Exhibit 6-8

Project 8 – County of Santa Barbara Agricultural Commissioner's Office, Santa Ynez River Tamarisk and Arundo Project

Exhibit 6-8

Exhibit 6-8 contains the following information related to Project 8 – County of Santa Barbara Agricultural Commissioner's Office, Santa Ynez River Tamarisk and Arundo Project:

- **Figure 6-8a**, Project Location Map
- **Exhibit 6-8a**, Proposal for Santa Ynez River Tamarisk and Arundo Project.
- **Exhibit 6-8b**, *Ecology and Management of Arundo Donax, and Approaches to Riparian Habitat Restoration in Southern California, G.P. Bell*
- **Exhibit 6-8c**, *Element Stewardship Abstract for Tamarix ramosissima (Ledebour) Tamarix Parviflora (De Candolle) Saltcedar Salt Cedar Tamarisk. A.T. Carpenter*

Santa Barbara County

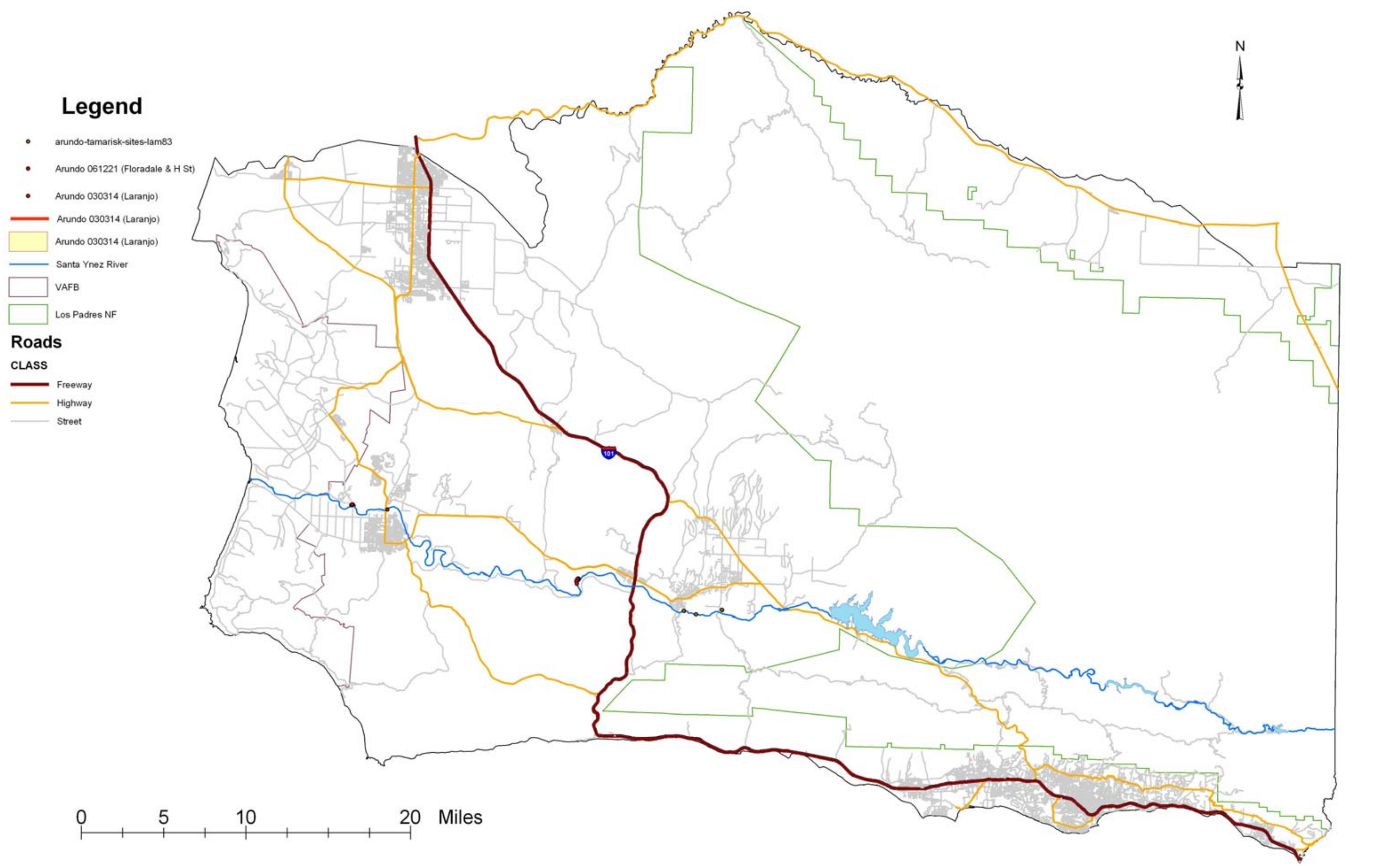

EXHIBIT 6-8a

Santa Ynez River
Arundo and Tamarix Mapping Survey

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Scope of the Problem

Invasive species pose a significant threat to biodiversity throughout the world (Wilson 1999). The 90 mile long Santa Ynez River, the largest river course north of Ventura River and south of Salinas River, is no exception.

Invasion by plants is not as dramatic as the sudden events of wildfire, oil spills or clear-cutting, but invasive plants are spreading at an alarming rate (D'Antonio and Vitousek 1992). In the National Parks alone, invasive plants are expanding their range by 8-12% per year (Hiebert and Stubbendiek 1993). The impact of invasive plants to wildlands around the world is enormous (D'Antonio and Vitousek 1992), and they are a significant factor affecting the preservation of native biodiversity- one of the major challenges of this century (D'Antonio and Meyerson 2002). Fourteen percent of the federally listed endangered species nationwide in 1996 became increasingly threatened as a result of plant invasions (Chen 2001). Competition for resources has been documented to have caused a decline in 18% of federally endangered species (Wilson 1999).

Invasive plants can increase the rate of soil erosion by diverting stream flow in watercourses, by replacing a deeply tap-rooted native species with a shallowly rooted Invasive plant such as *Arundo donax* (giant cane). Resulting erosion by water, wind and gravity, strips away valuable plant liter and topsoil, and releases sediments that flow downhill into streams, rivers and water bodies, resulting in the alteration of flood channels and degradation of water quality (Lacey et al. 1989). Fire regimes can be altered by *Arundo donax*, which remains flammable throughout the year in riparian habitats that are not adapted to fire.

Research in riparian habitats has shown lower bird diversity and density in areas dominated by *Tamarix ramosissima* (salt cedar), versus areas of native cottonwood and willow dominated vegetation (Hass 2002). *Tamarix ramosissima* require larger amounts of water for survival than do many native plants (Hass 2002), and it can lower surface and ground water levels to where native flora and fauna can not access it, and they are forced to either migrate or die; this subsequently alters the local microclimate and trophic structure (Randall and Hoshovsky 2000). Fortunately, land managers have witnessed the rapid return of both native vegetation and surface waters once *T. ramosissima* has been removed (Hass 2002).

Although it is difficult to quantify the level of degradation of the recreational value of wildlands by invasive plants (Richardson and van Wilgen 2004; Eiswerth 2005), it is obvious that invasive plants do pose a threat to this resource use. The Santa Ynez River watershed is known for its beauty, wine production, and outdoor recreation opportunities; however, when invasive plants like *A. donax* or *T. ramosissima* infest an area, they directly or indirection diminish the recreational and wildlife habitat value and beauty of wildlands, which can make the area undesirable recreationalists such as hikers, bikers, equestrians, hunters, and nature enthusiasts.

Land mangers are often faced with attempting to control invasive plants through a form of triage, where they hastily identify which species will be targeted for control and which ones will be left to possibly spread. This is often based on anecdotal and unverified data (Pete Hollaran 2006, personal communication). Land managers often function as physicians who are entrusted with healing their patient (the land), and a good doctor should give his or her patient a proper examination (survey) before prescribing a remedy to cure an illness (weed control) (Knapp and Knapp 2005). A proper physical will also provide a sound scientific foundation to guide future management actions.

Invasive plant management programs require a full understanding of the invading species' abundance, and distribution in order to make the best management decisions and utilize limited resources effectively. Funding is often very limited for invasive plant management, and it is critical to prioritize both species and population for control to utilize resources effectively (D'Antonio and Meyerson 2002). Managing invasive plants without the knowledge of their population abundance and distribution has been compared to fighting a wildfire without knowing the location and size of the fire; this can negate the effectiveness of fire fighters and potentially jeopardize their lives (Schoenig et al. 2002). Likewise, managing invasive plants without the relevant data often limits the effectiveness of management efforts while potentially wasting time and money and jeopardizing the health of the ecosystem.

