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FINAL REPORT

Survey and Eradication of Arundo donax and Tamarix parviflora Tehama County

CSU, CHICO RESEARCH FOUNDATION
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CALFED Ecosystem Restoration Program Project 01-N04

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Project Background Information:

This project was submitted to CALFED in May of 2001, proposing to eradicate *Arundo donax* (*Arundo)* on a number of northern California streams in Butte, Glenn and Tehama Counties. A reduced award focused the work on two streams in Tehama County—Reeds and Red Bank Creeks—considered some of the most important contributors to *Arundo* and *Tamarix parviflora* (*Tamarix*) in the Sacramento River system. Other streams in the proposal were eliminated from the scope of work. In 2003, the project was amended to increase the budget and extend the project end date to December of 2006. The degree of infestation of *Tamarix* discovered during the mapping and on-the-ground surveys caused project managers to concentrate efforts on that species, testing eradication methods and revegetation success following eradication.

The partners for this project include the CSU, Chico Research Foundation, the CSU, Chico Geographic Information Center, the Tehama County Resource Conservation District, the Tehama County Department of Agriculture and Sole Terra Farms. The Research Foundation provided project management, monitoring design, monitoring data collection and analysis, and revegetation design and implementation. The Geographic Information Center provided aerial photography overflights and data analysis and mapping of monitoring data. The Tehama County Resource Conservation District conducted landowner outreach workshops and provided a $50,000 match from a State Water Resources Control Board Section 319 grant. The Tehama County Department of Agriculture provided eradication services early in the project and ongoing consultation on eradication methods. Sole Terra Farms conducted the majority of the eradication, including both herbicide application and mulching of dead vegetation.

The project consisted of the following components:

- Aerial photography, mapping and assessment of the infestation;
- Landowner outreach to obtain permission to treat the target species on private property and to provide education on the non-natives impact and management;
- Permitting and environmental review for the eradication project;
- Testing of different herbicide mixes and application methods;
- Implementation of herbicide spraying;
- Mulching of dead *Tamarix* in the active channel and continued spraying in subsequent years;
- Restoration test plots to evaluate passive vs. active restoration and to assess mulching’s impact on restoration success; and
- Follow-up aerial photography, mapping and assessment of the infestation.

Figure 1 - *Arundo* on Deer Creek, Tehama County

Arundo is recognized by CALFED under section 3.2 Ecosystem Restoration Strategic Goals, Goal 4 – Habitat and under Goal 5 – Non-native Invasive species as a concern. It is a “C” listed species by the Department of Food and Agriculture. The impacts of *Arundo* and *Tamarix* are well documented. *Arundo* did not evolve in California and has no effective competitors in California riparian systems. It is a perennial rhizomatous grass native to India that was introduced to Tehama County in the 1920 and 1930’s and specifically to the Red Bank Creek area in about the 1940’s. The tall and dense plant can reach over 40 feet tall, growing 2.5 to 3 inches per day, quickly displacing native vegetation. The result is monoculture of with little habitat value. *Arundo* thickets support much-reduced populations of insects, upon which many wildlife species depend (Herrera 1997). Also, it consumes three times more water than native plants and can survive years of severe drought. It is estimated that an acre of Arundo uses 5.6 acre-feet of water per year, where native species use 1.9 acre-feet.

Arundo responds well to soil disturbances and propagates vegetatively through a rhizome. Although it flowers, the flowers are seldom fertile in northern California. *Arundo* can also propagate from clumps or canes that break off during flood events, which float for miles, reroot and create new, downstream infestations (Else and Zedler, 1996). Clumps commonly break off during high flows, as it is shallow-rooted vegetation and easily undercut and destabilized. Landowners often believe that *Arundo* is an excellent plant for maintaining bank stability, as it forms such dense stands. However, it is actually a threat to bank stability because of its root system and because it can reroot in the main channel and cause stands and gravel bar formation that can deflect flows onto previously stable banks. The method of propagation is important, as control methods must focus on the most upstream occurrences to prevent reinfestation from those sources.

Arundo's flammability and the volume of its debris pose serious economic problems. In the Santa Ana River near the city of Riverside, an Arundo-fueled wildfire stopped just before burning down a bridge, only because a pilot Arundo removal project formed a firebreak. Aside from fire, bridges in San Diego County have collapsed twice during high flows because of Arundo debris trapped behind the structures.

Arundo also causes negative impacts on water quality. It lacks the structure to provide bank shading that is typically exhibited in northern California riparian systems. This allows for higher photosynthesis activity, promoting algae growth and elevated pH levels. High pH facilitates the conversion of total ammonia to toxic un-ionized ammonia, degrading water quality downstream.

Tamarix, a native of southeastern Europe was introduced to Tehama County in the 1920's and 1930's and specifically to the Red Bank Creek area in the 1940's. *Tamarix* has invaded extensive portions of riparian habitat in many Sacramento Valley west-side streams, particularly in the Tehama County area. *Tamarix* spreads through seed distribution, which is exacerbated during flood events. *Tamarix* alters the nature of the stream channel, degrading riparian and aquatic habitats for many fish and wildlife species. The salt substance that it exudes from its leaves is very damaging to the soils.

Figure 2 - *Tamarix* on Red Bank Creek, Tehama County

Tamarix forms dense stands up to 8 meters tall that displaces native riparian species and creates unsuitable habitat for a variety of sensitive aquatic and riparian wildlife species (Bell 1997). *Tamarix* can change the quality and timing of organic litter inputs that form part of the trophic base for steelhead trout, Coho salmon, and freshwater shrimp. This is a vital concern in the context of watershed protection plans to promote the recovery of a variety of listed salmonid species and subspecies. *Tamarix* will likely continue to out compete the native plants, leading to decreased biodiversity and decreased habitat value where it occurs.

Tamarisk is thought to be as much of a fire hazard as Arundo, although the research is not as extensive. In the catastrophic fire that raged through this area in 1999, there were landowner accounts of the fire moving down through Red Bank Creek at a life threatening pace only to stop at the area of the creek devoid of Arundo and Tamarisk. There is a stretch of the creek where there is little to no Arundo or Tamarisk; it was in this area that the fire burned out. (Landowner account, personal comm. 2001).

Location

This project was conducted in the Sacramento Valley Ecosystem Restoration Program Region and in Ecological Management Zone 6.2 in Tehama County. A map of the Red Bank Creek location is provided in Figure 3 and Reeds Creek location is provided in Figure 4. These streams are typical of west side tributaries of the Sacramento River. They exhibit flashy flows, highly mobile gravel beds and generally no summer flows. They drain the east side of the Coast Range to the Sacramento River.

