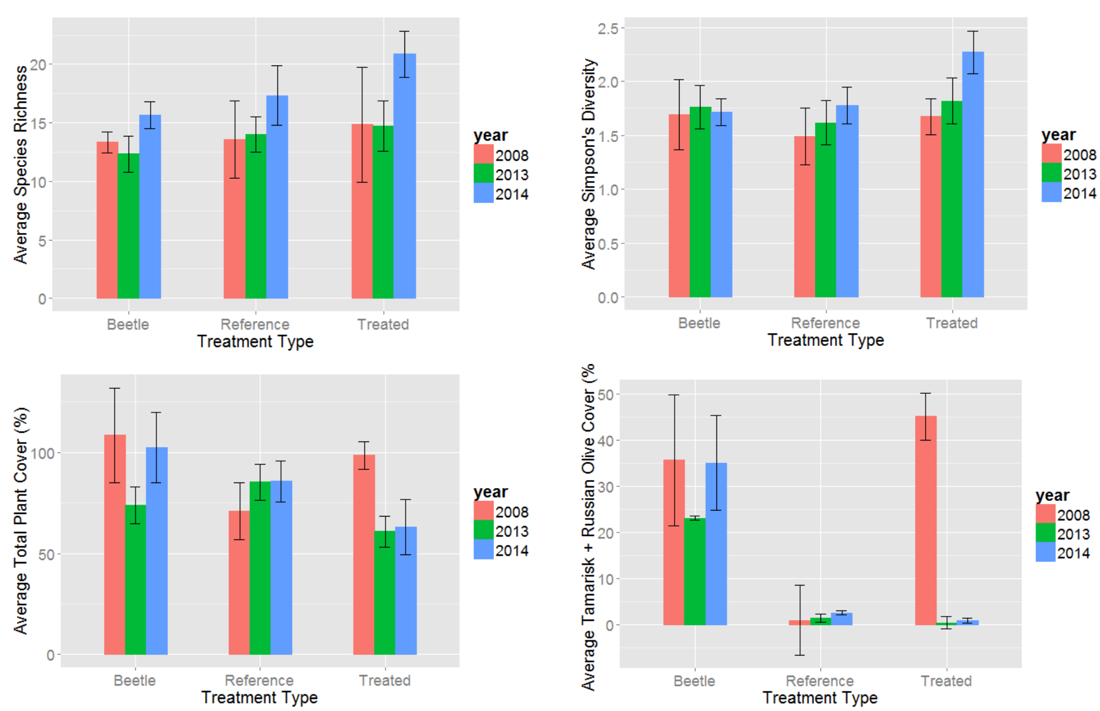


Figure 9. Comparison of Vegetation Characteristics Pre- and Post- treatment between Beetle, Treatment, and Reference Transects. Error bars indicate the standard error of the mean.

These analyses indicate that: 1) Species richness and species diversity (measured using Simpson's Index) were similar among transect types pre-treatment. Species richness and diversity increased slightly more in treatment transects as compared to other types in 2014; 2) Removal activities reduced total plant cover in treatment transects; and 3) Tamarisk and Russian olive cover was much higher in treatment and beetle transects pre-treatment and was significantly reduced as a result of removal activities in treatment transects. This is an obvious result, but it also indicates that little detectable regrowth of tamarisk or Russian olive has occurred since the treatments were conducted.

Multivariate analysis of community data

Multivariate analysis of plant community data collected at the transects was completed by comparing transect types using Analysis of Similarity (ANOSIM, Clarke 1993), and visualizing differences in species composition using Non-Metric Multi-dimensional Scaling (NMDS) in the statistical package PRIMER (Clarke et al. 2006). ANOSIM compares variation in species composition within a given transect type to variation between two different transect types, to determine how similar one type is to another. An R statistic is used in this analysis as a measurement of this similarity, with a value of 0 indicating that the vegetation community in the two types of transects are *completely similar*, and a value of +/-1 indicating that the vegetation community in the two types of transects are *completely different*. An NMDS ordination diagram assists in visualizing these differences. ANOSIM results are included in Table 3 and the NMDS diagram is included in Figure 10. Prior to analysis, plant cover data were square-root transformed to down-weight the importance of the most abundant species (so that the less common species would also be taken into account in the analysis). This analysis is intended to provide insight into overall changes in the composition of the plant community as a result of removal activities. For the sake of simplicity, we did not include the Beetle transects in this analysis.

Table 3. ANOSIM results for pair-wise comparisons of plant community composition of the Pre (2008)- and Post (2014)- Treatment and Reference transects. Statistically significant results are highlighted in bold font.

Pairwise Comparison	R-Statistic	Significance (p)
ReferencePre, TreatmentPre	**0.381**	**0.003**
ReferencePost, TreatmentPost	0.117	0.093
ReferencePre, ReferencePost	0.000	0.441
TreatmentPre,TreatmentPost	**0.358**	**0.005**

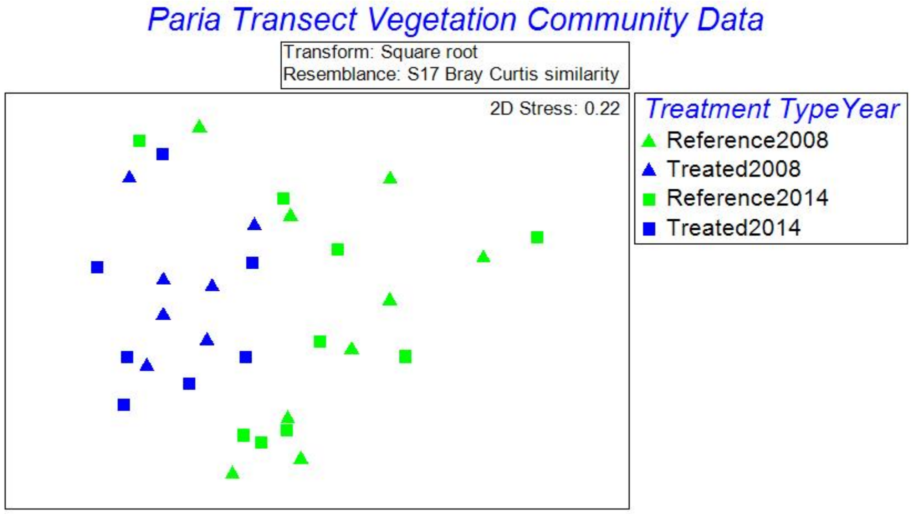


Figure 10. NMDS ordination diagram showing similarities between pre- and post- reference and treatment transects.

In general, this analysis shows that treatment and reference transects were initially distinct (R=0.381, p=0.003; little overlap in figure 10) and that after removal occurred, Pre- and Post- Treatment transects differed significantly (R=0.358, p=0.005), and Treatment transects became slightly more similar to Reference transects. Table 2 lists the five species with the highest cover values for each transect type. The majority of cover on reference transects both pre- and post- treatment included cottonwood (*Populus fremontii*), coyote willow (*Salix exigua*) and baccharis (*Baccharis emoryi*). The main change in Treatment transects was the elimination of tamarisk (*Tamarix ramosissima*).

Table 4. Dominant species for each transect type.