The results of an island-wide invasive plant survey conducted by Native Range's parent company Prohunt Inc. in the spring of 2007 on Santa Cruz Island, has provided The Nature Conservancy and the National Park Service with the science-based information needed to develop a comprehensive invasive plant management plan. Fifty-six invasive plant species of all sizes were surveyed over 92 mi^2 (62,000 acres), roughly the same area as the length of the Santa Ynez River, in only 41 days. Approximately 90% was surveyed by helicopter, and 10 % on foot. The results of the survey yielded nearly 6,000 populations, and included both *A. donax* and *T. ramosissima*. When *T. ramosissima* is in bloom (March-April) (Fig. 1), it is easy to identify, including *A. donax* when traveling as a speed of 20 mph and from an altitude of 5-30 feet off the ground; the speed and height of the helicopter while surveying. Of the 6,000 populations, individual plants were the most encountered population size for nearly every species surveyed. This means that incipient (recently established) populations can be detected easily, and subsequently eradicated. Species that have recently colonized are relatively easy and cost effective to eradicate (Zavaleta et al. 2001), and their impacts are minor compared to widespread species (Zavaleta 2000).

Figure 1. A photograph taken form a helicopter of a single four-foot T. ramosissima (red arrow) invading dense willow and mule fat vegetation in a riparian corridor on Santa Cruz Island.

Project Methods

Advanced techniques and methods utilized on conservation projects to remove introduced mammals have been developed and successfully implemented throughout the world, and it has been identified that similar techniques need to be developed for successful plant eradications (Dolan et al. 2003). Prohunt Inc. has answered this call, and have adapted their successful animal control strategies and methods to map and eradicate invasive plant species in rugged areas by offering their services through their sister company, Native Range Inc. (Native Range). The owners and staff of Native Range have over 30 years of field experience conducting large-scale conservation projects world-wide. Our work has focused on the eradication of non-native species but also included wildlife capture and handling and consultation on broad-scale restoration management plans. Our staff has extensive invasive plant ecology, survey, and mapping knowledge, plus geographic information system database management. Our field personnel are capable of hiking in rugged terrain, managing projects efficiently, communicating closely with the contracting entity, collecting accurate field data, and completing projects within proposed timeframes and budgets.

Native Range proposes to conduct an aerial survey of the Santa Ynez River streambed for *A. donax* and *T. ramosissima*. This proposal outlines our methods in detail, project scope of work, project timeline, staff, and budget.

Unique Methods
Aerial survey method developed by Native Range provide a number of significant advantages that other methods cannot. These benefits are listed below:

- Better vantage point to detect and survey infestations
- Individual small plants can be detected
- Fast and accurate
- Eliminates dispersal of invasive plants
- Eliminates impact to habitat
- Eliminates chances of injury associated with hiking (and associated downtime)
- Cost effective

Figure 2. A Schweitzer-269C 2-person helicopter in flight (photo-1). Mappers calibrating GPS units prior to conducting a field survey. John Knapp in foreground with red cap (photo-2). An infestation of Verbascum thapsis (wooly mullein) (green dot-like vegetation), rosettes - inches tall, which is easily seen from the air (photo-3).

Field Work
A field crew consisting of a project manager, mapper, helicopter pilot, and ground support will be utilized to survey the main stream bed of the Santa Ynez River from Gibraltar Reservoir to Surf Beach. We will only use one highly experienced invasive plant mapper for the entire project, John Knapp, which insures that data collection will be consistent and accurate. The primary survey method used will be visual identification and population size and density estimates from a two-person helicopter flying between 5-30 feet off the ground (dependent on weather and vegetation) at speeds of 20 mph. Areas that cannot be accessed by helicopter such as urban areas and areas with too many power lines will be mapped from the best vantage point available on the ground. Every population will be captured as point data with a sub-meter Trimble GeoExplorer Series global positioning system (GPS), and then exported to a geodatabase for analysis. A population would be defined by 100 feet or greater between individual plants or edges of two populations, thus providing a detailed account of species distribution.

Population Data Collection
All field data will be recorded with a sub-meter GPS. An identical second or backup unit will always be on site during surveys to ensure no loss in time or resources due to equipment malfunction. All data

will be collected as point data with a series of attributes recorded (Table 1). In addition to the Trimble GPS units, the helicopter and ground survey crew will carry a Garmin e-Trex GPS to record their mapping routes, on foot and via vehicle. In the end, a map will be produced that will shows the tracks of both aerial and ground survey activities. If a GPS does not work in a certain location (a deep canyon for example) the data point will be recorded on a paper map and the map coordinates entered in the computer manually. On average, each population can be recorded within 5-20 seconds. Data collected each day will be downloaded that evening, and saved on the hard drive of a laptop computer, as well as on an external hard-drive to ensure no loss of data in the event of a computer "crash" during the project.

Attribute	Comments
Mapper	3-letter initials of mapper (JJK)
Date	Month,day,year format
Species	*Arundo donax, Tamarix ramosissima* , other species
ID Confidence	100%, 50%, 1%
Population Size	Population area length x area width
Population Cover	Expanded Daubenmeir cover-classes: 0-5, 6-25, 36-50, 51-75, 76-95, 96-100 %
Number of Plants	For populations less than 15 individuals
Age Class	Mature, sapling, seedling
Comments	General comments, or if other species of importance are found

Table 1. A list of population attributes collected for each and every population detected.

GIS Data Management

Native Range has an experienced GIS specialist who will work with the field crew on a daily basis to allow for efficient project management. The duties will include GPS downloads, quality checks, and data management, and backing up all files on a daily basis. The GIS specialist will create maps for the survey crew as progress is made to aid in efficient project implementation. At the end of the project, all data will be provided, in addition to a final project report, in the form of ESRI ArcView shape files and in an Excel spreadsheet, or other specified by the S.B. Co. Ag. Commissioners Office. All population data will be summarized to express the following for each species:

- Number of populations
- Average population size
- Median population size
- Minimum population size
- Maximum population size
- Mode or most frequent population size recorded
- Gross area infested
- Net area infested (gross population size X population cover).

In addition to collecting geo-referenced data, photographs will be taken to visually document a selection of populations and surrounding vistas that then could be used by the contracting agency in the future for outreach materials and control project funding proposals.

Project Scope

<u>Field Work</u>

- 90 miles of the Santa Ynez River (main channel or water course) will be surveyed

- All populations of *Arundo donax* and *Tamarix ramosissima* encountered will be mapped.
- John Knapp will conduct all surveys (aerial or ground).
- Ground surveys will only be used when aerial survey is not possible due to urban areas restrictions or extensive utility wires at the immediate site.
- If time and budget allows, other notable invasive plants will be mapped.

GPS Data Collection and GIS Data Management

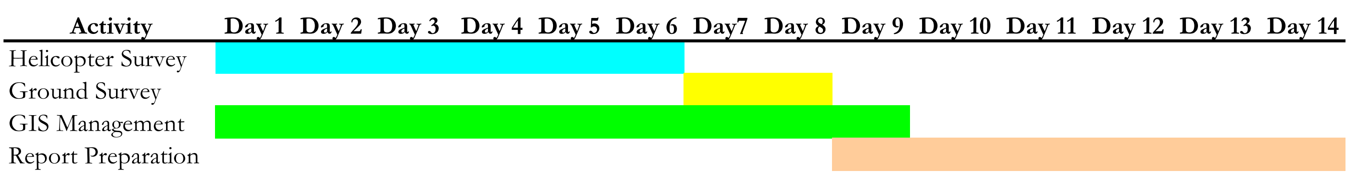
- Data will be recorded using a Trimble GeoExplorer GPS.
- Data will be downloaded and quality checked nightly.
- All data will be stored on a laptop computer and backed up on an external hard-drive.

Reporting

- The final project report will contain 1) a record of daily activity for the survey crew, 2) field data in digital format specified by S.B. Ag Commissioners Office, and 3) a written description of the current status of the project in relation to the objective. Our final report will be a final submission of the entire proofed dataset, along with a cumulative project report. Native Range will submit both of these deliverables within six days after the end of field data collection period.
- Along with final report, an invoice for work completed will be included. Native Range will format and itemize the invoice as the S.B. Ag Commissioners Office requests in the project contract.