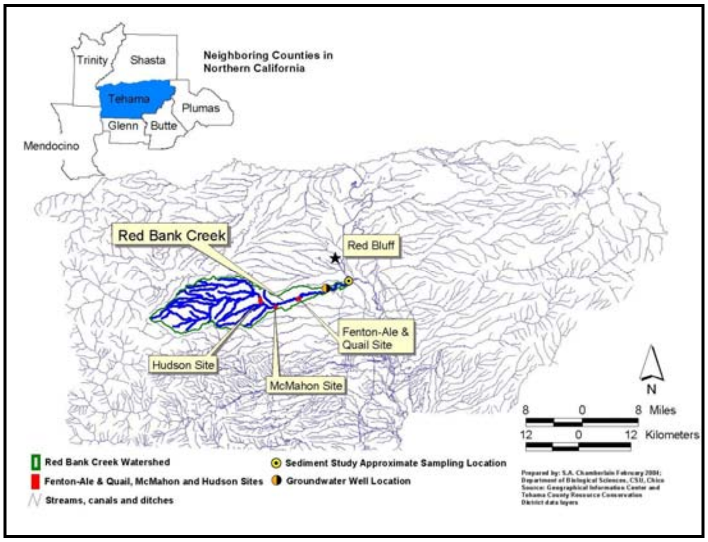

Figure 3 - Red Bank Creek Location Map

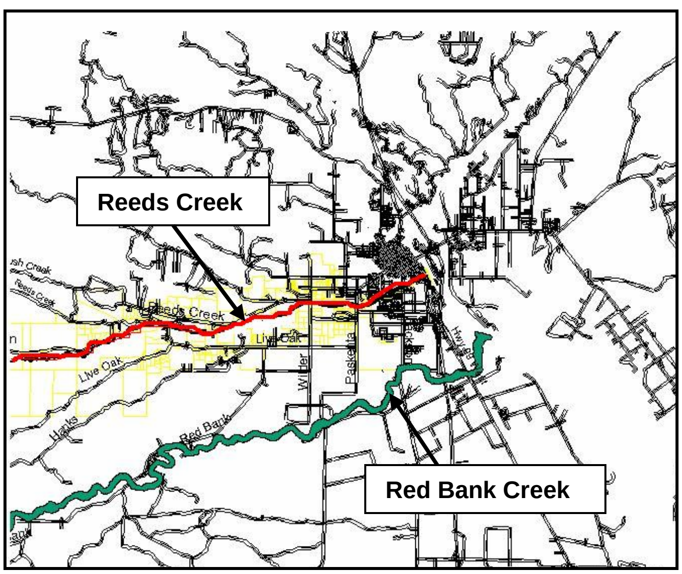

Figure 4 - Reeds Creek Location Map

Objectives

This project has two complementary objectives related to the eradication of non-native species. One objective of the project was to identify and eradicate areas infested by Arundo donax and Tamarix on Red Bank Creek and Reed's Creek. Project activities supporting this objective included mapping of the non-native vegetation, obtaining landowner permission for eradication activities, permitting, application of herbicides, mulching of dead non-natives that were infesting the active stream channel, follow-up spraying and monitoring of eradication success. The project also examined how native plant abundance and diversity varied among successfully eradicated areas that were actively vs. passively restored. This objective was accomplished through the implementation of two test sites on Red Bank Creek in areas of heavy *Tamarix* infestation. Work towards accomplishing these two objectives is described below.

Hypothesis tested

The conceptual model for this project was simple: removal of non-native species will result in opportunities for the regeneration of native riparian vegetation. Infestation mechanisms are reasonably well understood, but research on native recolonization following eradication is limited. Thus, this project proposed three hypotheses. While they were originally envisioned to be applied to *Arundo* infestations, the research sites were implemented in areas of *Tamarix* eradication as a result of the extreme nature of the infestation that was discovered during the initial mapping of Red Bank Creek and the willing cooperation of two landowners with large stream frontage that allowed multiple text plots at each site. The three hypotheses tested were:

1. Native species of woody riparian plants will colonize the space opened by the removal of non-native vegetation.
2. Planting of nursery grown riparian plants in the space opened by the removal of non-native vegetation is more effective restoration than natural regeneration.
3. Removal of non-native vegetation from entire reaches of a creek will change the channel geomorphology and lessen flood damage issues.

Relationship to ERP goals

The ERP Strategic Plan identified twelve areas of scientific uncertainty on which better information and understanding is needed. As noted the concept of limiting factors is an important aspect of scientific uncertainties. The success of our restoration efforts are ultimately tied to the appropriateness of management action which can be assessed on how favorably the native plant species respond to the removal of non-native species. Many different factors control plant growth responses under different environmental conditions, and those factors most limiting to the distribution and abundance of populations are usually unknown. This project sought to gain greater level of knowledge of the conditions necessary for successful native plant propagation following non-native species eradication.

The Strategic Plan identified non-native invasive species as one of the most important issues facing the CALFED Ecosystem Restoration Program. Our goal is to assist in answering questions pertaining to the competitive relationships between native and non-native species and the most effective way to prevent new infestations and manage those that already exist.

Specifically, this project addresses:

Goal 5 of the Ecosystem Restoration Program to "Prevent establishment of additional non-native species and reduce the negative biological and economic impacts of established non-native species"

- Objectives **6** to "halt the introduction of invasive aquatic and terrestrial plants into
- Central California" and
- Objective **7** to "focus control efforts on those introduced species for which control is most feasible and of greatest benefit."

These project objectives correspond with Goals **I, II,** and **III** of the Nonnative Invasive Species Plan to prevent and control the spread of NIS through appropriate management, and reduce their negative ecological and economic impacts. This project addresses the issues identified in the plan of leadership, authority and organization, coordination, cooperation and partnership, and education and the primary objective of this project is to protect remaining native riparian habitat from destruction by the nonnative invasive vegetation**.**

Project work

The project area encompassed approximately 630 acres of stream bed and banks and 16.7 km of stream channel. On Red Bank Creek, the project focused on *Tamarix*, as the infestation proved to be of such a magnitude it warranted the majority of the project resources to address. Eradication on Reed's Creek focused on *Arundo*.

Mapping

The Geographic Information Center conducted aerial overflights of Reeds and Red Bank Creeks in July of 2002. Airphotos were flown at the nominal scale of 1"=800' (RF 1:9600) and a forward overlap of 60 percent. The 9 X 9″ contact color prints were scanned at 400 DPI (dots per inch), transformed into digital orthophotographs, and interpreted onscreen using a "heads-up digitizing" process in ArcView GIS. *Arundo* and *Tamarix are* clearly distinguishable on photography at this scale. The mapping scope incorporated all riparian plant types including both native and non-native species. Our classification system was based on the CNPS (California Native Plant Society) vegetation classification system developed by Sawyer and Keeler-Wolf *(A Manual of California*

Vegetation). Final mapped data is referenced with base maps showing various native and non-native habitat types including *Arundo* and *Tamarix* distributions.

The photo interpreted non-native vegetation was followed up by on-the-ground assessment of the project areas on Reeds and Red Bank Creeks. CSU, Chico biology students mapped all the *Tamarix* between the County gravel pit (the upstream end of the project area) and the Ale and Quail property (the downstream end), except for those properties where permission had not yet been secured (See Appendix A for monitoring protocol). These polygons were overlain on the 2002 aerial photography and maps produced for field use.