Reference Pre	Reference Post	Treatment Pre	Treatment Post
Populus fremontii	*Populus fremontii*	*Tamarix ramosissima*	*Ericameria linifolia*
Salix exigua	*Salix exigua*	*Ericameria linifolia*	*Artemisia ludoviciana*
Bromus tectorum	*Ericameria nauseosa*	*Bromus tectorum*	*Brickellia longifolia*
Ericameria nauseosa	*Baccharis emoryi*	*Ericameria nauseosa*	*Ericameria nauseosa*
Baccharis emoryi	*Bromus tectorum*	*Salix exigua*	*Bromus tectorum*

Given the prevalence of cheatgrass (*Bromus tectorum*) and other non-native species on the transects at the beginning of the project, we were also concerned that these species might colonize areas where tamarisk removals occurred. Figure 11 shows cover of native and non-native grasses and forbs, before and after removals. Treatment transects tended to have higher native and non-native grass cover initially than reference transects but non-native grass cover was actually slightly less in treatment transects and higher in Reference transects in 2013 and 2014. Treatment and reference transects were similar in terms of native and non-native forb cover initially, and both types of forb cover were higher in both transect types in 2014. Thus, although non-native forb cover increased in 2014, it does not appear the treatments have promoted invasion of these non-native species.

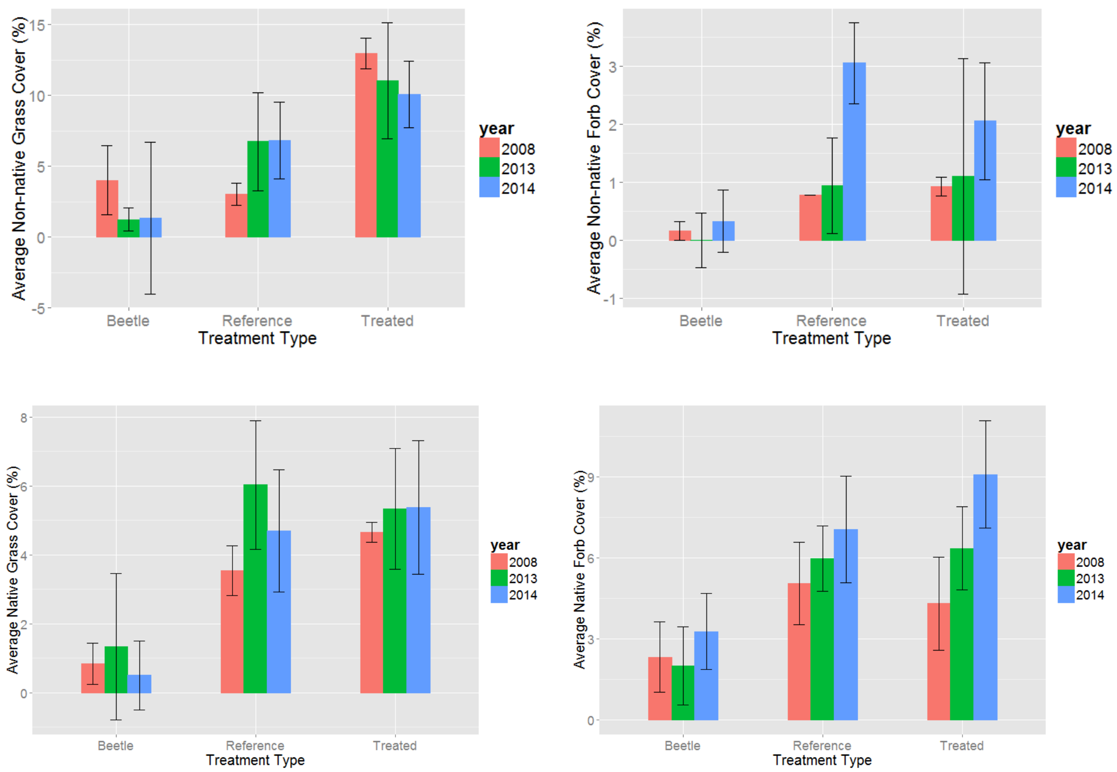


Figure 11. Comparison of cover by non-native and native grasses and forbs in Pre- and Post- Beetle, Treatment, and Reference transects. Error bars show one standard error from the mean.

We expected that we would see greater differences in treatment transects over time than in reference or beetle transects and hoped to see the treatment transects become more similar to the reference transects following tamarisk and Russian olive removals. We also expected that Tamarisk + Russian Olive Cover would no longer be significantly different among treatment and reference transects at the end of the project period. We expected Total Cover to be significantly reduced in treated areas over the short term, and species richness and diversity to increase over the longer term in these transects, as a variety of new species colonize areas previously occupied by tamarisk. Our analyses suggest that these expectations were generally met over the short time period for which monitoring has occurred.

Analysis of Total Vegetation Volume data

Total vegetation volume measurements (TVV) were collected in the three plots in each transect. This measurement may serve as a proxy for habitat structure, and has been shown to relate strongly to breeding bird populations (Mills et al. 1991, Fleishman et al. 2003). Average TVV for Pre- and Post-Beetle, Treatment, and Reference transects is shown in Figure 12. TVV was similar among transect types pre-treatment and was substantially reduced in the treatment transects. We expected TVV to initially be reduced in treatment transects following removal but to see an increasing trend toward that of the reference transects over the long term. Results indicate that removal had a substantial impact on TVV and an increasing trend in TVV in Treatment transects is not yet evident.

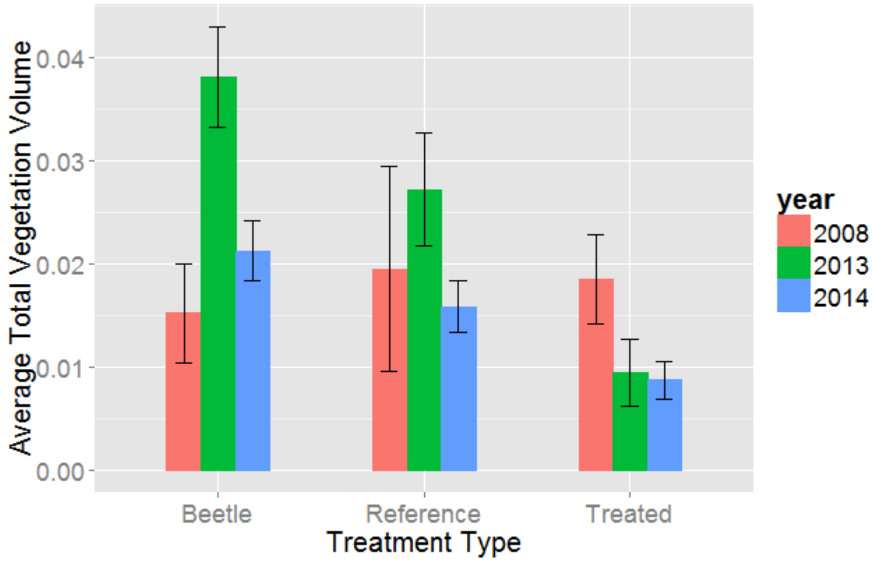
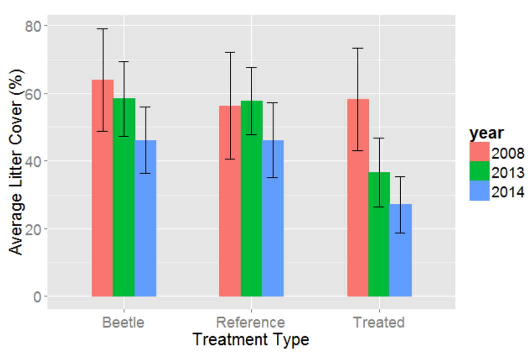
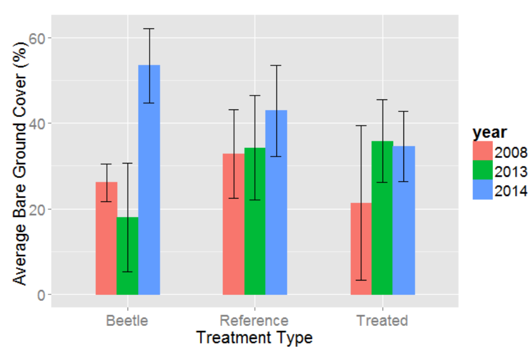


Figure 12. Average Total Vegetation Volume for Pre- and Post- Beetle, Treatment, and Reference transects. Error bars show one standard error from the mean.