Projected Timeline

Native Range will complete the entire project in no more than two weeks. Since *A. donax* is easily visible throughout the year, the optimal time to conduct the survey is between March and April, when *T. ramosissima* is in peak bloom.



Project Staff

Project Manager and Ground Support, Kelvin Walker

Kelvin began his career as a professional hunter for the New Zealand Forest Service 1983 (through 1987) and later returned as a Conservation Officer for the Department of Conservation (NZ) in charge of field hunting operations from 1990 -2001. Kelvin's is a 50% partner in Prohunt and responsibilities include: managing field operations, human resources and finance, as well as looking after all OSH and quality management requirements. During the Santa Cruz Island program Kelvin managed the ground hunting program, Judas pig program and hunting dog welfare. Kelvin managed the island-wide weed mapping survey on Santa Cruz Island for TNC.

Botanist and GIS Specialist, John Knapp

Following the success of these projects, Prohunt formed Native Range Inc. in 2007 to provide a suite of unique vegetation management services. Shortly thereafter, John Knapp who holds an M.S. in Weed Science from California Polytechnic University, San Luis Obispo, and a B.A. in Physical Geography from U.C. Santa Barbara was hired as the Division Director. John serves as a board officer of the California Invasive Plant Council, and has extensive invasive plant management experience that include: conducting a ground survey of 76 invasive plant species on Catalina Island, developed and managed the Catalina Island Conservancy's Invasive Plant Management Program, and has served as TNC project advisor for the Santa Cruz Island Weed Mapping Survey. He has authored comprehensive management plans for both TNC's and the Catalina Island Conservancy's invasive plant management programs.

Helicopter Pilot, Ken Hutchins
Ken has amassed over 8500hrs PIC logged helicopter time, over 5500hrs have been on wild animal recovery projects, specifically aerial shooting, wild animal capture, radio telemetry and Judas / Sentinel animal work. In addition to this work, he is an experienced pesticide aerial applicator in rugged terrain. He has worked for Prohunt on projects since the late 1990's; he has been a key pilot in the Santa Cruz Island Project, and is rated as one of the top eradication pilots in the world.

Project Budget
The following is an itemized budget of the project expenses.

Santa Ynez River Arundo and Tamarix Survey

#	Item	Expense	Comments
1	Helicopter: $550/hr @ 30 hrs (5 hrs/day @ 6 days)	$16,500	Schweitzer-269C 2-person helicopter (incl fuel, insurance, maintenance, ferry time)
2	Vehicle: $65/day @ 7 days	$455	4-wheel drive vehicle to carry helicopter fuel and ground mapping
3	Vehicle fuel: $0.42/miles @ 1,050 miles	$441	Project and commute mileage
4	Radio: $20/day x 2 @ 7 days	$280	Emergency and project support radios (2) for remote area communication
5	GPS: $60/day @ 7 days	$420	Trimble Geo Explorer XT (sub meter), including helicopter and emergency back-up unit
6	Binoculars: $10/day @ 7 days	$70	Invasive plant identification
7	Camera: $15/day @ 7 days	$105	Project photographs, and to record site/species
8	Range finder: $15/day @ 7 days	$105	GPS antenna height confirmation
9	Mapper: $100/hr @ 40 hrs (7 days)	$5,600	John Knapp, invasive plant mapper (one mapper = consistent data collection
10	Pilot: $85/hr @ 30 hrs (6 days)	$2,550	Ken Hutchens, alpine and agriculture pilot (experience mapping target species)
11	Ground support: $50/hr @ 32 hrs (4 mapping days)	$1,600	Certified to transport fuel within California (refuels helicopter along project transect)
12	GIS Specialist: $45/hr @ 20 hrs	$900	Data downloads, GIS data base
13	Travel and accommodation: 5 nights @ $120/night + $80/day	$1,000	Hotels and meals for 2 people
14	Project Manager: $50/hr @ 48 hrs	$2,400	Project oversight, updates, report writing
15	*Sub-total*	*$32,426*	*Sub-total*
16	Indirect: @ 15%	$4,864	Indirect project related costs
17	**Total**	**$37,290**	

Conclusion
Native Range has developed an effective method to survey large remote areas by helicopter, which are otherwise inaccessible or inadequate on foot. Our methods eliminate the spread of invasive plants or damage caused to habitat by the mapper. We have successfully completed projects within budget and on schedule, and quite often significantly ahead of schedule. Our staff has relevant and extensive experience managing large complex projects, such as landscape-level invasive plant surveys. We offer a "one stop shop," where every aspect of the project is conducted internally from data collection to data management and presentation, as well as other services related to invasive plant management. Our survey methods are a perfect example of early detection, and we also have the ability to conduct rapid response, by transporting Qualified Applicators to remote locations to eradicate populations quickly-spending more time treating plants than accessing them.

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Supplemental Information

Financial Solvency

- Native Range has a $5M Liability Insurance policy.

Safety

<u>Experience and Past Performance</u>

Native Ranges' parent company, Prohunt was established by Norm Macdonald and Kelvin Walker in 1994 to undertake pest management and eradication projects in New Zealand and overseas. Since then Prohunt has successfully completed more than 500 projects in New Zealand and has worked on or supplied staff and expertise to various high profile eradication projects in the Galapagos, Costa Rica, Australia, Mexico and the United States. The most recent projects have been 1) the successful removal of feral pigs from Santa Cruz Island, and 2) the island-wide weed mapping survey of 56 species on Santa Cruz Island. Given the extensive amount of ground that we have covered, we have only incurred minor scrapes and bruises.

Prohunt's work demonstrated the following:

<u>Strategic planning</u>

- Developed specific eradication techniques for the project and location.
- Designed and implemented a comprehensive work plan.
- Developed and maintained quality standards throughout the project.
- Developed protocols and trained staff which prevented any negative impact on Endangered species and archeological sites during the program.
- Developed survey methods for low-level aerial surveys.

<u>Effective field work</u>

- The GPS tracks of the hunters collected during the project revealed the team's systematic coverage of all portions of the island, including steep canyons, coastal bluffs, and areas of dense vegetation.
- Despite weather and other island-user constraints, the project was completed successfully, ahead of schedule, and within budget.

<u>Geo-database management</u>

- Collected GPS field data from traps, helicopters, dogs, pigs and staff.
- Using ArcGIS 9, managed geodatabase by conducting daily field data downloads, file archiving, and data proofing.
- Created progress reports and maps weekly for field crew and TNC's project advisor.
- Sent proofed data files to TNC GIS staff as requested.
- In addition, Prohunt developed a positive working relationship and effective communications between Prohunt staff, the helicopter pilot, TNC, NPS, the UC Field Station, Island Packers, and other island users.

<u>New Zealand Projects</u>

Between 1994 and 2005 Prohunt completed over 500 pest control projects and a wide range of other tasks which included:

- Wild animal capture
- Commercial venison recovery
- Judas/ sentinel programs
- Wild animal survey/census
- Aerial telemetry tracking endangered species (kiwi, pigeon, and teal)
- Helicopter aerial transport operations
- Consulting

Additional Island Restoration Project Experience

- Galapagos Islands- Consulting, training, supplying dogs, and infrastructure
- Lord Howe Island- Consulting and goat eradication
- Coco's Island- In association with the Charles Darwin Foundation, developed an eradication program for ungulates, cats, rats, and invasive plants
- Guadalupe Island- Consulting, training, and expertise

ECOLOGY AND MANAGEMENT OF *ARUNDO DONAX*, AND APPROACHES TO RIPARIAN HABITAT RESTORATION IN SOUTHERN CALIFORNIA.

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Abstract

By far the greatest threat to the dwindling riparian resources of coastal southern California is the alien grass species known as *Arundo donax*. Over the last 25 years the riparian forests of coastal southern California have become infested with *A. donax* which has spread by flood-fragmentation and dispersal of vegetative propagules. *Arundo donax* dramatically alters the ecological/successional processes in riparian systems and ultimately moves most riparian habitats towards pure stands of this alien grass. By current estimates there are tens of thousands of acres of *A. donax* along the major coastal drainage systems of southern California, including the Santa Ana, Santa Margarita, Ventura, Santa Clara, San Diego, and San Luis Rey rivers. The removal of *A. donax* from these systems provides numerous downstream benefits in terms of native species habitat, wildfire protection, water quantity and water quality.