Outreach

Aerial photography produced by the Geographic Information Center was overlain by parcel lines and numbers, along with the photo-interpreted location of *Arundo* and *Tamarix*. This information identified those key parcels that needed to be included in the eradication effort. The Tehama County Resource Conservation District was the lead for outreach when it initiated in 2002. After compiling addresses form county assessor's records, outreach began with an invitation that was mailed to all riparian landowners along Red Bank and Reeds Creek to a workshop where the project goals and scope were discussed. (The challenge in working with these records should be noted as addresses and/or ownership was not current and required significant resources dedicated to follow-up.) The workshop stressed the importance of landowner participation and the opportunities for continual landowner input. A key issue that the landowners identified was the potential loss of bank stability from eradication of *Tamarix* on stream channels on Red Bank Creek. The program managers provided the option to landowners to condition their landowner agreements to prohibit any eradication work on the banks including spraying and only allow spraying and mulching within the active channel. Three landowners elected to condition their agreements in this way. Follow-up mailings sought additional participants.

In addition to the mailings, outreach coordinators went door to door to seek signed agreements from those landowners who had not responded to the mailings. The Tehama County Department of Agriculture assisted with outreach to landowners, as did CSU, Chico personnel the eradication crews once work had initiated.

Outreach followed up with additional mailings and with door to door visits for properties where no response was received. As coordinators worked to obtain additional signed landowner agreements, the next phase of outreach sought landowner input on the eradication strategy document in 2003. This document was provided to all landowners who had signed agreements, with a request for their review and input. Another workshop was held to discuss the results of the landowner input.

Outreach on the project resulted in thirty-five participating landowners on Red Bank Creek. On Reeds Creek, all of the *Arundo* infested property was included in the project with full landowner participation. One landowner on Reeds Creek rescinded her agreement, but rejoined the project once she was given information about the safety of the herbicides and application methods. One landowner on Red Bank rescinded their approval, but did not have *Tamarix* on their property. One landowner upstream of the treatment area refused to participate, despite repeated requests from project staff and the Tehama County Department of Agriculture. The landowner was offered herbicide to allow her own application and the County offered to treat the *Tamarix*. Nothing could convince her to participate. Unfortunately, this property was the most upstream occurrence of *Tamarix* on Red Bank Creek. An additional neighbor just downstream is an absentee owner and did not respond to repeated mailings. Their number was not listed in the phone directory. One additional landowner within the treatment area refused to participate, but owned very little of the creek and no *Tamarix* was located on his property.

Outside of these few instances, the project was able to secure landowner permission to treat all the *Tamarix* along 16.7 km of stream channel. Three of the landowners limited their approval to the active channel only, with no permission granted for eradication on the stream banks.

A copy of the agreement between the landowners and the Tehama County Department of Agriculture and the eradication strategy document, are included in Appendix B.

Permitting

The California Department of Fish and Game was the lead agency for the project under CEQA and issued a streambed alteration agreement for the eradication. The City of Red Bluff was able to amend an existing streambed alteration agreement for non-native eradication and bank stabilization work, significantly reducing permitting timelines and cost. Fish and Game was also the lead agency and issued a streambed alteration agreement for the restoration experiment. Neither project component came under Army Corps of Engineers jurisdiction under Section 404 of the Clean Water Act or Regional Water Quality Control Board jurisdiction under Section 401.

U.S. Fish and Wildlife Service authorization was required in order as elderberry was found at the Fenton revegetation test plot (see description under Restoration Experiment). The Service did not require a full consultation, instead authorizing the project to proceed based on avoidance of all impact to the Valley Elderberry Longhorn Beetle. National Marine Fisheries Service authorization was not required as all work was conducted in a dry stream channel.

Eradication

Eradication of *Arundo* and *Tamarix* is an herbicide based program. Generally, a systemic herbicide licensed for use near water such as Rodeo or Aqua Master and or Round-Up Pro and Stalker for plants out of the active flood channel, was applied to kill the root system of the nonative plants. Timing of the herbicide application is the critical element to the success of the control effort. For *Arundo,* herbicide application in the fall right before the plant goes dormant is best, however the plants do respond well to multiple sprayings through out the year. However, it should be stressed that application in the fall is critical. Determining when the *Arundo* plant will go dormant can be tricky. In general, we look for signs of slowed plant growth and a slight browning of the leaves.

Tamarisk can be treated at anytime, and responds well to multiple applications timed throughout the season. Tamarisk does not respond to Glyphosates, but instead seems to do better with Imazapyr based herbicides.

Following treatment with herbicides, the project tested the use of a skid steer-mounted masticator on vegetation that had colonized the active stream channel (See Figures 5 and 6. It was also used to mulch test plots in the revegetation experiment as described below. The skid steer is equipped with rubber tracks, instead of metal ones, which have much more negative impact on the stream channel. The bobcat is extremely maneuverable and this maneuverability assists with avoiding non-target species. The masticator is well suited to *Arundo* and *Tamarix* mulching, as they generally grow in dense monocultures.

Figure 5 - Masticator

Figure 6 - Skid Steer with Rubber Tracks

Follow-up treatments are usually necessary for one to five years after the initial treatments. We did see re-sprouting from the tree root area, this is not uncommon and we were told by the lead chemist from BASF that the Imazapyr takes longer to get into the root system often making the plant sick but not killing entirely in one season. This project accomplished three years of eradication work on most properties. Often in the lower, frequently-flooded stream banks, we will see spontaneously re-infestations appear. These same areas often revegetate with natives more easily with the upper banks needing more assistance.

One of the big issues on Red Bank Creek is the lack of native riparian vegetation in many of the heavily infested sites. Many of the landowners are very concerned that if the Tamarisk in particular is removed that they will have no vegetation to protect their banks. This concern, along with CALFED interest in understanding whether eradication results in increased native species, led to the design and implementation of the restoration experiment.

Initially we treated the Tamarisk at the top of the watershed on Red Bank Creek concentrating our efforts on a 200 acre piece of property (Duffy Eaton). We used this property with the approval of the landowner and his niece to help us determine the most effective herbicide mixed needed to control Tamarisk. David Stoffell, senior biologist with Tehama County Agricultural Commissioners office, worked closely with Sole Terra to determine efficacy of herbicide and surfactant mixes and dosages.

It was our ultimate goal to establish the highest percentage of kill with the least amount of herbicide while reducing the costs as low as possible. The end result of these experiments resulted in a 5% glyphosate, 2 % Imazapyr and a 2% surfactant such as Pro-spreader recommendation.

Restoration Experiment

A critical question in non-native species eradication concerns the type of plant communities that recolonize the areas in which the non-natives have been killed. Will other non-natives take hold in the areas of dead vegetation or can native riparian species outcompete? Will active restoration (planting, irrigating and weeding) of native species create a richer riparian habitat compared to allowing species to recolonize the eradicated area? Can we use techniques in eradication to help non-native species recolonize? This project includes an experiment on Red Bank Creek to look at these questions. They are important for resource managers as active restoration is complex and expensive. The data from this experiment can help them to distribute the available resources so that the greatest environmental benefit is gained. The experiment also included testing of willow wattles to assess whether this technique could help address landowner concerns about loss of bank stability with the loss of the streambank non-native vegetation.