Analysis of Ground Cover data

Ground cover data were collected in each of the three plots, averaged for each transect, then compared among the three transect types and years. We expected to see increases in bare soil and decreases in leaf litter following treatment in the treatment transects, as plant cover was removed. Although we saw this generally occur in all transect types, the differences were generally greater in the treated transects. We also saw a substantial reduction in biological crust cover in treatment transects after removal. We speculate that this reduction is due to the ground disturbances associated with removal activities, including pile burning, which occurred directly on at least two of the transects. Over the longer term, we anticipate that ground cover attributes such as presence of biological soil crusts and leaf litter may influence recovery rates of native vegetation.





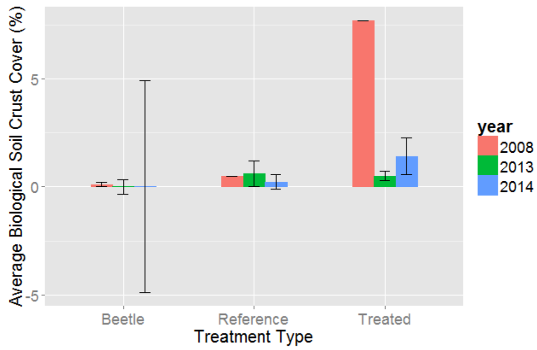


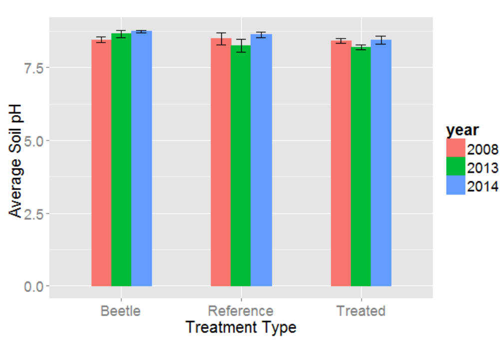
Figure 13. Average values for ground cover for Pre- and Post- Beetle, Treatment, and Reference transects. Error bars show one standard error from the mean.

Analysis of Soils Data

Comparison of Soil pH and Electrical Conductivity

Tamarisk has been shown to alter soil properties such as pH and salinity due to glandular salt secretions and decomposing leaf litter. While salinity has been shown to increase, pH has been shown to decrease due to the presence of organic acids (Ladenburger 2006). Soil pH and electrical conductivity were measured in samples collected in the three plots located on each transect and averaged for the entire transect. Overall, soil tended to be alkaline, with pH measurements ranging between 8.2 and 8.6 (See figure 14). Average electrical conductivity ranged from low (~ 0.1 millisiemens) to high (~ 2.3 millisiemens).

Pre- and post- treatment values of soil electrical conductivity (a surrogate for soil salinity) and pH are shown in Figure 14. While conductivity was generally slightly lower post-removal in the reference transects, a wide range of values were observed in the treatment transects in 2013. Both of these transects had fire scars following pile burning, which may explain these values, which were more similar to pre-treatment values in 2014. Ultimately, given the wide interannual variation in post-treatment values of soil electrical conductivity, the role of our treatments on this parameter is unclear. Soil conductivity may be an indicator of other factors that may influence vegetation recovery, and patterns may emerge with long-term monitoring.



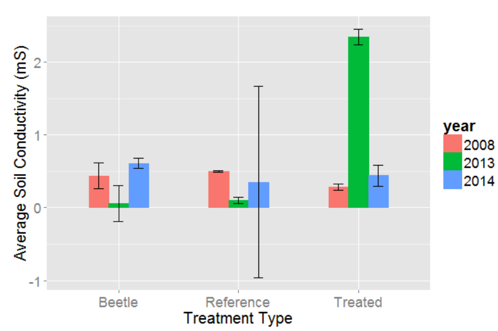


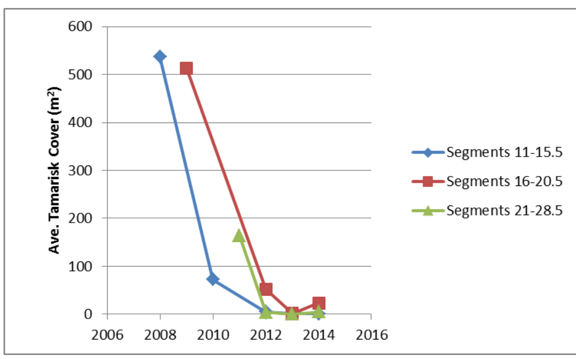
Figure 14. Comparison of soil pH and electrical conductivity among Pre- and Post- Beetle, Treatment, and Reference transect types. Error bars show one standard error from the mean.

Analysis of *Diorhabda sp.* (tamarisk leaf beetle) Monitoring Data

Five sweep net samples were collected along the three beetle transects and on two of the seven treatment transects that had tamarisk regrowth. Although *Diorhabda* sp. was detected in small numbers in every transect that was sampled in 2013, none were observed in 2014. Defoliation values in 2014 ranged from 0% to 30% (as compared to 4% to 100% in 2013) and no refoliation was observed. Qualitatively, we observed areas with near-complete defoliation (e.g., at Buckskin Gulch) as well as areas with no defoliation. Overall, our qualitative observations suggest that the effects of the tamarisk beetle continue to be highly patchy and were less extensive in 2014 as compared to 2013.

Analysis of Exotic Removal data

In addition to the transect data, other data were collected during exotic removal activities, and during post-treatment monitoring trips. Tamarisk and Russian olive cover was estimated and totaled for each 500 m segment of stream within the portion of the project area that got treated. Initial tamarisk removal began in Fall of 2008 and was completed in 2012, and most areas were retreated at least once in 2011 or 2012. Regrowth was observed in the 1-2 years between initial treatment and retreatment, and mainly occurred in the flood zones (see previous Exotic Removal reports). For the segments treated initially in 2008 and 2009, average regrowth in terms of total cover 2-3 years later was about 12% for tamarisk and 9% for Russian olive. After retreatment occurred regrowth was < 1% of the original amount and very little regrowth has been observed (see Figure 15).



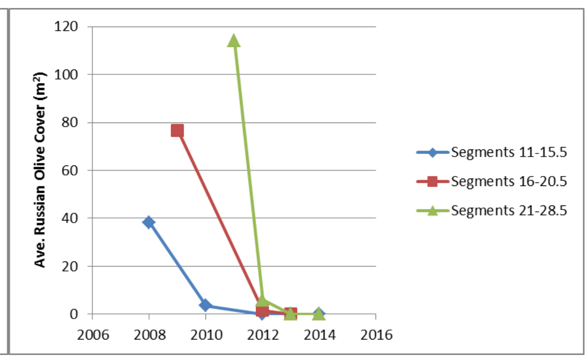


Figure 15. Estimates of Tamarisk and Russian olive cover n areas that were treated throughout the duration of the project period. The blue, red, and green lines show trends for segments that were initially treated in 2008, 2009, and 2011. Points along the lines indicate when initial or retreatments occurred, with the exception of 2013 and 2014, when no treatments occurred.

Monitoring Conclusions

Monitoring for this project was aimed at four primary questions. We review our conclusions to date and suggest several key considerations for the future both of this project and for Southwestern riparian restoration generally.