Introduction

Arundo L. is a genus of tall perennial reed-like grasses (Poaceae) with six species native to warmer parts of the Old World. *Arundo donax* L. (giant reed, bamboo reed, giant reed grass, arundo grass, donax cane, giant cane, river cane, bamboo cane, canne de Provence), is the largest member of the genus and is among the largest of the grasses, growing to a height of 8 m (Fig. 1). This species is believed to be native to freshwaters of eastern Asia (Polunin and Huxley 1987), but has been cultivated throughout Asia, southern Europe, north Africa, and the Middle East for thousands of years and has been planted widely in North and South America and Australasia in the past century (Perdue 1958, Zohary 1962). It was intentionally introduced to California from the Mediterranean in the 1820's in Los Angeles area as an erosion-control agent in drainage canals, and was also used as thatching for roofs of sheds, barns, and other buildings (Hoshovsky 1987). Subsequent plantings have been made for the production of reeds for a variety of musical instruments including bassoons and bagpipes. Today it is an invasive pest throughout the warmer coastal freshwaters of the United States, from Maryland to northern California.

Arundo donax is a hydrophyte, growing along lakes, streams, drains and other wet sites. It uses prodigious amounts of water, as much as 2,000 L/meter of standing *A. donax*, to supply its incredible rate of growth (Purdue 1958; Iverson 1994). Under optimal conditions it can grow more than 5 cm per day (Purdue 1958). *Arundo donax* stands are among the most biologically productive of all communities. Under ideal growth conditions they can produce more than 20 tons per hectare above-ground dry mass (Perdue 1958).

Perhaps as much as 90% of the historic riparian habitat in the southern part of California has been lost to agriculture, urban development, flood control, and other human-caused impacts (Jones & Stokes 1987; Katibah 1984). The greatest threat to the remaining riparian corridors today is the invasion of exotic plant species, primarily *Arundo donax*. This alien grass readily invades riparian channels, especially in disturbed areas, is very competitive, difficult to control, and to the best of our knowledge does not provide either food or nesting habitat for native animals. *Arundo* competes with native species such as *Salix* (willows), *Baccharis salicifolia* (mulefat), and *Populus* (cottonwoods) which provide nesting habitat for the federally endangered bird, the least Bell's vireo (*Vireo bellii pusillus*), the federally threatened bird, the willow flycatcher (*Empidonax traillii eximus*) and other native species (Hendricks and Rieger 1989; Franzreb 1989; Zembal 1986 and 1990).

Ecological value of native riparian systems

Like most riparian systems, the cottonwood/willow riparian forest is a dynamic community, dependent upon periodic flooding to cycle the community to earlier successional stages (Warner and Hendrix 1985). Periodic floods of large magnitude and migration of the river channel are essential to depositing fresh alluvium where seeds and vegetative propagules of *Baccharis*, *Salix*, and *Populus* can germinate and take root (Gregory et al. 1991; Richter and Richter 1992). Adequate moisture and an absence of subsequent heavy flooding is critical to the survival of the young trees through their first year. As these seedlings mature they increase channel roughness and alter flow during small flood events, increasing sediment deposition (Kondolf 1988; Richter and Richter 1992; Stromberg *et al.* 1993). Sediment deposition builds river terraces and, as they elevate, other plant species colonize resulting in further diversification in the floodplain community (Richter and Richter 1992).

When *Populus/Salix* riparian scrub, which may include such species as *Baccharis salicifolia*, *Vitis californica*, *Rubus ursinus*, and *Urtica dioica* ssp. *holosericea*, reaches four or five years of age, it begins to exhibit the structural diversity required for breeding by the bird, the least Bell's vireo (Franzreb 1989, Hendricks and Rieger 1989). Least Bell's vireo, along with the riparian birds, southwestern willow fly-catcher, yellow-breasted chat (*Icteria virens*), yellow warbler (*Denroica petechia*), and many other species may continue to use this diverse community for another ten to twenty years. Gradually the canopy of the maturing willows and cottonwoods begins to shade out the diverse understory of vascular plants required by these birds. Older riparian gallery forests will continue to be used by western yellow-billed cuckoo (*Coccyzus americanus occidentalis*), Cooper's hawk (*Accipiter cooperii*), warbling vireo (*Vireo gilvus*) and other species (Zembal 1990; Zembal *et al.* 1985), but as the stand ages the diversity of the flora and fauna within the forest declines. Annual flooding, channel migration, and occasional large flood events maintain this cycle of succession and therefore maintains a mosaic of diverse natural communities (Gregory *et al.* 1991).

Arundo donax as a competitor

Within its introduced range, *A. donax* is an aggressive competitor. *Arundo donax* flowers in late summer with a large, plume-like panicle. Fortunately for California land managers, the seeds produced by *A. donax* in this country are seldom, if ever, fertile. It is not known if this is because of clonal isolation or because of the physiological effects of climate as has been observed in the related *Phragmites communis* (common reed) (Haslam 1958; Rudescu et al. 1965). *Arundo donax* is well adapted to the high disturbance dynamics of riparian systems as it spreads vegetatively. Flood events break up clumps of *A. donax* and spread the pieces downstream. Fragmented stem nodes and rhizomes can take root and establish as new plant clones. Thus invasion, spread, and therefore management, of *A. donax* is essentially an intrabasin and downstream phenomenon.

Once established *A. donax* tends to form large, continuous, clonal root masses, sometimes covering several acres, usually at the expense of native riparian vegetation which cannot compete. Root masses, which can become more than a meter thick, stabilize stream banks and terraces (Zohary and Willis 1992), altering flow regimes. *Arundo donax* is also highly flammable throughout most of the year, and the plant appears highly adapted to extreme fire events (Scott 1994). While fire is a natural and beneficial process in many natural communities in southern California it is a largely unnatural and pervasive threat to riparian areas. Natural wild fires usually occur during rare lightening storm events in late fall, winter, and early spring. Under these conditions the moist green vegetation of riparian areas would normally act as a fire break. Human-caused wild fires, in contrast, often occur during the driest months of the year (July through October). Drier conditions in riparian zones at this time of year make them more vulnerable to fire damage. Because *A. donax* is extremely flammable, once established within a riparian area it redirects the history of a site by increasing the probability of the occurrence of wildfire, and increasing the intensity of wildfire once it does occur. If *A. donax* becomes abundant it can effectively change riparian forests from a flood-defined to a fire-defined natural community, as has occurred on the Santa Ana River in Riverside County, California. *Arundo donax* rhizomes respond quickly after fire, sending up new shoots and quickly out-growing any native species which might have otherwise taken root in a burned site. Fire events thus tend to help push riparian stands in the direction of pure *A. donax*. This results in river corridors dominated by stands of giant reed with little biological diversity.

***Arundo donax* as habitat**

All evidence indicates that *A. donax* provides neither food nor habitat for native species of wildlife. *Arundo donax* stems and leaves contain a wide array of noxious chemicals, including silica (Jackson and Nunez 1964), tri-terpines and sterols (Chandhuri and Ghosal 1970), cardiac glycosides, curare-mimicking indoles (Ghosal *et al.* 1972), hydroxamic acid (Zuñiga *et al.* 1983), and numerous other alkaloids which probably protect it from most native insects and other grazers (Miles *et al.* 1993, Zuñiga *et al.* 1983). Areas taken over by *A. donax* are therefore largely depauperate of wildlife. This also means that native flora and fauna do not offer any significant control mechanisms for *A. donax*. It is uncertain what the natural controlling mechanisms for this species are in the Old World, although infestations of corn borers (Eizaguirre *et al.* 1990), spider mites (El-Enany 1985) and aphids (Mescheloff and Rosen 1990) have been reported in the Mediterranean. In the United States a number of diseases have been reported on giant reed, including root rot, lesions, crown rust, and stem speckle (USDA 1960), but none seems to have seriously hindered the advance of this weed.