The experiment established two test sites in areas of severe *Tamarix* infestation, approximately 7 km apart on Red Bank Creek: the McMahon site and the Fenton/Ale & Quail site. These sites provide typical examples of Tamarix infestation, with both instream stands and streambank stands. For a complete description of the sites, please see Appendix C, Section 2. Each test site included a series of plots to evaluate differences in responses in vegetation including plant species richness, native plant species survival and abundance.

The test sites were compared to a reference site upstream (the Bradford property), which exhibited a relatively intact ecosystem with only a few individual *Tamarix* occurrences. A four factor randomized block experiment was designed as follows: 1) Bank stabilization treatment (NBS=no bank stabilization; WW=willow wattles; RW=rootwads); 2) *Tamarix* treatment (TDS=*Tamarix* left dead and standing or TM=*Tamarix* mulched); 3) Restoration Type (PR=passive restoration, no native plantings or AR=active restoration, native plantings); and 4) Plot, which was used a blocking factor to partition out variation due to location along the creek. There were nine 12 x 30 m plots in the experiment, each with nine 2 x 12 m subplots representing the treatment combinations. There were three bank stabilization treatments when the plots were laid out in preparation for *Tamarix* mulching. The rootwad stabilization treatment had to be dropped due to costs and the lengthy permit process, thus the third bank stabilization subplot was assigned to one of the remaining treatments (NBS and WW) in a stratified random manner.

Active restoration subplots were planted in bands that run parallel to the channel flow to mimic natural riparian forests (Everitt 1968, Noble 1979). Species representing four native plant communities were planted (Holland 1986). Going away from the stream edge these communities were: willow scrub, mule fat scrub, cottonwood riparian forest/valley wildrye grassland and valley needlegrass grassland. Plant community subplot size was maintained but planting area was adjusted to follow topography (e.g. active channels were not planted), and the valley needlegrass grassland community was omitted where not appropriate. The plant communities ranged in area as follows: mule fat scrub from 2 to 15 m^2, cottonwood riparian forest/valley wildrye grassland from 2 to 15 m^2, willow scrub from 3 to 10 m^2, and valley needlegrass grassland from 3 to 8 m^2.

Plots needed to be located entirely within existing stands of *Tamarix*. The size of the streambank *Tamarix* stand at McMahon limited the number of plots there to one. Each plot consisted of three bank stabilization treatment subplots (NBS, WW; see note above) with 3 m buffers between each subplot. Within each bank stabilization subplot were three 2 m wide *Tamarix* treatment subplots (TDS-PR, TM-PR and TM-AR) with 1 m buffers between them. *Tamarix* left dead and standing did not receive native plantings due to the logistical impossibility of movement within the dead stems (thus TDS-PR only). *Tamarix* mulched subplots were either the passive restoration (TM-PR) or active restoration (TM-AR) treatment. Within each active restoration subplot individuals were planted from the four plant communities described above, with plant species locations randomized within each community. A total of 3,284 individuals were planted. The mulched portions of the plots were fenced in 2005 to limit herbivory.

Tamarix mulching and plot placement were done in Summer 2004 with the active restoration planting occurring in Spring 2005. To account for transplant mortality, a 30-day census was completed in Spring 2005 for survival of planted individuals in the active restoration plots. Surviving individuals were used as the baseline for subsequent survival analysis. Monitoring for plant species richness, abundance and survival of restoration plantings was completed in Fall 2005 and 2006. Photographic monitoring of all plots was done at each census period.

To ensure that local ecotypes were used for planting, cuttings of mule fat (*Baccharis salicifolia*), Fremont cottonwood (*Populus fremontii*), narrow-leaved willow (*Salix exigua*), Goodding's black willow (*Salix gooddingii*), red willow (*Salix laevigata*), and arroyo willow (*Salix lasiolepis*) were obtained primarily from Red Bank Creek and secondarily from nearby locations along the Sacramento River. The two remaining woody species, pipevine (*Aristolochia californica*) and California wild grape (*Vitis californica*), and the forbs were local ecotypes obtained from Floral Native Nursery in Chico, CA. The grasses and sedge were planted as plugs and were local ecotypes obtained from Hedgerow Farms in Winters, CA. Plant nomenclature follows The Jepson

Manual (Hickman 1993). If no common name is listed in The Jepson Manual, then Oswald (2002) was used.

Randomized planting maps were generated for each of the 125 plant locations within each 12 x 2 m active restoration subplot. There was careful attention not to plant active channels within a plot. Woody plants (trees, shrubs and vines) were planted on 1-m centers, and grasses, sedges and forbs were planted on 0.5-meter centers. After plant installation, plants were preliminarily watered by hand and then by aboveground rainbird sprinklers.

At each willow wattle bank stabilization treatment subplot, 28 individual willow cuttings were planted at the toe of the bank, approximately 1 foot apart. Four willow species were planted, following Holland (1986) community types. The following numbers of cuttings of each species were planted: 8 narrow-leaved willow, 8 Goodding's black willow, 8 red willow, and 4 arroyo willow.

Follow-up Monitoring

A seven mile stretch of Red Bank Creek was surveyed in July and August 2004 and occurrences of tamarisk were mapped in GIS as either polygons or points. Tamarisk were generally only mapped as points if they were less than 2-4 meters in diameter and not contiguous to a larger stand. When tamarisk plants were mapped as points, estimates of their canopy area and height were recorded. In this set, 586 tamarisk points and 655 tamarisk polygons of various sizes (hereafter referred to as 'tamarisk patches', because both are area measurements) were recorded. Total acreage of tamarisk canopy (live and dead) was estimated by this technique to be approximately 46 acres. The percent of the patch that was living (i.e. vigorous growth) was also recorded. Extent of live tamarisk canopy in the survey area was estimated to be 28 acres.

Occurrences of tamarisk received one of three treatments beginning 2003 and 2004: treated with herbicide ('sprayed'), sprayed and mulched, or untreated (control). Tamarisk patches receiving these treatments were so identified in the GIS.

In order to assess the potential effects of the tamarisk control treatments in a cost-effective manner that avoided having to resurvey the entire study reach, a subset of the original set of tamarisk patches was selected for resurvey using the same methodology as in 2004. Using the information in the GIS data dictionary on the 655 polygons and 586 points from 2004, and eliminating those patches that were not clearly identified as to treatment type and those whose field notes indicated potentially confusing circumstances, a list of 51 patches (26 polygons and 25 points) was obtained. In November 2006 the areal extent of each the 51 patches was recorded using a combination of GPS points and tape measures. A paired t-test was used to assess the before/after changes in tamarisk area on a patch basis.

An aerial overflight of Red Bank Creek was also conducted in November of 2006 to assess success on a larger scale. The overflight was photointerpreted for *Tamarix* and that interpretation was compared to the initial flight in 2001. The photos are included as Appendix D. The photos were also interpreted for channel changes, comparing 2001 to 2006. Those photos are included as Appendix E.

Results and Findings

Eradication

Changes in areal extent of tamarisk were used as the metric to assess the success of the eradication effort. The changes were analyzed for both points (occurrences of *Tamarix* small enough that a satellite receiver could be placed at the center of the plant) and polygons (occurrences large enough the patch had to be GPSed by walking around the patch). The GPS locations for the points and polygons are provided in Figures 7 and 8.