How effective were our exotic removal methods? Initial tamarisk removal began in Fall of 2008 and was completed in 2012, and most areas were retreated at least once in 2011 or 2012. Retreatment appeared to be necessary in many places to address tamarisk and Russian olive regrowth after the initial removals. Following retreatment, regrowth was minimal (< 1%), suggesting that methods were somewhat effective in the short term. The fact that we are continuing to see none to minimal regrowth in the initial 2008 treatments six years post treatment, is very encouraging.

We were interested in assessing the effectiveness of treatments that occurred in spring vs. fall and in flood zones vs. riparian terraces. Given complications associated with year of removal, number of retreatments, and the fact that most removals ended up occurring in the fall, we were unable to assess the relative effectiveness of spring vs. fall removal in a meaningful way. We have reported in previous exotic removal reports that we effectiveness of removals tended to be higher on the riparian terraces relative to the flood zones, however the fact that different herbicide formulations were used on terraces vs. flood zones confounded our ability to determine whether this is due differences in water availability or if this is due to the herbicide used.

How has vegetation recovered following exotic removal? To address this question we measured vegetation as well as a number of things that may influence vegetation recovery, including soils and ground cover. Our analysis of the overall plant community suggested that the biggest change in the community is the absence of tamarisk and that community composition is otherwise relatively unchanged in treatment transects. We did observe a greater increase in species richness and diversity in treatment transects as compared to others, indicating that new species are beginning to colonize the treatment transects, albeit slowly. Post-Treatment transects also had generally lower vegetation volume, lower cover of biological soil crusts and litter, and higher cover of bare soil than reference transects and we hope to see a positive trend in these parameters in the future, as these, along with recovery of native vegetation, will be important indicators of overall project success. We were concerned about the potential for other invasive species to colonize areas previously dominated by tamarisk and Russian olive and are encouraged by the fact that this has not occurred. In summary, with the exception of tamarisk and Russian olive plant cover, changes in vegetation, soils, and ground cover attributes we measured have generally been subtle over the short term and are generally changing in the direction we anticipated.

How are treatments affecting channel form?

As described in our 2013 monitoring report, we ultimately felt that the cost and logistics associated with collecting final measurements related to treatment impacts on channel form made collection of these measurements highly impractical. The channel width and form data we collected so far suggest that the Paria is a very dynamic river, where floodplain rearrangement occurs regularly with high flow events. A study that examines effects of removal treatments on channel form would require more extensive, more abundant, and more precise measurements than we were able to collect in this study. In some parts of the canyon, remote sensing methods may be a useful tool for comprehensively assessing background variation in channel morphology as well as treatment effects, if they exist.

Are tamarisk beetles present and have they affected tamarisk in the project area? Our data suggest that tamarisk beetles are present ephemerally throughout the project area. They were present in every sweep net sample that was collected in 2013 -- even though most of those places had very little tamarisk --, but they were not present when collected in 2014. Despite their absence on the transects, patchy defoliation was observed in 2014. Overall, it is unclear what the long term effectiveness of the beetle will be in controlling tamarisk, or what the long term implications of their presence will be to the riparian ecosystem of Paria Canyon, especially given their seemingly ephemeral nature.

Looking forward: Will these short-term trends persist? It is likely too soon to say definitively how effective our exotic removal methods were for the treatments and retreatments that occurred in 2011/2012, as it is possible for tamarisk or Russian olive to resprout even a few years after being treated. Moreover, the effects of the presence of tamarisk beetles in the system will likely take several more years before they can be fully determined. We find the positive trend in species richness and diversity, the lack of non-native grasses and forbs, and the lack of significant resprouting of tamarisk in the short term encouraging, albeit inconclusive on this short time scale. Given the substantial investment in both treatment and monitoring, we feel it is imperative to continue monitoring these changes over the longer term to determine whether the effects seen to-date will persist after treatment efforts have ceased.

Public Outreach

Objectives

The main objectives for public outreach were to educate and inform Paria Canyon recreational users, the general public and project volunteers about exotic vegetation removal and the importance of native vegetation to Arizona's stream systems. In partnership with the Bureau of Land Management (BLM), the Grand Canyon Trust (GCT) accomplished these objectives using a variety of educational outreach efforts, including educational seminars, conference presentations, magazine and newspaper articles, on-trip project presentations, web-based communications, interpretive materials and volunteer recruitment and engagement.

Volunteer Recruitment

In April 2008, GCT hosted an in-house recruitment event at their Flagstaff headquarters, as well as other recruitment efforts throughout the year to reach out to residents regional to the project area. Events included tabling at Flagstaff's Earth Day and Sustainable Living Fair and presentations for Flagstaff Arts and Leadership Academy, Flagstaff

Festival of Science, and the Arizona Botanists Meeting. During these recruitment events the public learned about volunteer opportunities, interacted with GCT staff, asked questions, and had the opportunity to sign up to volunteer.

In August 2009, GCT hosted an in-house recruitment event at their Flagstaff headquarters, as well as other recruitment efforts throughout the year. Events included tabling at Flagstaff's Earth Day, Museum of Northern Arizona's Heritage Festival of Hopi, Navajo and Zuni cultures, Albuquerque's Sustainable Living Symposium and a presentation for the Western National Parks Association in Tucson. GCT also produced recruitment fliers for the Paria project and distributed them around Flagstaff, Kanab, St. George and several REI stores in the Phoenix metropolitan area.

In May 2010, GCT hosted a recruitment event at the Orpheum Theater in Flagstaff in May, as well as other recruitment efforts throughout the year. Events included tabling at Flagstaff's Earth Day, and presentations for the Colorado River Guide annual training in Marble Canyon and the Western National Parks Association in Tucson. GCT also produced a timeless recruitment flier directing potential volunteers to the GCT website and distributed them around Flagstaff, Kanab, St. George and several REI stores in the Phoenix metropolitan area.

In 2012, GCT Volunteer Program staff participated in Flagstaff's annual Earth Day celebration, with a table at the event to publicize the project. Staff also presented information on the project to selected classes at Northern Arizona University.

Volunteer Engagement

In 2008, 6 volunteers participated on the two baseline monitoring trips and in 2013, 5 volunteers joined GCT staff for the project's annual monitoring trip. Volunteers donated 900 hours of service to the monitoring portion of the project, and one even took personal vacation time from her job with Grand Canyon National Park. Additionally, 4 of our 2013 volunteers who helped with monitoring were GCT youth interns. The Trust is committed to building the next generation of conservation leaders on the Colorado Plateau, and this opportunity to live and work in Paria Canyon for 8 days was a valuable learning experience for these young adults looking to develop careers in conservation. This project provides more than the visible changes you see in the canyon – it creates experiences for both young and retired volunteers that stay with them for a lifetime and moves them to become vocal ambassadors for conservation.

In 2014, two volunteers joined GCT staff for the project's annual monitoring trip. Volunteers gave 120 hours of service to the project.

Volunteer participation was significant and crucial to the project's success and accomplishments. Overall, 138 volunteers contributed 9888 hours toward the exotic removal and monitoring phases of the project (See Table 5). The hours were almost all accrued during exotic removal backpacking trips, plus two volunteers who contributed many hours of data entry. The volunteer hours donated to this work represent an in-kind match of $222,974.400 toward the project.[2]

Table 5. 2008-2014 Volunteer Numbers and Hours Summary

Year	Number of Volunteers	Number of Volunteer Hours
2008	41	3500
2009	35	2500
2010	16	912
2011	27	1704
2012	12	752
2013	27	400
2014	12	120
Totals	**138**	**9888**

The dedication and perseverance of all of the volunteers associated with the Paria River exotic removal was remarkable and contributed greatly to the overall success of the project. GCT staff and field leaders were consistently amazed by the positive influence volunteers had on all aspects of the project. Besides the fact that this challenging project would not have been feasible without their physical work, volunteers also provided moral, intellectual and sometimes financial support. Feedback from volunteers led to innovations with tools, methods and equipment that improved effectiveness. Many volunteers had life-changing experiences on backcountry exotic removal trips and often returned to do several trips a year or even serve as future field crew leaders. Grand Canyon Trust's volunteers were as passionate about our work as GCT staff and were critical to achieving our goals.