Recent studies by the Santa Ana Watershed Project Authority (Chadwick and Associates 1992) suggest that *A. donax* also lacks the canopy structure necessary to provide significant shading of bank-edge river habitats, resulting in warmer water than would be found with a native gallery forest of *Populus* or *Salix*. As a result, riverine areas dominated by *A. donax* tend to have warmer water temperatures, which results in lower oxygen concentrations and lower diversity of aquatic animals, including fishes (Dunne and Leopold 1978). In the Santa Ana River system this lack of streambank structure and shading has been implicated in the decline of native stream fishes including *Gila orcuttii* (arroyo chub), *Gasterosteus aculatus* (three-spined stickleback), *Rhinichthys osculus* (speckled dace), and *Catostomus santaanae* (Santa Ana sucker). This lack of stream-side canopy structure may also result in increased pH in the shallower sections of the river due to high algal photosynthetic activity. In turn, high pH facilitates the conversion of total ammonia to the toxic unionized ammonia form which further degrades water quality for aquatic species and for downstream users (Chadwick and Associates 1992).

Control Methods

A suite of methods is needed to control *A. donax* depending upon the presence or absence of native plants, the size of the stand, the amount of biomass which must be dealt with, the terrain, and the season.

The key to effective treatment of established *A. donax* is killing of the root mass. This requires treatment of the plant with systemic herbicide at appropriate times of the year to ensure translocation to the roots. Only one herbicide is currently labeled for wetlands use by the EPA; Rodeo®, a tradename formulation of glyphosate, produced by Monsanto Corporation. Glyphosate is a broad-spectrum herbicide which can be used on *A. donax*, *Tamarix ramosissima* (saltcedar), and most other monocots and dicots. It has proven very effective against *A. donax* (Finn and Minnesang 1990; Jackson 1994; USDA Forest Service 1993). Other herbicides might also be used as labels and conditions allow. Monocot-specific chemicals, such as Fusilade-DX® (fluazapop-butyl) and Post® (Sethoxidan), might be particularly useful for treating *A. donax* in stands with a substantial component of native dicots; however, neither is currently labeled for wetlands use.

The most effective treatment on *A. donax* is the foliar application of a two-to-five percent (2-5%) solution of Rodeo applied post-flowering and pre-dormancy at a rate of 0.5 to 1 L/hectare. During this period of time, usually mid-August to early November, the plants are actively translocating nutrients to the rootmass in preparation for winter dormancy which results in effective translocation of herbicide to the roots. Recent preliminary comparison trials on the Santa Margarita River (Omori. 1996) indicate that foliar application during the appropriate season results in almost 100% control, compared with only 5-50% control using cut-stem treatment. Two to three weeks after foliar treatment the leaves and stalks brown and soften creating an additional advantage in dealing with the biomass: cut green stems might take root if left on damp soil and are very difficult to cut and chip. Treated stems have little or no potential for rooting and are brittle. They may be left intact on the ground or chipped *in situ* for mulch.

Cut-stem treatment requires more time and manpower than foliar spraying and requires careful timing. Cut stems must be treated with concentrated herbicide within one to two minutes in order to ensure tissue uptake (Monsanto 1989). This treatment is also most effective post-flowering. The chief advantage of the cut-stem treatment is that it requires less herbicide that can be more-or-less surgically applied to the stem. Because of its reduced efficacy, and due to the labor required, it is rarely cheaper than foliar spraying except on very small, isolated patches or individual plants.

A popular approach to dealing with *A. donax* has been to cut the stalks and remove the biomass, wait three to six weeks for the plants to grow to about one meter tall, then apply a foliar spray of herbicide solution. The chief advantage of this approach is that less herbicide must be applied to treat the fresh growth compared with tall, established plants, and that coverage is often better because of the shorter and uniform-height plants. However, cutting of the stems may result in the plants returning to growth-phase, drawing nutrients from the rootmass. As a result there is less translocation of herbicide to the roots and less root-kill. Therefore many follow-up treatments must be made which negates any initial savings in herbicide and greatly increases the manpower costs.

Pure stands (>80% canopy cover) of *A. donax* or *T. ramosissima* are most efficiently treated by aerial application of an herbicide concentrate, usually by helicopter. Helicopter application can treat at least 50 hectares per day. Special spray apparatus produces extremely fine droplets (400 microns) of concentrated herbicide which actually reduces herbicide use, minimizes over-spray, and results in greater kill.

In areas where helicopter access is impossible, where *A. donax* makes up the understory, where patches are too small to make aerial application financially efficient, or where weeds are mixed with native plants (<80% cover), herbicides must be applied by hand. Street-vehicles with 400 liter spray tanks are a good alternative where road access is available, but small "quad-runner" vehicles equipped with 60 liter sprayers are the preferred approach where the streambed is not so rocky as to prevent access. Twenty liter backpack sprayers are the final alternative where the vegetation is too dense, or the landscape too rugged for vehicles to be effective.

Methods for vegetation removal include use of prescribed fire, heavy machinery (e.g. bulldozers), handcutting by chainsaw or brushcutter, hydro-axe, chipper, biomass burning or removal by vehicle. Removal of the biomass should only be done where the weed cover is so dense as to prevent recovery by native vegetation after treatment, or where cut vegetation might create a debris-dam hazard during flood events. Prescribed fire, or burning piles of stacked biomass, is the most cost-effective way of removing biomass as long as it does not threaten native vegetation or other resources. Chipping is more costly in terms of equipment and labor, and cut, dried chips pose no threat for regeneration or for forming debris dams. Hauling of biomass by vehicle is extremely expensive and should only be done as a last resort. Most landfills will not accept *A. donax* and those that do will only accept if cut into short lengths and bagged into plastic trash bags, making the labor costs far too great. The use of heavy machinery such the Hydro-ax® is extremely expensive. The machines are very slow - a Hydro-ax can only cut about 3-4 acres per day.

Riparian restoration and management

One of the prime incentives for riparian habitat restoration has been endangered species recovery, including the federal Endangered Species Act (ESA). The ESA has focused attention on declining species and sought to protect those species in greatest risk by provisions against take (Under the ESA the term "take" means to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct.). Focus of the legislation has been on individual protected species with little attention given to the dynamics of the natural systems of which these species are a part. There are important historical and legislative reasons for this approach. In the 1970s, when the ESA was drafted, ecologists and wildlife managers were highly focused on single species; system-oriented approaches were not widely applied. In addition, it is far easier to attach legal definition to something tangible, such as an individual animal, than it is to the more vague concept of ecological processes (Gregory *et al.* 1991).

The concept of habitat restoration developed in response to the "take" provisions of the ESA as a means of mitigating site-specific damage. While revegetation has been carried out in a wide variety of natural community types, its earliest successes and its greatest application has been in mitigation of losses of riparian forests. In southern California, riparian revegetation has been pursued as an ever-evolving artform in response to the perceived need for replacement of habitat for the federally and state endangered least Bell's vireo (*Vireo bellii pusillus*) and a suit of other endangered or candidate species including the western yellow-billed cuckoo (*Coccyzus americanus occidentalis*), and the willow flycatcher (*Empidonax traillii*) (Anderson and Miller 1991; Baird and Rieger 1989; Parra-Sjizz 1989; RECON 1988).

It may be argued that the main reason why riparian revegetation has received so much attention is because it is so relatively easy to achieve. This ease is a result of the very dynamics of riparian systems - they are high-disturbance systems composed of flood-adapted and resilient species. *Salix, Populus, Baccharis,* and other riparian plant species establish easily by fragmentation in flood events in addition to seeding in flood-washed sediment beds. As a result riparian revegetation essentially requires only plant material (cuttings or rooted stock) and water (irrigation). However, such revegetation projects can be extremely expensive.

It is also important to recognize that revegetation does not necessarily equate with habitat restoration. While the matrix plant species of habitats are relatively easy to establish, the dynamics of native riparian communities are poorly understood.

Establishing a *Salix/Populus* stand on a streamside terrace will probably not provide the community diversity of a natural stand or the dynamic processes required to establish it. While some revegetation programs have been successful in terms of establishing a matrix of riparian habitat which is used by some native species, revegetating is the not necessarily the best way to create habitat.

The best way to address habitat loss in southern California riparian systems is through a comprehensive program of eradication of *A. donax*, *T. ramosissima*, and other invasive aliens, and relying on natural physical processes, especially flood dynamics, for the recovery of native natural communities and species. This approach might be just as easily argued for other high disturbance-adapted communities.