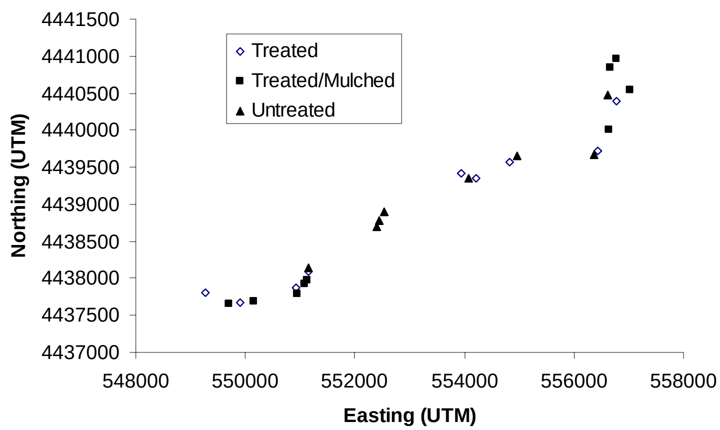

Figure 7 - Geographic locations of resampled polygons along Red Bank Creek in 2006

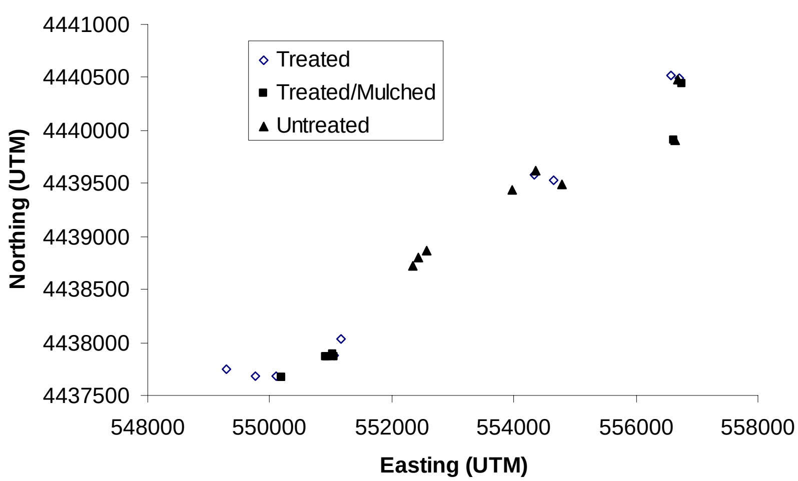

Figure 8 - Geographic locations of resampled points along Red Bank Creek in 2006

Table 1 gives the changes in areal extent of tamarisk polygons from 2004 to 2006 according to treatment type. Untreated polygons (n=8) were virtually unchanged in area during the study period, whereas both sprayed (n=9) and sprayed/mulched patches (n=9) exhibited reductions in area. However, only the sprayed/mulched treatment showed a statistically significant reduction, at 55%.

Table 1 – Changes in areal extent of tamarisk from 2004 to 2006 in polygons

Treatment Type	No. Polygons Sampled	Mean Tamarisk Area (m^2)		Percent Reduction	Paired t-test (p value)
		2004	2006		
Sprayed Only	9	1128.2	893.3	21%	0.147
Sprayed/Mulched	9	229.3	102.3	**55%**	**0.03**
Untreated	8	344.4	332.5	3%	0.50

(Values in bold are statistically significant)

Table 2 gives the changes in areal extent of tamarisk points from 2004 to 2006 according to treatment type. Untreated points (n=8) expanded to more than double their original area, whereas both sprayed (n=9) and sprayed/mulched patches (n=8) exhibited reductions in area. However, as seen above for polygons, only the sprayed/mulched treatment showed a statistically significant change, a reduction of 97%.

Table 2 - Changes in areal extent of tamarisk from 2004 to 2006 in points

Treatment Type	No. Points Sampled	Mean Tamarisk Area (m^2)		Percent Reduction	Paired t-test (p value)
		2004	2006		
Sprayed Only	9	4.6	2.4	46%	0.09
Sprayed/Mulched	8	4.3	0.1	**97%**	**0.01**
Untreated	8	1.8	3.9	-121%	0.19

(Values in bold are statistically significant.)

The results of this study show that spraying combined with mulching is the only statistically significant method of tamarisk reduction. Spraying alone does achieve reduction, but the high variance in response renders this method not statistically significant in this study. However, the results suggest that further experimentation with spraying alone is warranted.

No method achieves 100% reduction. The best method that of spraying and mulching, only achieves 55% reduction in polygons. This suggests that repeated applications of any treatment are required to prevent tamarisk regrowth, especially in established patches of large areal extent.

Greater reduction in tamarisk points, as opposed to polygons, may be due to the fact that some points are clusters of seedlings or very young plants which may be more sensitive to herbicide than well established adult plants. The small areas of points may also mean that they received more complete herbicide coverage than larger areas, with greater proportions of plants receiving herbicide.

It is our deduction that mulching and herbicide applications together result in better control due to native plants from the surrounding area's ability to colonize in and around the treated plants, thus reducing the light exposure and competition for water. The already sick Tamarisk plant does not have the ability to rebound as easily under these circumstances.

The aerial photographs indicate some areas of greater success in eradication. For example, on photo 11 (the most westerly parcel of the treatment area), an extremely large, mid-channel patch of *Tamarix* was successfully eradicated (Parcel 025-080-12-1). This parcel was under lease to Tehama County, and eradication work was initiated in 2003, so this parcel received four years of treatment, rather than three. At the request of the landowner, the streambank infestations on this property, along with four downstream properties, were not treated, and results in remaining infestations as documented on the aerial photograph. The mid-channel patches in this area were all sprayed and mulched and resulted in successful eradication. The photo interpretation indicates that mid-channel, mulched patches generally responded better to the eradication (Photos 11, 10, 9, 3,).

Aerial photographs also indicate some channel movement in Red Bank Creek from the 2001 flight to the 2006 flight. For Map 11 (See Appendix D), it is evident that, where the channel had been flowing against the bank in 2001, the eradication of the large patch discussed above was associated with the channel movement away from the bank (See Figure 9). There was also channel movement in the area of a mid-channel *Tamarix* patch removal on the McMahon study site (see Map 9 in Appendix D).