Educational Seminars

In September 2008, GCT hosted a public educational seminar on riparian restoration titled: "Bringing Rivers Back to Life: Riparian Restoration on the Colorado Plateau," as a part of our Community Educational Lecture Series. The seminar featured two different presentations, the first being an overview of stream restoration efforts on the Colorado Plateau by regional expert and partner, Tom Moody of Natural Channel Design, Inc. Christine Albano and Kate Watters then gave a presentation about the Paria River project. The seminar was attended by 35 people and generated an interesting question and answer session as well as good support for the project. The seminar was free and open to the public and advertised in local media outlets (including local Flagstaff newspapers and radio stations, and the GCT volunteers website) to maximize attendance.

In October 2009, GCT hosted a public educational seminar on riparian restoration titled: "Tamarisk Leaf Beetle: Distribution and Expansion Across the Colorado Plateau." Levi Jamison from the Colorado Department of Agriculture and Clark Tate from the Tamarisk Coalition presented the results of their third year of monitoring the distribution of the tamarisk leaf beetle *(Diorhabda carinulata.)* in the Colorado River Watershed. Surveys

[2] http://www.independentsector.org/volunteer_time

monitored beetle populations along the Colorado, Dolores, Escalante, Green, Gunnison, San Juan, Virgin and White Rivers, as well as other major tributaries. The presentation included a description of Diorhabda carinulata and its interaction with tamarisk, maps of beetle population locations in 2009, and a discussion on the beetle's place in the ecosystem. The seminar was attended by 35 people from veteran tamarisk removal volunteers to U.S. Fish and Wildlife biologists and other area land managers from as far away as Tucson, and generated a dynamic question and answer session as well as good information on the tamarisk beetle, which at the time was hotly contested in Arizona due to its effect on the endangered southwest willow flycatcher. The seminar was free and open to the public and advertised in local media outlets (including local Flagstaff newspapers and radio stations, riparian-related email list-servs, and the GCT volunteers website) to maximize attendance.

In September 2010, GCT hosted a public educational seminar on riparian restoration titled: "The Tamarisk Leaf Beetle: What It Means to You and Our Rivers." Spreading rapidly across the region, the northern tamarisk leaf beetle *(Diorhabda carinulata)* has now established itself over approximately half of the Colorado Plateau. Beetle activity has affected aesthetics, wildlife habitat, recreation, and invasive species in both positive and negative ways. The presenters were restoration ecologist Nathan Ament, Tamarisk Coalition biological control specialist Levi Jamison, and special guest Mary Anne McLeod, long-term manager of southwestern willow flycatcher monitoring for SWCA Environmental Consultants. The seminar examined the beetle's effect on the Colorado River system and addressed the need for management and research to be understood as an interconnected phenomenon at a broad regional scale. The goal of this presentation was to inform attendees about the rapid ecological changes that accompany the beetle, and to answer questions about the future health of western riparian zones. The seminar was held at the Cline Library auditorium on the campus of Northern Arizona University in Flagstaff and co-sponsored by the School for Earth Sciences and Environmental Sustainability. Another diverse turnout of 90 people attended the talk, which was free and open to the public and advertised in local media outlets (including local Flagstaff newspapers and radio stations, riparian-related email list-servs, and the GCT Volunteer Program website) to maximize attendance.

In December 2011, GCT hosted a public educational seminar on riparian restoration titled: "The Birds and the Beetles: Responding to Rapid Ecological Change on the Colorado and Virgin Rivers". The event explored current distribution of the tamarisk beetle, its effects on the Colorado River, and restoration efforts on the Virgin River. Guest speakers included Season Martin, restoration coordinator with the Tamarisk Coalition, and Mary Anne McLeod, manager of southwestern willow flycatcher monitoring for SWCA Environmental Consultants. The goal of this seminar was to continue public outreach and education about GCT's role in riparian management, to highlight current work by other organizations, and to answer questions from the public about invasive species and their impact on riparian health. The seminar was held at the Cline Library auditorium on the campus of Northern Arizona University (NAU) in Flagstaff, and co-sponsored by the NAU School of Earth Sciences and Environmental Sustainability, GCT and the Tamarisk Coalition. 97 people attended the talk, from experienced tamarisk removal volunteers to concerned scientists and several NAU students. The seminar was free and open to the public. To increase and maximize attendance, the event was advertised in local media outlets (including local Flagstaff newspapers and public radio, riparian-related email list-servs, and the GCT main website and the GCT Volunteer Program website), as well as via Facebook and Twitter. All presentations are included on DVD Appendix V.

Conference Presentations

In January 2009, GCT's Christine Albano and Kate Watters created a poster presentation about the Paria River exotic removal project for the Tamarisk Coalition's Research Conference to reach the scientific and restoration practitioner audience. It was a great networking tool to engage others in discussions about the project successes and challenges. The poster was updated and utilized for the 10-year anniversary of the Arizona Strip National Monuments Celebration in January 2010.

In March of 2013, GCT's Andrew Mount presented the results of exotic removal in Paria Canyon at the Tamarisk Coalition's Research Conference in Grand Junction, CO. Entitled "Lessons Learned from a Multi-Year Exotic Removal Project: A Case Study of the Paria River Wilderness" this was an ideal forum in which to share our unique experiences with this project. The presentation itself was a hit with the audience and quite a success, while the conference overall was a great opportunity to network with others professionals in the riparian restoration community across the western U.S. We hope to present at this conference again in the near future to share our final monitoring results from our work in Paria Canyon. All presentations are included on DVD Appendix V.

Press

In 2008, the Paria River exotic removal project had successful coverage in local, regional and national magazines. One example of national press attention the project received included a mention in the July 2008 issue of *Shape Magazine,* encouraging readers to "Blast calories while you give back." Over 150 people contacted the GCT volunteer program looking to volunteer or get more information about the project. The Paria project also received regional attention from author Mike Wolcott, who described the Paria River exotic removal efforts in his article "No Pay, No Problem: New volunteerism on public lands can change your life," in the November/December 2008 *InsideOutside Southwest. The Lewis and Clark Chronicle* also mentioned the project and included a full color photograph of college student participants that helped with the baseline assessment portion of the project. Additionally, *The Plant Press*, a publication of the Arizona Native Plant Society, published an article that highlighted the Paria River project titled, "Grand Canyon Trust Volunteers: Partners in Protecting Biodiversity."

In 2009, the Paria River exotic removal project had less coverage in national and local newspapers and magazines than the overwhelming success of 2008. Local press attention the project received included a mention in the Arizona Daily Sun about the prescribed fires in the Paria Canyon as part of a riparian restoration project and an article in the *Flagstaff Live!* by Kate Watters entitled "What would Ruess do? The uncertain fate of desert streams."

In 2010, press coverage for the project was restricted to a thank you letter written to the Kane County Rescue Team that was printed in the Southern Utah News. Copies of all of the publications and presentations associated with the project are included in Appendix 4.

In January 2015, Kate Watters, from Grand Canyon Trust and Kevin Wright, from Vermilion Cliffs National Monument, were interviewed on KSUB Talk Radio 590 in Cedar City about the project.