This strategy is based upon two of important factors. First, riparian habitats are flood-dynamic communities, dependent upon natural cycles of flood scouring and sediment deposition to create the proper conditions for community establishment (Gregory *et al.* 1991; Richter and Richter 1992; Stromberg *et al.* 1991). The Santa Ana, Santa Margarita, San Luis Rey, and many other southern California streams have all of the factors necessary for the recovery and maintenance of healthy riparian communities and riparian species. These watersheds retain flood regimes sufficient to move and sort sediment and extensive sources of seed and vegetative propagules for *Salix* and other native riparian plants. Second, the only real threats to the integrity of the system are (1) habitat fragmentation by development and (2) introduced exotic species which have altered the successional dynamics and stability of the natural communities. In other words, the native riparian communities of the Santa Ana and other major riparian corridors (and thus riparian-dependent species such as least Bell's vireo) are limited, not by the capacity of the community to regenerate, or the available area of riparian zones, but by the capacity of native species to compete with aggressive invasive exotic species, chiefly *A. donax*.

The majority of the limited resources available for riparian management on these rivers should therefore be directed at managing for the process of riparian systems: removing the key perturbation from the system, thereby allowing natural flood dynamics to operate and the natural communities to recover. Attempts to revegetate riparian species in floodplains that retain both native riparian species and flood regimes are redundant, and resources spent to this end are largely wasted. This is not to imply that riparian (and other habitat) revegetation efforts should not be applied; however, they should be applied judiciously and only in situations where specific management goals are achieved by carrying out a revegetation project (e.g. closing up an important corridor or reestablishing native species in a depauperate watershed). Relying on natural processes for the recovery of the riparian communities has the following major benefits:

a. Cost-effectiveness. Riparian forest restoration is extremely expensive, often on the order of tens of thousands of dollars per hectare. This necessarily limits the size, and therefore the biological value, of any funded restoration project. *Arundo donax* can be removed from most areas of a river for a fraction of the cost of revegetation, opening up areas for natural re-colonization by native riparian species.

b. Biological value. As indicated above, the high cost of revegetation limits the size of restoration projects. Additionally, artificially-produced riparian habitat lacks the high stem densities characteristic of naturally regenerating riparian habitat, making the actual biological value of revegetated sites questionable. Much higher value may be achieved by removing invasive exotics such as *A. donax* from the system. Areas opened up for recolonization which are subsequently flood-scoured and naturally seeded or "planted" with vegetative propagules spread by the flood are more likely to recover in high stem density habitat.

c. Natural vulnerability. Riparian systems are, by nature, dynamic. The natural flood process that produces the conditions for natural riparian establishment also puts artificially (and naturally) created habitat areas in flood jeopardy. This makes riparian revegetation a high-risk investment of limited resources. Several expensive revegetation projects on the Santa Margarita and Santa Ana Rivers were damaged or lost to flood scouring in January 1993. Some of these areas recovered with high stem-density *Salix* scrub when *A. donax* was controlled. Other sites, without such weed control efforts, succeeded to high density *A. donax* colonies.

Summary

By virtue of its growth characteristics, adaptations to disturbance, especially fire, its lack of natural predators and competitors in North America, and its unsuitability as food or habitat for native wildlife, *Arundo. donax* has established itself as one of the primary threats to native riparian habitats in the western United States.

Control and management of giant reed within a watershed requires a coordinated, watershed-wide approach. *Arundo donax* should be removed from the watershed beginning in the upper tributaries to prevent reinfestation of treated downstream sites from upstream sources. Removal of *A. donax* requires treatment with systemic herbicides in order to kill the large root mass.

Past practices of riparian restoration have focused on revegetation of small sites without consideration of natural riparian processes. Resources should be spent on managing for the natural dynamic processes of these systems on a watershed-wide scale. In coastal southern California the primary perturbation to the natural riparian succession process in invasion by *A. donax*, and its removal from river systems will have a far greater beneficial effect on most riparian species than planting of riparian vegetation.

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EXHIBIT 6-8a

ELEMENT STEWARDSHIP ABSTRACT

for

Tamarix ramosissima Ledebour
Tamarix pentandra Pallas
Tamarix chinensis Loureiro
Tamarix parviflora De Candolle

Saltcedar
Salt cedar
Tamarisk

To the User:

Element Stewardship Abstracts (ESAs) are prepared to provide the Nature Conservancy's Stewardship staff and other land managers with current management related information on species and communities that are most important to protect, or most important to control. The abstracts organize and summarize data from many sources including literature and researchers and managers actively working with the species or community.

We hope, by providing this abstract free of charge, to encourage users to contribute their information to the abstract. This sharing of information will benefit all land managers by ensuring the availability of an abstract that contains up-to-date information on management techniques and knowledgeable contracts. Contributors of information will be acknowledged within the abstract.

The Nature Conservancy Wildland Weed Management and Research Program is responsible for updating and maintaining this ESA. Anyone with comments or information on current or past monitoring, research, or management programs for the species or community described in an abstract is encouraged to contact the Wildland Weed program at 124 Robbins Hall, University of California, Davis, CA 95616.

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Author of the Abstract: Alan T. Carpenter, Land Stewardship Consulting, 2941 – 20th Street, Boulder, CO 80304 (303/443-8094)

THE NATURE CONSERVANCY
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SPECIES CODE
PDCPR030G0

SCIENTIFIC NAMES (GNAME)
Tamarix ramosissima Ledebour
Tamarix pentandra Pallas
Tamarix chinensis Loureiro
Tamarix parviflora De Candolle
Tamarix gallica L.

Tamarisk is a member of the Tamarisk Family (Tamaricaceae). There is some dispute regarding the correct taxonomy of the deciduous species of tamarisk that have escaped and become invasive in western North America. Robinson (1965) stated that two species of *Tamarix* have escaped cultivation in western North America, namely *T. pentandra* Pallas and *T. gallica* L. Horton and Campbell (1974) studied tamarisk collections from the southwestern United States and grew plants under controlled conditions. They did not find consistent differences among the plants and proposed assigning all deciduous specimens to *T. chinensis*. Welsh et al. (1987) classifies deciduous tamarisk species in Utah as either *T. ramosissima* which has flower parts in 5's (5-merous) or *T. parviflora* which has flower parts in 4's (4-merous). According to Weber (1990), some experts consider the proper name of *T. ramosissima* Ledebour to be *T. chinensis* Loureiro. Sudbrock (1993) stated that *T. ramosissima* and *T. chinensis* are difficult to distinguish, appear to hybridize and that many researchers lump them both into *T. chinensis*. Other researchers lump all deciduous tamarisk species into *T. pentandra*. For the purpose of this abstract, I will follow what appears to be the recent common practice of referring to all 5-merous deciduous tamarisk species that have become naturalized in western North America as *T. ramosissima*, while the 4-merous deciduous species will be referred to as *T. parviflora*. The 5-merous deciduous tamarisk appears to be more widespread in North America than the 4-merous species. In practice, however, little distinction is made among the deciduous tamarisk species for management purposes.

There is an evergreen species of tamarisk, the athel tree, *Tamarix aphylla* (L.) Karsten, which occasionally escapes and becomes established in hot deserts of the United States; however, it does not appear to be nearly as invasive as the deciduous tamarisk species.

COMMON NAMES
Tamarix ramosissima and *T. parviflora* are both commonly referred to as tamarisk or saltcedar. The name 'tamarisk' is clearly based on the genus name *Tamarix* but the derivation of that name is not clear. It may be derived from the Tambre (Tamariz) River in Spain but it may also come from the Tamaro River in Nepal or from the Hebrew word *tamaruk* (Crins 1989). Saltcedar refers to the plants' fine, cedar-like foliage and their ability to grow in saline or alkaline soils.

DESCRIPTION AND DIAGNOSTIC CHARACTERISTICS
As noted above, deciduous tamarisk species in the western United States are herein referred to as either *T. ramosissima* or *T. parviflora*. They can be distinguished using the characteristics in Table 1.

Both species are deciduous, loosely branched shrubs or small trees. The branchlets are slender with minute, appressed scaly leaves. The leaves are rhombic to ovate, sharply pointed to gradually tapering, and 0.5 –3.0 mm long. The margins of the leaves are thin, dry and membranaceous. Flowers are whitish or pinkish and borne on slender racemes 2-5 cm long on the current year's branches and are grouped together in terminal panicles. The pedicels are short. The flowers are most abundant between April and August, but may be found any time of the year. Petals are usually retained on the fruit. The seeds are borne in a lance-ovoid capsule 3-4 mm long; the seeds are about 0.45 mm long and 0.17 mm wide and have unicellular hairs about 2 mm long at the apical end. The seeds have no endosperm and weigh about 0.00001 gram (Wilgus and Hamilton 1962; Stevens 1990).