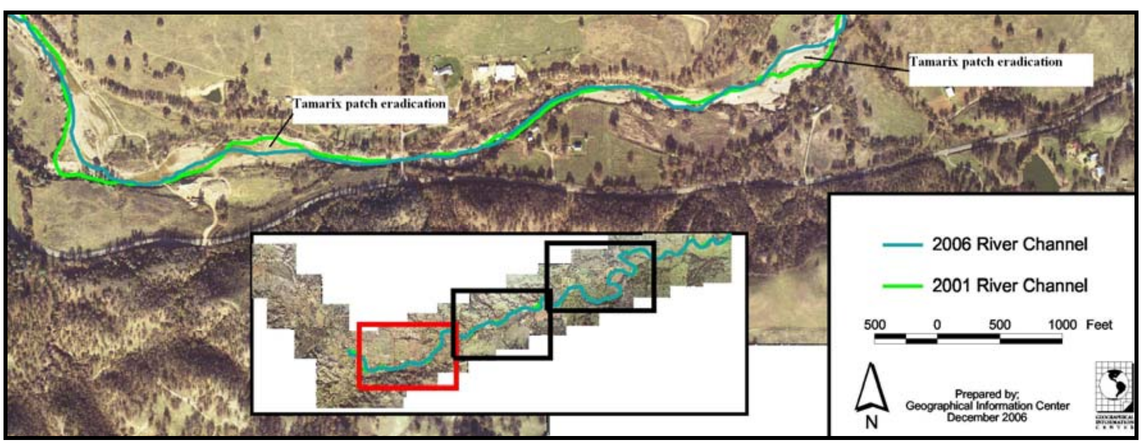

Figure 9 - Channel change associated with *Tamarix* Removal

However, channel shifts also took place in areas where there was no mid-channel eradication of *Tamarix*. These shifts are exhibited in Figure 10 below, with the eradication indicated on Maps 5 and 6 in Appendix D. Therefore, it is difficult to conclude that eradication of mid-channel *Tamarix* will restore natural channel mobility, as the data is limited. However, the data indicate that further research is warranted.

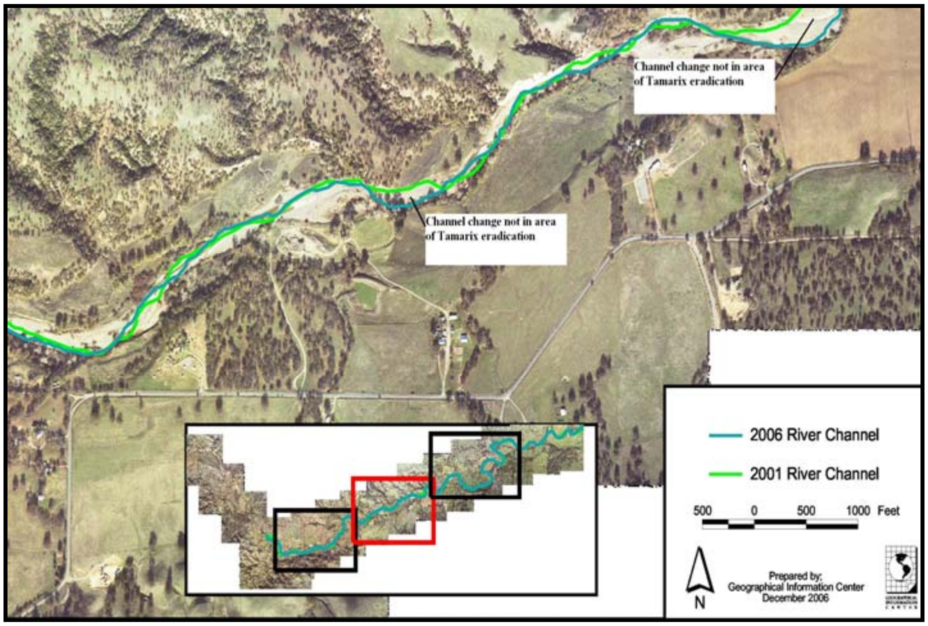

Figure 10 - Channel Change not Associated with *Tamarix* Removal

An additional issue with eradicating large patches was exhibited by a disturbing trend in the third year of the eradication program. Large patches that were sprayed in year one of implementation appeared dead in year two, indicating a successful kill rate. However, in year three, many large patches resprouted along the highest and most interior branches, after appearing dead for two years. The spring of 2006 (year 3) was very wet, with late and consistent rains into May. At about this time, the Imazapyr was reaching the end of its two year effective span after application. As the herbicide wore off, the abundant soil moisture may have been enough to bring the plant out of an extended dormancy.

As noted earlier the lead chemist for BASF was consulted and indicated that these results while initially disappointing do not indicate that the herbicide has failed to work. Imazapyr takes a while to fully affect the root system of the intended plant. In almost every case a large percentage of the plant did not show regrowth. The small areas that did show regrowth were generally in areas that were easy to retreat. It has always been our contention that this program was intended to direct an effort towards discovering the most effective, cost conscience method to control both Arundo and Tamarisk. With the Landowner DVD we have developed and the landowner meetings generating interest in controlling non-natives it is our hope that the individual landowners on each of these creeks and in the surrounding areas will take charge of their watersheds. We intended to try to give them the best tools possible to ensure their success.

Restoration

The restoration experiment produced data and results that are appropriate to be submitted to a scientific, peer reviewed journal. A draft of the submittal is attached to this report as Appendix F. The results are excerpted in the following section.

Planting occurred in March 2005 and was timed to minimize risk of loss from flooding and still be within the wet season. However, it should be noted that the irrigation system was not yet in place at the time of planting and unseasonably high temperatures occurred within a few weeks of planting, resulting in limited hand watering. Further, once the irrigation system was in place, it was minimally functional during the last two weeks of June, a very hot period. Thus, difficulties with irrigation strongly influenced the results of this study. Taking into account the irrigation influence, the test sites were evaluated for three characteristics: survival, abundance, and species richness.

Survival

Survival refers to survival of planted native species (i.e. active restoration). Any plant that did not survive to the 30 day census period in spring 2005 was eliminated from subsequent survival analysis. Survival to 30 days was generally above 75% for most species, with lowest values for western goldenrod (*Euthamia occidentalis)*, Fremont cottonwood, and Goodding's black willow (See Table 3 below).

Ten of the thirteen (77%) willow wattle bank stabilization subplots had live willow wattles 30 days after planting (Spring 2005). By the Fall 2005 monitoring there were only 3 subplots (23%) with live willow wattles. For the two subplots at Fenton-Ale & Quail with live willow wattles, the number of live individuals, 1 and 2, was too small to be effective for bank stabilization. These individuals were dead by the Fall 2006 monitoring. However at the McMahon site there was still 50% survival at the Fall 2005 monitoring of the single willow wattle treatment planted there. This dropped to 32% (9 plants) by the Fall 2006 monitoring. Thus since most of the willows in the bank stabilization willow wattle treatment died due to improper irrigation during the first season this treatment was eliminated from the analysis.

Survival exhibited locational differences, being much higher at the McMahon site, where irrigation was more consistently supplied. Erosion also appeared to have affected the Fenton-Ale & Quail site, with two plots exhibiting loss of plants that is likely associated with erosion. Survival also exhibited species differences, with mugwort (*Artemisia douglasiana*) having the highest mean survival at the end of the study in Fall 2006 (46.5%), followed closely by mule fat (*Baccharis salicifolia)* (45.7%).