On-trip Project Presentations

On both Paria River removal and monitoring trips, GCT field leaders incorporated a project presentation based on our educational seminars into the project orientation, sometimes even giving the PowerPoint on a laptop computer at the trailhead picnic table the night before hiking into the canyon. This allowed volunteer participants to understand the background and history of the Paria River and how the project came to fruition. GCT field leaders also conducted an approximately 3-hour-long training at the trailhead before each trip, covering topics such as: exotic and native species identification; cutting techniques; herbicide safety; burn pile construction; data collection methodology; and Leave No Trace practices

On the October 18-25, 2008 exotic removal trip, participants joined a field trip about tamarisk removal efforts with the Colorado Plateau chapter of the Society for Conservation Biology. Regional experts discussed issues surrounding tamarisk removal. Talks included GCT's restoration coordinator, Christine Albano, who gave a short presentation on the Paria River exotic removal project. Volunteers were able to mingle with 25 conservation biologists at the project site, and gain insight into how the project is nested within larger riparian restoration issues, such as the introduction and spread of the tamarisk leaf beetle.

In addition to these formal presentation opportunities, GCT field leaders continued to informally educate volunteers and Paria recreational users throughout the duration of backcountry trips on the methods and significance of the project.

Web-based Communications

The GCT utilized both the Volunteer Program website and Kane and Two Mile Ranches website which were updated in 2008 thanks AWPF support. These portions of the GCT website include background information about the importance of riparian ecosystems for preserving biodiversity in the southwest and details outlining Paria River exotic removal activities. This web-based communication was a successful public outreach tool for recruitment and education about the project. AWPF is acknowledged on the links/resources and partners page of the GCT Volunteer Program website.

Via the internet, potential volunteers and the public could see the project area, and participants had the opportunity to share their experiences through comments. An intern from Northern Arizona University also made a short film called "The Volunteer

Experience," which highlights the Paria River exotic removal efforts among other projects. This film was added to the GCT YouTube Channel for the public to view:

Exotic removal trips were advertised on the Grand Canyon Trust Volunteer Program website, where potential volunteers could read project background information and descriptions and sign up for trips online. The Volunteer Program also created an online photo gallery to link viewers to photographs of Paria River exotic removal trips. This allowed potential volunteers can get an idea of what trips are like and gave volunteers the opportunity to share their experiences.

Information about the project was available on the Vermillion Cliffs National Monument website for the interested public and potential volunteers to find out about the project.

Interpretive Materials

Throughout project implementation, GCT crews had very positive interactions with visitors while living and working in Paria Canyon, although many hikers were not aware that the project was underway. Brochures at trailheads and visitor centers were crucial to inform both day and overnight visitors about the project and educate the public about the importance of exotic removal for the health riparian ecosystems. In 2009, GCT began discussions with BLM Grand Staircase-Escalante National Monument interpretive staff to discuss brochure and interpretive sign design at Paria Canyon trailheads in order to better reach the public about the significance of the project. There were concerns about too many signs at trailheads since there were already two signs at each trailhead about the importance of riparian areas. This led to redirecting funds that were allocated in the budget for interpretive signs towards printing more brochures.

In January 2010, GCT's Kate Watters updated the poster presentation about the Paria River exotic removal project for the Tenth Anniversary of Vermilion Cliffs and Grand Canyon Parashant National Monument. This updated our BLM partners about the project and was a great networking tool to engage others in discussions about the project's successes and challenges. On May 24-25, 2010, GCT's Christine Albano presented this poster and a Power Point presentation about the Paria and other GCT projects at the National Landscape Conservation System Science Symposium in Albuquerque to an audience of BLM natural resource managers.

In 2012, we finished the design of the project brochure with input from the BLM, AWPF, botany experts and a new partner, the Friends of the Cliffs, who committed to help us raise funds for subsequent printings and revisions after the AWPF funding has expired. GCT hired a graphic designer to complete the brochure and printed an initial run of 5000 copies. The brochure provided general information about riparian areas in layperson terms and highlighted both exotic and native plants for visitors to learn about while they hiked Paria Canyon. Copies of all of the interpretive materials associated with the project are included in Appendix 4.

Lessons Learned

Logistical Challenges

We encountered a few challenges throughout our volunteer-driven exotic removal project in a wildness setting. Unquestionably, one of the most significant was the extremely isolated and potentially hazardous environment. The sheer remoteness of the project area influenced the amount of actual work we could accomplish, and by final year of exotic removal, crews were hiking 15 miles one-way. As a result, a 7 day trip would entail three full days of hiking, significantly reducing the amount of available time to get on-the-ground work done.

Similarly, the weight and bulk of tools, herbicides, food, human waste, and other gear presented a significant challenge. A week's worth of food alone for a group of up to 10 people could weigh many hundreds of pounds. Several gallons of liquid herbicide, along with numerous hand tools and data collection supplies added significantly more weight to crew's packs. Additionally, since GCT crews practiced "Leave no Trace" principles in Paria Canyon, which involved carrying out all solid human waste, the ability to significantly lighten pack weight over the course of a trip was reduced. We were able to identify a horse packer to help haul some gear into and out of the project area, although this added to the project cost and, potentially, impacted the recreation experience of other visitors.

The above concerns, coupled with the resulting bulky and awkward packs, made it imperative to recruit and properly screen volunteers to assure they were appropriate for the project and up to the physical and mental demands presented by the Paria River.

The preceding issues add up to one significant overarching challenge: *risk management*. In a deep, long narrow canyon with little communication with the outside world, difficult terrain, heavy packs, hard physical work, the very real threat of flash floods and physical injury (we had firsthand experience with both), and hours or even days of foot travel to the nearest trailhead, thorough plans and protocols for communication aand emergency response must be in place. These same issues should be carefully considered when undertaking restoration work in any remote environment.

Herbicide Use

In addition to the herbicide-related challenges mentioned above, herbicide use with volunteers in a backcountry setting presented other challenges. In particular, while the project's site-specific Environmental Assessment (EA) required the use Triclopyr-based herbicides, we learned midway through the project that Imazapyr-based herbicides would have been preferable. Imazapyr is lighter in overall weight because it can be used in smaller concentrations than Triclopyr. It is less toxic and does not pose the threat of irreversible eye damage that certain Triclopyr-based herbicides do. Additionally, Imazapyr is widely reported (including reports from the vegetation crews at Grand Canyon National Park) to be more effective at treating exotics, although we did not test that in the field because of EA constraints. Despite this, our data suggest that Triclopyr was effective at killing exotics following initial and follow-up treatments.

The BLM required that at least one field leader on each trip be a BLM-certificated Pesticide Applicator. While this week-long training cost the project $1500 (including travel and lodging) per certification, plus time away from the office, the classes were, unfortunately, primarily focused on overviewing a wide variety of pesticide uses and did not focus specifically on tamarisk and Russian olive treatment methods. As a result, we still a lot to learn after the formal training process, much of which was learned by trial and error. Additionally, we had to develop our own secondary containment, mixing, spill management and transportation protocols. Herbicide applicator trainings for backcountry hand application projects could be improved to provide backcountry-specific information and hands-on training. This would make them more appropriate and cost-effective.

Treatment Methods

We observed substantial regrowth following initial treatments in many of the treatment areas but regrowth was considerably less following retreatment. Initial treatments in the flood zone were less effective than on benches and terraces. This could have been due to a number of factors, including possible differences in effectiveness between Garlon 3a and Garlon 4 Ultra, greater dynamism and resilience within the flood zone, or simply the tiny size of seedlings commonly found in the flood zone and the resulting difficulty in fully eradicating them. Similarly, it was often difficult to distinguish initial vs. re-treatment of seedlings and saplings in the floodplain. Despite this, we did not see substantial differences between the two zones following retreatment. Thus, our data suggest that at least one, and more ideally two follow up treatments are necessary for treatment success, especially in the flood zones.