Table 1. Distinguishing characteristics of *T. ramosissima* and *T. parviflora* based on Welsh et al. (1987).

Characteristic	*Tamarix ramosissima*	*Tamarix parviflora*
Size	< 5 m tall	< 6 m tall
Bark	reddish brown	dark brown to deep purple
Bracts	scarcely translucent	more or less translucent
Flowers	parts in 5s	parts in 4s
Sepals	outer two narrower than inner; all more or less acute	outer two keeled and acute; outer flat or slightly keeled and obtuse
Stamen filaments	inserted under the disc near the margin between the lobes	arising gradually from disc lobes
Petals	obovate, 1-1.8 mm long	oblong to ovate, 1.9-2.3 mm long

STEWARDSHIP SUMMARY

Tamarisk is an aggressive, woody invasive plant species that has become established over as much as a million acres of floodplains, riparian areas, wetlands and lake margins in the western United States (Johnson 1986). I found no recent precise estimate on the area occupied by tamarisk. Tamarisk is a relatively long-lived plant that can tolerate a wide range of environmental conditions once established. It produces massive quantities of small seeds and can propagate from buried or submerged stems. It can replace or displace native woody species, such as cottonwood, willow and mesquite, which occupy similar habitats, especially when timing and amount of peak water discharge, salinity, temperature, and substrate texture have been altered by human activities. Stands of tamarisk generally have lower wildlife values compared to stands of native vegetation, although tamarisk can be important to some bird species as nesting habitat. Tamarisk is a facultative phreatophyte, meaning that it can draw water from underground sources but once established it can survive without access to ground water. It consumes large quantities of water, possibly more than woody native plant species that occupy similar habitats. Tamarisk is tolerant of highly saline habitats, and it concentrates salts in its leaves. Over time, as leaf litter accumulates under tamarisk plants, the surface soil can become highly saline, thus impeding future colonization by many native plant species.

Tamarisk is commonly controlled in riparian areas and wetlands and along lake shores because of its potential to displace native vegetation and its lower value as wildlife habitat. However, control over large areas is difficult in situations where hydrologic processes have been greatly altered, due to the high control cost and the likelihood that tamarisk will re-invade areas from which it is eliminated. Areas where tamarisk is to be managed should be selected carefully to maximize the likelihood of success.

Tamarisk can be controlled by five principal methods: 1) applying herbicide to foliage of intact plants; 2) removing aboveground stems by burning or mechanical means followed by foliar application of herbicide; 3) cutting stems close to the ground followed by application of herbicide to the cut stems; 4) spraying basal bark with herbicide; and 5) digging or pulling plants. In addition, The USDA has tested and proposed the release of two species of insects for tamarisk biocontrol but releases have not yet been permitted.

Selecting an appropriate control method involves considering the size of the area where tamarisk is to be controlled, restrictions on the use of particular herbicides or herbicides generally, the presence or absence of desirable vegetation where tamarisk is growing, the presence or absence of open water, adjacent land uses that might restrict prescribed burning, and the availability and cost of labor.

For larger areas (> 2 hectares) that are essentially monotypic stands of tamarisk, the best methods would likely be foliar application of imazapyr (Arsenal®) herbicide to the intact plants or burning or cutting plants followed by foliar application of imazapyr or triclopyr (e.g. Garlon4® or PathfinderII®) to the resprouted stems. Foliar application of imazapyr or imazapyr in combination with glyphosate (e.g. Rodeo®) can be effective at killing large, established plants. Over 95% control has been achieved in field trials during the late summer or early fall. The herbicide can be applied from the ground using hand-held or truck-mounted equipment or from the air using fixed-wing aircraft. Foliar application of herbicide works especially well in monotypic stands of tamarisk, although experienced persons using ground equipment can spray around native trees and shrubs such as cottonwood and willow. As an alternative to herbicides, prescribed fire or a bulldozer can be used to open up large stands of tamarisk. Once opened, the resprouts can be sprayed when they are 1 to 2 m tall using imazapyr, or imazapyr plus glyphosate, or triclopyr.

Tamarisk eradication in areas that contain significant numbers of interspersed, desirable shrubs and trees is problematic. Depending upon site conditions, it may not be possible to rapidly kill tamarisk plants without also killing desirable shrubs and trees. It such situations, it may be necessary to cut and treat tamarisk stumps with herbicide, as outlined in the next paragraph. While this method is relatively slow and labor-intensive, it will spare desirable woody plants. Alternatively, it may be more cost-effective to kill all woody plants at a site and replant desirable species afterward.

For modest-sized areas (< 2 hectares), cutting the stem and applying herbicide (known as the cut-stump method) is most often employed. The cut-stump method is used in stands where woody native plants are present and where their continued existence is desired. Individual tamarisk plants are cut as close to the ground as possible with chainsaws, loppers or axes, and herbicide is applied immediately thereafter to the perimeters of the cut stems. The herbicides triclopyr (e.g. Garlon4® or PathfinderII®) and imazapyr (Arsenal®) can be very effective when used in this fashion. This treatment appears to be most effective in the fall when plants are translocating materials to their roots. The efficacy of treatments is enhanced by cutting the stems within 5 cm of the soil surface, applying herbicide within one minute of cutting, applying herbicide all around the perimeter of the cut stems, and retreating any resprouts 4 to 12 months following initial treatment.

No matter how effective initial treatment of tamarisk might be, it is important to re-treat tamarisk that is not killed by initial treatment. It is also essential to continue to monitor and control tamarisk indefinitely because tamarisk is likely to re-invade treated areas. However, follow-up control is likely to require much less labor and materials than the initial control efforts.

IMPACTS (THREATS POSED BY THIS SPECIES)

During the past century, tamarisk has become naturalized along river bottoms and lake margins in the western United States, particularly in Arizona, New Mexico, California, Texas, Colorado, Utah, Nevada, Oklahoma and Wyoming. There are multiple, interacting factors involved in the invasion of tamarisk, and specific cause-and-effect relationships have not been determined (Everitt 1980). Factors that probably facilitated the spread of tamarisk include: intentional tamarisk plantings designed to protect streambanks and control erosion; conversion of native riparian forests to agricultural uses; damming of rivers fed by snowmelt which has shifted the time of peak discharge below the dams from spring to summer; creation of large areas of fine sediment that provide the ideal substrate for tamarisk colonization along the margins of reservoirs; increased salinity of rivers due to irrigation return flows and evaporation from reservoirs; reduced flood frequency downstream of reservoirs; and more stabilized base flows in rivers due to reservoir construction (Everitt 1980).   Everitt (1980) noted that tamarisk has not become established in all western rivers, particularly those that still experience large floods and those where spring, rather than summer flooding still predominates. It is likely that the spread of tamarisk has been and continues to be greatly facilitated by human activities.

Tamarisk possesses a number of undesirable attributes, according to a number of authorities. It 1) crowds out native stands of riparian and wetland vegetation; 2) increases the salinity of surface soil rendering the soil inhospitable to native plant species; 3) provides generally lower wildlife habitat value than native vegetation; 4) dries up springs, wetlands, riparian areas and small streams by lowering surface water tables; 5) widens floodplains by clogging stream channels; 6) increases sediment deposition due to the abundance of tamarisk stems in dense stands; and 7) uses more water than comparable native plant communities. However, data to support these claims by various authors do not always exist.

Crowding out native vegetation

There is little doubt that tamarisk can crowd out native riparian and wetland vegetation. A variety of field observations support this view. However, it is likely that human-induced changes in hydrologic regimes of rivers, as well as other factors, have paved the way for tamarisk invasion (Everitt 1980). For example, along the lower Colorado River in Arizona and California, the elimination of flooding due to the construction of dams, the salinization of the soil and recurrent wildfires have virtually eliminated the cottonwood-willow riparian forests (R. D. Ohmart, personal communication). Tamarisk is now the dominant riparian plant species. It appears that tamarisk is much less invasive along rivers where natural hydrologic processes are relatively intact.

Presumably, lack of regeneration of native shrubs and trees at a site would facilitate tamarisk invasion, but I found no studies to substantiate this. In some cases, tamarisk probably replaces rather than displaces native riparian vegetation that has been destroyed by human activities.