Table 3 - 30 day survival and mean percent survival of planted native species

Species Planted	Common Name	30 Day Survival (%)	Mean Survival to Fall 2006 (%)	n	SE
Artemisia douglasiana	mugwort	82	46.5	609	.020
Baccharis salicifolia	mule fat	65	45.7	186	.037
Muhlenbergia rigens	deergrass	86	28.8	284	.027
Carex barbarae	Santa Barbara sedge	80	20.5	156	.032
Euthamia occidentalis	western goldenrod	47	19.0	79	.044
Leymus triticoides	creeping wildrye	83	18.2	314	.022
Urtica dioica ssp. *holosericea*	hoary nettle	63	12.6	167	.026
Aristolochia californica	California pipevine	93	10.3	39	.049
Elymus glaucus	blue wildrye	86	7.4	310	.015
Nassella pulchra	purple needlegrass	94	5.3	208	.016
Vitis californica	California grape	79	4.6	22	.046
Populus fremontii	Fremont cottonwood	51	2.5	118	.015
Salix lasiolepis	arroyo willow	73	2.4	84	.022
Melica californica	California melic	88	0	90	
Poa secunda	one-sided bluegrass	88	0	43	
Salix exigua	narrow-leaved willow	75	0	111	
Salix gooddingii	Goodding's black willow	40	0	152	
Salix laevigata	Red willow	79	0	61	

(Fall 2006 survival was calculated using individuals that survived to 30 days as a baseline. Sample size (n) is the number of plants alive at the 30 day census; SE=standard error and is not defined for mean=0.0.)

Actively restored community types also exhibited significant differences in survival. Mule fat scrub had the highest overall mean survival at 34.2 %, followed by cottonwood riparian forest/valley wildrye grassland at 19.7 %, willow scrub at 13.5%, and valley needlegrass grassland at 6.1%. There were also large significant differences among the native species within the four community types as shown in Table 4 below.

Table 4 - Mean percent survival of planted native species within community types

		Community Type			
		CWRF/VWG	MFS	VNG	WS
Species	Common Name	Mean Percent Survival (n)	Mean Percent Survival (n)	Mean Percent Survival (n)	Mean Percent Survival (n)
Aristolochia californica	California pipevine	10.3 (39)			
Artemisia douglasiana	mugwort	54.6 (141)	53.4 (268)		31.7 (199)
Baccharis salicifolia	mule fat		45.7 (186)		45.7 (186)
Carex barbarae	Santa Barbara sedge		28.1 (59)		20.5 (156)
Elymus glaucus	blue wildrye	6.8 (132)	10.2 (59)	8.2 (73)	4.4 (46)
Euthamia occidentalis	western goldenrod	12.9 (31)		22.9 (48)	19.0 (79)
Leymus triticoides	creeping wildrye	19.1 (168)	20.2 (99)		0 (90)
Melica californica	California melic			0 (90)	
Muhlenbergia rigens	deergrass	30.3 (132)	33.0 (94)		19.0 (58)
Nassella pulchra	purple needlegrass			5.3 (208)	5.3 (208)
Populus fremontii	Fremont cottonwood	1.9 (89)			2.5 (118)
Poa secunda	one-sided bluegrass			0 (43)	0 (43)
Salix exigua	narrow-leaved willow	0 (16)	0 (39)		0 (111)
Salix gooddingii	Goodding's black willow	0 (97)			0 (152)
Salix laevigata	red willow	0 (10)			0 (61)
Salix lasiolepis	arroyo willow	7.7 (13)	2.4 (42)		2.4 (84)
Urtica dioica ssp. *holosericea*	hoary nettle	24.6 (65)	7.6 (53)		12.6 (167)
Vitis californica	California grape	6.3 (16)			4.6 (22)

(Sample size is in parentheses (n=number of plants alive at the 30 day census). CWRF/VWG=cottonwood riparian forest/valley wildrye grassland; MFS=mule fat scrub; VNG=valley needlegrass grassland; WS=willow scrub.)

Abundance

Total abundance refers to the sum of percent cover for all species in a plot (native and non-natives were analyzed separately). In active restoration plots we did not distinguish the abundance of planted individuals from that of naturally recruited conspecific individuals. Overall, the total abundance of native species in plots averaged 61.3%, as compared to 23.1% for non-native species.

Abundance was further analyzed to assess the influence of active vs. passive restoration and *Tamarix* left standing vs. *Tamarix* mulched. Due to the impossibility of planting within dead-standing *Tamarix,* there were twice as many passive restoration subplots (both dead standing and mulched) as active restoration subplots (mulched only), resulting in an unbalanced model. Therefore, one analysis of variance was performed with the active restoration plots excluded, to compare passive restoration between dead standing and mulched *Tamarix*. Another was performed with the dead standing *Tamarix* plots removed, to compare active versus passive restoration in mulched plots without the confounding effect of passive restoration in dead standing *Tamarix*.

In comparing active vs. passive restoration in mulched plots, differences were significant for both the restoration type and plot itself. The mean native abundance (percent cover) in active restoration mulched plots was 86.1% versus a mean of 63.4% for passive restoration mulched plots. By comparison, passive restoration in *Tamarix* dead standing plots resulted in a mean native abundance of 34.5%. Together, both sets of passive restoration plots (dead standing and mulched *Tamarix*) averaged 48.9% native abundance.

A second analysis compared mulching vs. leaving *Tamarix* left standing dead for passive restoration. The mean native abundance (percent cover) in dead standing *Tamarix* plots was 34.5% versus a mean of 63.3% for mulched plots.

The data were also analyzed for non-native species abundance, with no significant effect found for any variable analyzed. Therefore, non-native species abundance was apparently not affected by plot location, *Tamarix* treatment, or restoration type. Mean values of non-native species in the treatments are given in Table 5.

Table 5 - Treatment means of total abundance of non-native species in Fall 2006

	Mean Non-native Cover	**n**	**SE**
Tamarisk Treatment			
Dead standing	24.4%	27	3.40
Mulched	27.0%	54	2.40
Restoration Type			
Active	23.4%	27	3.40
Passive	28.0%	54	2.40

(SE=standard error.)

Species Richness

Species richness refers to the number of species recorded in subplots. Native and non-native species were analyzed separately. Over all plots there was a mean of 6.38 native species versus a mean of 6.19 non-native species, with no statistical difference between these two means (t-test; $p>0.5$). Thus, native species and non-native species colonized the experimental plots overall at about the same rate, in spite of the contribution by active restoration. However, both types of species responded to the experimental treatments (as discussed below).

Native species richness was analyzed as a response variable to active vs. passive restoration in mulched plots, with dead standing *Tamarix* plots excluded. The results were not significant for Plot (block), but were highly significant for restoration type (active vs. passive). As expected, there was a significantly greater number of native species in active restoration mulched plots (mean = 8.4) as opposed to passive restoration mulched plots (mean = 6.2).

A second analysis of species richness addressed passive restoration in dead standing versus mulched *Tamarix* plots. The variance was highly significant for both Plot (block) and *Tamarix* Treatment. There was a significantly greater number of native species in passive restoration mulched plots (mean = 6.2) than in passive restoration dead standing *Tamarix* plots (mean = 4.6).

As in the Abundance section above, the data were also analyzed for nonnative species richness, with the response significant at all levels. There was a significantly greater number of non-native species in mulched *Tamarix* as compared to dead and standing *Tamarix* and there was a significantly greater number of non-native species in passive restoration as opposed to active restoration (Table 6).