In a backcountry setting, it is very important to have an appropriate ratio of herbicide sprayers to tree cutters. This helps assure that every cut stem and stump gets sprayed, and in a timely manner. We found that a 4:1 cutter-to-sprayer ratio was the largest manageable size. Smaller ratios can be even better, helping assure more accurate data collection if the rush to spray all cuts is reduced. It is also important to strike a balance between the amount of time spent digging out stumps buried in soil, litter and debris before cutting and spraying them and simply cutting them and moving on. Too much time spent digging rather than cutting and spraying can be counterproductive.

Data Collection

Due to group size limits, volunteer experience, and attempts to track the number of cut stems vs. individual trees, our data might not have always been as accurate as possible. It can be very difficult, if not impossible, to tell an individual tamarisk from one that is partially buried with numerous branches above the soil surface. Protocols for making these judgments are difficult to develop and agree upon, but should be sought. It was therefore helpful and ultimately very valuable to quantify removal by both stems and canopy cover. Overall, we felt that cover estimates were more accurate and consistent than individual trees, again related to time-intensiveness and "what constitutes a single plant" issues. These canopy cover estimates were also more accurate for quantifying re-growth percentages.

While many projects don't collect the kinds of data in the preceding paragraph, the information is very valuable to give an accurate measure of treatment effectiveness. We also separately tracked removal by geomorphic surface (flood zone and terraces) and by age class. These data sets allowed us to quantify differential effectiveness of treatments by age class and geomorphic surface.

Pile Burning

Burning piles of slash from exotic removal activities by BLM fire crews was part of the project plan from the outset. In the end, we were not certain if this had significant benefits because it also presented significant challenges. The area's remoteness and logistical difficulties were sometimes challenging for BLM fire crews and the piles were not always burned right away. It takes greater care and effort to build piles that will burn well. Furthermore, in the narrow parts of Paria Canyon there often was simply not enough room to burn piles without some unavoidable negative consequences.

We started the project by building burn piles on terraces. The resulting burns had the potential to burn unwanted areas, damage native vegetation, encourage recruitment of other exotic species (including red brome, cheatgrass, and Russian thistle), or leave unsightly scars in this popular recreation destination with limited camping availability. However, in many areas native vegetation recovery was strong.

Over the last two years of the project, we switched to burning in the floodplain. This presented different challenges. For example, it could be exceptionally difficult to build burn piles when majority of growth was on terraces because of the need to drag cut material greater distances than burning on the site it was cut. Piles could also negatively impact the visual experience of recreationists or impair river crossings by getting swept downstream in floods. This also poses the potential spread of tamarisk as the cut branches are capable of rerooting. However, if done in a timely manner, we felt that burning in the floodplain was best since the scars wash away in time and the risk of encouraging the growth of subsequent exotic species was diminished.

Adaptive Management

Due to previously described unforeseen circumstances, progress in treatment implementation was slower than initially anticipated. Moreover, we recognized during 2010 that we would not be able to treat the entire project area with the funds allocated by AWPF. Additionally, the tamarisk leaf beetle (*Diorhabda carinulata*) arrived on site sometime around 2009-2010, well after the project was underway. Due to slower than anticipated progress and the newfound presence of the tamarisk leaf beetle, which was actively defoliating tamarisk in the project area, we shifted our priority to initial treatment of Russian olive and focused tamarisk removal to our monitoring transects. We were able to be flexible and re-purpose some transects that were never treated to monitor beetle impacts. An adaptable approach like this is particularly important in remote environments, where unforeseen challenges can necessitate creative changes in order to achieve exotic removal progress and still collect meaningful data.

Monitoring

Through the course of the project, we collected a large amount of data that will allow us to assess project effectiveness over the long term. Our monitoring design assumed that we would finish the project, and in retrospect, we wish we had anticipated that we may not have completed the work and established more transects further upstream so that we could ensure treatment of all of the monitoring transects that were established.

We collected several measurements to attempt to characterize treatment effects on channel morphology but these measurements ultimately did not prove to be useful for a number of reasons. Due to the nature of the canyon, we were not able to establish physical benchmarks for our measures of active channel width and this proved problematic in terms of being able to accurately remeasure these features following treatments. We did establish physical benchmarks for our five cross-sections in our baseline monitoring effort but this required a survey rod, tripod, and total station and this equipment was both heavy and awkward and ultimately not reasonable to carry in to such a remote project area. Perhaps most importantly, given the dynamic and constantly changing nature of the Paria River, we realize that it is likely that it would take a much more substantial removal effort than ours to be able to detect geomorphic change and that high-resolution remote sensing may be a more appropriate tool for doing so than the measurements we collected.

Our baseline assessment data analysis highlighted substantial differences in the vegetation communities between flood zones and riparian terraces. We also saw differential treatment effectiveness between these zones, with initial treatments showing somewhat more regrowth in the flood zone than on the terraces (though there was ultimately no difference following retreatments). Because we did not treat all of the transects, we ultimately will not be able to assess differences in ecological outcomes following treatments between these two zones because our sample size is not sufficiently large. However, we think this design element is important to consider in future removal monitoring efforts, particularly because exotic removal from drier riparian terraces may be more likely to result in an overall decrease in habitat structure as they are more likely to be colonized by short-stature upland grasses and shrubs. Thus long-term trajectories following removal are likely to differ among these zones and this is important to keep into consideration.

Our post-treatment vegetation monitoring data suggest that changes beyond removal of exotics have been small and incremental and it will likely be many years before we can truly assess project success. In retrospect, we would have liked to have built in a longer time interval to conduct post-treatment monitoring into the original proposal and scope of work to ensure that funding was secure to conduct measurements on a time scale in which we can more definitively characterize project success. That said, and we hope to secure additional financial support to continue our monitoring work over the longer term, for example, on the basis of once every 5 years.

Photopoint Data

We learned several lessons establishing and retaking long-term photopoints for this project. One unfortunate unforeseen problem was due to the funding schedule and volunteer group availability, we had to do our baseline monitoring in March, when the trees were leafless. Thus, the comparison between the pre-and post-exotic removal photos is not ideal. Secondly, establishing long-term photopoints with college students was not a great decision. There are several segment photopoints that do not show a significant stand of tamarisk or Russian olive, due to the fact that the volunteers were new to this kind of task that requires careful thought. However, the transects and campsites are for the most part, the best examples of the long-term change after removal. Another challenge was organizing and storing six years of repeat photography. The format in which we have them organized is not very easy to interpret. This is due to the design of the Access database where we have them stored and organized. Unfortunately it is very quirky and the person who created it is no longer working for the Trust to be able to fix the bugs. It would be way too time consuming for us to rectify this for every single photograph, at this point in the project. However we did include a subset of the most representative photos in this report, by extrapolating them from the database and putting them in a Powerpoint file with some descriptive text interpreting what is being represented. See Appendix 2.

Public Outreach and Partnerships

Riparian restoration offers opportunities for public/private partnerships between land management agencies, state funding agencies, non-profit organizations, and the public. This project allowed a unique partnership between BLM, AWPF, GCT, volunteers and recreationists. This allowed us to engage a broad base of the public to increase public support for restoration on public lands, and model a new, inclusive, and multi-stakeholder approach to public lands management. We quickly and frequently observed that *hikers and backpackers love tamarisk killers*. The overwhelmingly positive interactions between work crews and recreationists helped build good will between land managers, non-profits and the public.