Table 6 - Treatment means of non-native species richness

	Mean Non-native Richness	**n**	**SE**
Tamarix **Treatment**			
Dead standing	4.74	27	0.41
Mulched	6.41	54	0.20
Restoration Type			
Active	4.57	27	0.41
Passive	6.57	54	0.29

Conclusions/Recommendations

Eradication

Mulching exhibited a significant beneficial effect on eradication success. This effect was pronounced for smaller patches of *Tamarisk* (categorized as points in the monitoring protocol), with a 97% reduction in areal extent of these patches, compared to only a 46% reduction for small patches that were sprayed only. Mulching of small infestations might be reasonably accomplished in a three - four year eradication program, with follow-up pot treatments by a landowner. The additional costs of mulching would be offset by a reduction in the number of years it would take to successfully control the *Tamarix*.

Mulching is also an option to help reduce the incidence of the resprouts that appeared two years after apparent successful treatment with herbicide. These occurred on hard to reach locations on large patches, some of which reach thirty feet and are extremely difficult to cover with herbicide. Mulching of the dead portions of the *Tamarix* stand after a first year of herbicide treatment could increase access to the interior and topmost branches, allowing effective application of the herbicide to the leaf surface. If the Imazapyr's effective span does impact the resprouting, timing would be important, as you would want to mulch prior to diminishing of the herbicide's effectiveness, but once the herbicide has had time to impact the plant.

Restoration

One of the main goals of the study was to test the hypothesis that mulched *Tamarix* would provide a better recruitment environment for native species than dead standing *Tamarix*. This hypothesis was supported by the results. In passive restoration, mulched *Tamarix* plots achieved 63.3% native cover and 6.2 native species as compared to 34.5% native cover and 4.6 native species for dead standing *Tamarix* plots. Although the mechanisms for this recruitment increase in mulched plots are unknown, it is likely that increased light availability, greater seed germination potential, and non-native seed bank suppression are contributing factors. Active restoration was also successful in increasing native abundance and richness. Active restoration mulched plots achieved 86.1% native cover and 8.4 native species as compared to 63.4% native cover and 6.2 native species for passive restoration mulched plots. Thus, mulching following herbicide application is recommended as an eradication technique for *Tamarix* regardless of whether active restoration is employed. Further, as to be expected, active restoration will result in the greatest success of native species to replace *Tamarix*.

The factors that likely promote native species establishment in mulched *Tamarix* plots over that of dead standing *Tamarix* plots, e.g. increased light and improved seedbed, would also seemingly apply to non-native species. Indeed, there was a significantly greater number of non-native species in mulched *Tamarix* as compared with dead and standing *Tamarix* (mean of 6.4 versus 4.7). However, there was no significant difference in non-native abundance between mulched *Tamarix* and dead standing *Tamarix* (27.0% versus 24.4%). Recovering *Tamarix* had little effect on this comparison, as its abundance did not differ significantly between treatments (11.5% in dead standing plots versus 7.8% in mulched plots). Thus, although there were more non-native species in passively restored mulched plots than in dead standing plots, they weren't any more abundant. Given the native species' apparent preference for mulched plots, and the apparent non-discrimination of the non-native species, it appears that there is little cost to mulching in terms of increased non-native abundance. In other words, the weeds aren't going to be any worse if you mulch.

It is tempting to use the values for native plant abundance in passive restoration as estimates of the natural recruitment rate of natives along this section of Red Bank Creek. However, the degree to which these values were affected by planted species in adjacent active restoration plots is unknown. It is possible that vegetative propagules or seeds produced by planted individuals could have migrated into passive restoration plots and established there, thus increasing the abundance values in passive restoration plots over what might be observed in a more natural situation.

Survival of planted species was generally low due to improper irrigation. However, several species achieved good success in spite of this and thus could be considered for problematic riparian restoration situations in similar watersheds. These species are mugwort, mule fat, deergrass (*Muhlenbergia rigens*), Santa Barbara sedge (*Carex barbarae*), western goldenrod, and creeping wildrye (*Leymus triticoides*). Woody species such as willows and Fremont cottonwood, and the willow wattle treatment did not fare well in this experiment due to the irrigation problems. However it should be noted that in 2005, those willows outside the active restoration fencing were heavily browsed. Thus an unknown degree of the low survival of willow wattles can be attributed to herbivory.

The two species with highest survival, mugwort and mule fat, were significant components of the mule fat scrub community. Thus, the high survival of this community type was driven by these two species. The lower value for cottonwood riparian forest/valley wildrye grassland can be explained in part by the poor survival of its major component species, Fremont cottonwood and Goodding's black willow. The low value for willow scrub is largely due to the failure of several willow species planted in that community type. Despite being planted appropriately at the dry end of the hydrological spectrum, seedlings of valley needlegrass grassland species are still highly susceptible to drought stress, especially when planted as plugs with poor irrigation.

Active restoration requires significant financial and technical resources and can be challenging on streams such as Red Bank where access to water for irrigation is limited. The results of the restoration experiment indicate that mulching can be used to enhance passive restoration success following eradication of *Tamarix* where active restoration is impractical. Mulching of dead *Tamarix* was associated with almost 30% higher abundance (percent cover) of native species versus leaving the *Tamarix* standing. The species that survived the problems with irrigation might also be candidates for sites where some active restoration is desired, but resources for plant replacement or irrigation are limited.

This project initiated in 2002, and monitoring was complete in fall, 2006. The total budget was distributed as follows[1]:

[1] Budget numbers are approximate. Detailed budget information is provided in the final invoice.

Table 7 - Budget Allocation

	CALFED	SWRCB
Project Management and Outreach	$77,000	$10,900
Mapping (pre-project)	$18,000	
Eradication	$222,000	$49,500
Restoration project	$190,000	
Follow-up monitoring	$20,000	
Final report	$3,000	
Total	$530,000	$60,400

Project Management and outreach included project setup and reporting and initial outreach efforts to landowners. Mapping included pre-eradication aerials, ortho rectifying, photo interpretation, and vegetation mapping. Eradication included pesticide applicator contracts, on-the-ground project management, including scheduling, notice to landowners, site visits, trouble shooting, and eradication workshops for agencies. The restoration project included pre-project research, site assessment, development of a restoration plan, restoration at two sites, post-implementation monitoring over two yers and a final report. Follow-up monitoring included aerial photographs, ortho rectifying, photo interpretation, GPS data gathering, production of maps, analysis of data and a final monitoring report.

Information was disseminated during the project by workshops held in 2001-2003, through several landowner mailings and to the local area Resource Conservation Districts, Pesticide Applicators, agency personnel and other interested parties. A video was developed by the CSU, Chico Technology Learning Program (Appendix G). The video gives a brief overview of the tools and equipment needed to successfully treat Arundo and Tamarisk. The video was designed for landowners with little to no experience with non-native eradication.

The restoration experiment is being prepared for submittal to peer-reviewed journals which will reach the widest audience of scientists working on restoration following non-native eradication. The video of eradication methods will be provided to the Tehama County RCD for distribution to its landowners and will be disseminated to the Invasive Plant Council, Natural Resources Conservation Service and other area RCDs.

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