A unique aspect of our project was that volunteers were involved in every aspect from start to finish. From teens to retired adults, volunteers helped with the baseline assessment, exotic removal, monitoring, and some data entry. We also engaged numerous young people by partnering with American Conservation Experience, AmeriCorps' National Civilian Community Corps (NCCC) and college groups. The most cost effective of these was NCCC. In addition to helping further GCT's goal of building the next generation of conservation leaders, youth groups were simply a lot of fun to work with.

Another innovation related to the Paria River exotic removal project is the Plant Atlas of Arizona Project's (PAPAZ) "Budding Botanist" perennial volunteer program. PAPAZ is a partnership with the Arizona Native Plant Society, Grand Canyon Trust, Desert Botanical Garden, Forest Service, Northern Arizona University, and Museum of Northern Arizona to document the plant diversity of Arizona by training volunteer botanists. This project can serve as a model for achieving cost-effective restoration project monitoring, while simultaneously nurturing an active and knowledgeable constituency of volunteer stewards. Botanists-in-training learned plant identification, collection, and documentation skills throughout the year in field and classroom settings from regional experts. In turn, they brought high-level technical skills to assist with vegetation monitoring and documentation. We found that this was a win-win situation, by providing a means for interested volunteers to develop and hone a valuable skill set while increasing the capacity for higher-level project implementation work to be achieved by volunteers.

A further benefit of our work with volunteers was that a subset of individuals, after gaining exotic removal experience on the Paria River project, went on to become valuable resources for other regional exotic removal projects at places like Grand Canyon National Park. A set of these volunteers even helped advise GCT staff on the Paria River project itself.

Future Work

It is important to note that in remote backcountry settings, it is possible – even likely – that exotic removal projects will be more expensive and less productive than originally envisioned. Despite incredible effort by both staff and volunteers, we ultimately completed approximately 10 miles of the 13 miles we set out to treat, or 76% of our goal. While we certainly do not see this as a failure, it is an important consideration to bear in mind going forward. The concept of adaptive management takes on very real meaning when you are not able to treat the entire area you set out to, and toward the end of the project we ultimately adapted our approach to prioritize removal of Russian olive (given presence of the tamarisk beetle) and to treat our transects so that we could establish a strong foundation upon which to ultimately assess the effectiveness of the project in terms of meeting ecological objectives. With continued monitoring, these data can help to demonstrate the costs, benefits, and implications of future tamarisk and Russian olive removal efforts in Paria Canyon and elsewhere in the region– whether volunteer-driven or otherwise. That said, we hope to garner additional financial support to continue periodic monitoring to assess long-term trends associated with exotic removal as well as to monitor the effects of the tamarisk leaf beetle.

In 2014 we observed an increase in invasive Russian knapweed (*Acroptilon repens*) populations in both size and frequency since the initial monitoring trips in 2008. Early detection of this troublesome species and the formulation of an eradication and monitoring plan for this species should be a priority to prevent its spread.

Beyond actual exotic removal work, one of the biggest lessons we learned was that wilderness exotic removal projects are very logistically and risk intensive. Which brings up an important question: is it worth risking injury or even lives to kill trees? This is not a hyperbolic or merely rhetorical question, as we did experience some minor injuries and one significant flash flood event. While we completed the project essentially unscathed, we struggled with this. It is up to project managers to weigh risks and benefits on a case-by-case basis, but our experience indicates not to underestimate the importance of logistical and risk management challenges. Given a remote enough wilderness setting, it may be worth asking how to do this type of work efficiently and still collect meaningful data without helicopters, significant support via pack animals, and/or large, established base camps.

In December of 2014 Grand Canyon Trust met with Kevin Wright, the Vermilion Cliffs National Monument manager and several other key staff from the Bureau of Land Management Arizona Strip Field Office to discuss the project results and plan for continued work in the Paria Canyon. The BLM will be using the information presented in this report to plan subsequent phases of the project. Key to the success would be to identify Russian olive as the primary target for removal, and to establish blocks of time for conservation crews with experience with saws to work for longer periods of time. If exotic removal is to continue in the Paria Canyon significant evaluation will have to be made about the safety and cost effectiveness of the methodology.

On a more positive note, the Paria River exotic removal project was unquestionably a successful example of partnership and relationship building. Our public outreach efforts were critical to the project's success, and public involvement strengthened both the work and the sense of goodwill between citizens, land managers and non-profit organizations. GCT demonstrated to BLM that partnering with non-profit organizations and the public has positive benefits. We now have a formal research and stewardship partnership with BLM and have proven that this model can work. In December 2014, the Public Lands Foundation recognized the Trust with a 2014 Landscape Stewardship Certificate of Appreciation. See Appendix 4.

AWPF funding and support has been essential to getting this project off the ground, and allowed GCT and the BLM to actively protect and restore this valuable riparian ecosystem. We have established and value a good working partnership between with the BLM and engaged 138 people in over 9800 hours of stewardship in a world class wilderness area.

Literature Cited

Brewer,R. and McCann, M.T. 1982. *Laboratory and Field Methods in Ecology*, Saunders College Publishing, Philadelphia, PA

Clarke, K.R. 1993. Non-parametric multivariate analyses of changes in community structure. Australian Journal of Ecology 18: 117-143

Clarke, K.R. and R.N. Gorley. 2006. PRIMER v6: User Manual/Tutorial. PRIMER-E, Plymouth.

Fleishman, E., N. Mcdonal, R. MacNally, D.D. Murphy, J. Walters, T. Floyd. 2003. Effects of floristics, physiognomy, and non-native vegetation on riparian bird communities in a Mojave Desert watershed. Journal of Animal Ecology. 72: 484-490.

Garlon 4 Ultra an Garlon 3A [herbicide Label]. Indianapolis, IN: Dow AgroSciences; 2006.

Ladenberger, C. G., A. L. Hild, D. J. Kazmer, and L. C. Munn. 2006. Soil salinity patterns in *Tamarix* invasions in the Bighorn Basin, Wyoming, USA. Journal of Arid Environments 65:111-128.

Makarick, L and Watters, K. 2008. Management & Control of Tamarisk and Other Invasive Vegetation at Backcountry Seeps, Springs and Tributaries in Grand Canyon National Park. Arizona Water Protection Fund Contract Number 05-131WPF. Final Revision Submitted to Grand Canyon National Park Foundation and AWPF on February 22, 2008.

Mills, G.S., Bunning J.B. Jr, and JM Bates. The relationship between breeding bird density and vegetation volume. Wilson Bulletin 103:33, 468-479, 1991.

Nissen, S., A. Norton, D. Bean, A. Sher, and K. Lair. 2009. Tamarisk: Best management practices in Colorado watersheds.

Rosgen, D. 1996. Applied river morphology. Wildlife Hydrology, Pagosa Springs, CO.

Schoeneberger, P.J., Wysocki, D.A., Benham, E.C., and Broderson, W.D. (editors), 2002. *Field Book for Describing and Sampling Soils*, *Version 2.0*. Natural Resource Conservation Service, National Soil Survey Center Lincoln, NE.

Scott, M.L. and E. W. Reynolds. 2007. Field-Based Evaluations of Sampling Techniques to Support Long-Term Monitoring of Riparian Ecosystems along Wadeable Streams on the Colorado Plateau. U.S. Geological Survey. Open-File Report 2007-1266.

Scott, M.L. and E.W. Reynolds. In Review. *Integrated Riparian Monitoring Protocol for the Northern and Southern Colorado Plateau Networks of the National Park Service - Standard Operating Procedures (SOPs)*