Increasing salinity of surface soil

It appears likely that tamarisk increases the salinity of soils. The leaves and stems contain concentrations of soluble salts in the range of 5-15% (Hem 1967) which are absorbed by the roots from deeper soil layers, transported though the plant and concentrated in the leaves. These salts are later deposited on the soil when the deciduous leaves drop. Thus, the accumulation of tamarisk litter can greatly increase the salinity of soils in tamarisk stands.

Lower wildlife values

Anderson et al. (1977) found that tamarisk stands along the lower Colorado River had lower bird density, bird species richness and diversity than did the native cottonwood-willow vegetation. Engel-Wilson and Ohmart (1978) found lower bird density and diversity in tamarisk stands along the lower Rio Grande River compared to native cottonwood-willow riparian forest. Kasprzyk and Bryant (1989) studied birds and small mammals along the Virgin River upstream from its inflow to Lake Mead in Nevada. They found that bird density and diversity were lower in tamarisk communities than native riparian vegetation. Ellis (1995) studied bird use of tamarisk and cottonwood vegetation in central New Mexico along the Rio Grande River. She found that many bird species used both habitats, with three species using only tamarisk and six species using only cottonwood. Assuming the prediction by Howe and Knopf (1991) that tamarisk may completely supplant cottonwood habitat along the middle Rio Grande River in New Mexico over the next century, the richness of riparian bird species in that area would decline.

Brown and Johnson (1990) argued that, while tamarisk habitat along the lower Colorado River was much less valuable for breeding birds than native riparian habitat, the reverse was true along the Colorado River in Grand Canyon National Park. Hunter et al. (1988) proposed that bird nests in tamarisk along the lower Colorado River experienced higher heat loads than nests in multi-layered cottonwood forests that afford more shade. Anderson (1994) studied the Apache cicada in a native riparian community and a tamarisk stand along the lower Colorado River. He found that although cicadas were abundant in both communities, the insects emerged later in the native, cottonwood and willow-dominated communities when migrating and nesting birds were present. This change in temporal availability of this key food resource may help explain the low abundance of breeding birds in tamarisk communities.

Brown and Trosset (1988) stated that tamarisk stands in Grand Canyon National Park developed after construction of the of Glen Canyon Dam; comparable vegetation was not present along the river prior to construction of the Dam, so the tamarisk vegetation represented a new habitat type for that locale. In fact, black chinned hummingbirds (*Archilocus alexandri*) nested only in tamarisk-dominated habitats along the Colorado in the Grand Canyon (Brown 1992). Thus, Brown and Trosset (1988) argued that regional tamarisk management strategies must developed with respect to bird species.

Hunter et al. (1988) studied bird use in riparian vegetation along the middle Pecos River in New Mexico. There, birds used tamarisk as much as or more than other vegetation types year round. They noted that prior to invasion by tamarisk, this portion of the Pecos River had few tall, mature stands of vegetation. Thus, birds may have expanded their local ranges as tamarisk expanded. The lack of tall vegetation along the Pecos River contrasts with the condition of other desert riparian systems prior to Euro-American settlement (Ohmart and Anderson 1982).

The Federally Endangered Southwestern Willow Flycatcher (*Empidonax trailii extimus*) is known to nest in tamarisk-dominated areas (USFWS 1993). This subspecies of the Willow Flycatcher is widely distributed in scattered remnant populations across much of the area where tamarisk is invasive. Although it also feeds and breeds in riparian woodlands dominated by native plants including willows (*Salix* spp.) arrowweed (*Pluchea* spp.) and *Baccharis* species there has been concern that it might be further threatened if a biocontrol agent controls tamarisk over wide areas of the southwest. Others point out that even a highly successful biocontrol agent won't eliminate tamarisk and, that where it is reduced, native plants favored by breeding and feeding birds are likely to establish (Lovich and de Gouvenain 1998).

Most published studies of the value of tamarisk to wildlife in North America have focused on birds and purported benefits to certain bird species may or may not extend to other animals (Lovich and de Gouvenain 1998).

Increased water consumption

There is no doubt that tamarisk stands consume large amounts of ground water. Robinson (1965) cited studies which indicate tamarisk consumes on the order of 4 acre-feet of ground water annually (Table 2). Robinson (1965) projected that consumptive use of tamarisk in the United States would be 5 million acre-feet in 1970. To place this number in perspective, this is more than twice the quantity of water held behind the Glen Canyon Dam at full capacity. Weeks et al. (1987) reviewed studies that investigated water use by tamarisk in New Mexico and Arizona (Table 2). The estimates of water use were quite variable, presumably reflecting variations in weather and environment, as well as difficulties in estimating evapotranspiration precisely.

Table 2. Estimates of annual water use by tamarisk, with the first five references cited in Weeks et al. (1987).

Study author(s)	Estimate of water use (m / yr)
Blaney et al. (1942)	1.2 - 1.67
Gatewood et al. (1950)	1.2 – 3.0
U.S. Bu Rec (1973)	0.7 – 1.4
Van Hylckama (1974)	2.6 – 3.4
Culler et al. (1982)	0.8 – 1.0
Gay (1990)	1.73 – 1.82

Sala et al. (1996) found that individual *Tamarix ramosissima* plants used about the same amount of water per unit of leaf area as did the native riparian species *Pluchea sericea*, *Prosopis pubescens* and *Salix exigua*. Their study also confirmed previous work by Davenport et al.

(1982) that indicated evapotranspiration from riparian communities with high ground water availability is more dependent on stem density than on plant species composition. Sala et al. (1996) noted that tamarisk stands may have significantly more leaf area per unit of ground area than stands of native riparian vegetation. If so, the tamarisk stands would use more water per unit of ground area than the native stands and, replacing the tamarisk stands with native species would save water.

Weeks et al. (1987) estimated that tamarisk consumed about 0.3 m more water per year than replacement vegetation along the Rio Grand River in central New Mexico. Thus, conversion of stands of native riparian forest to a tamarisk stand may result in increased consumptive use of ground water. However, I found no other studies which demonstrated increases in ground water levels or stream flows following tamarisk removal, except on a very local scale in small streams or springs.

Many land managers, however, cite cases of springs that dried up following invasion by tamarisk, with springs flowing again after the tamarisk was removed (Barrows 1993, Neill).
Brotherson et al. (1982) found that the proportion of xerophytic plant species increased as the age of tamarisk stands increased. Thus, the longer a community had been occupied by tamarisk, the drier it became.

Widening floodplains and increasing deposition of sediment

Robinson (1965) claimed that dense stands of tamarisk could increase areas inundated by floods. This could occur because dense stands of tamarisk choke overflow and lateral channels, thereby reducing the capacity of a stream channel and associated flood plain to transport flood waters. Dense stands of tamarisk could increase deposition of sediment, due the increased channel roughness caused by tamarisk stems. However, Everitt (1980) said that, while vegetation can promote local sediment deposition, the idea that vegetation over large areas can increase regional deposition of sediment is unfounded.

GLOBAL RANGE

The genus Tamarisk is one of four genera of the family Tamaricaceae which is native to Africa, Asia, and Europe (Robinson 1965). The taxonomy of tamarisk is disputed. In the most recent monograph of the genus, Baum (1978) recognized over 50 species worldwide; however, other authorities lump many of these species. The natural range of the 5-merous tamarisk (here referred to as *T. ramosissima*) is from the southern Europe to Asia minor and eastward to Mongolia, Tibet, central China and North Korea (Crins 1989). The natural range of the 4-merous *T. parviflora* is southern Europe and perhaps northern Algeria (Crins 1989). Although *T. aphylla* is not regarded as invasive in North America, it is a severe pest of riparian areas in arid central Australia where it apparently has all the same bad impacts *T. ramosissima* and *T. parviflora* have in the southwestern U.S (Griffin et al. 1989).

Tamarisk has spread to all of the western and Great Plains states, with the greatest concentrations in Texas, Arizona and New Mexico (Robinson 1965). It is also abundant in California, Nevada, Utah and western Colorado. It is not clear whether or not the 5-merous species (*T. ramosissima*) dominates in some areas and the 4-merous species (*T. parviflora*) in others. Both the 5-merous species and the 4-merous species also escape from cultivation occasionally in the eastern U.S., particularly on sandy beaches and roadsides, but are not invasive there (Gleason and Cronquist 1991, Radford et al. 1968, Wunderlin 1998). Weber (1990) reported that the Spanish explorer Father Escalante mentioned tamarisk in his journals from his travels throughout the American Southwest in 1776. If this is correct, it means that the Spanish introduced this species at least 200 years ago, although Robinson (1965) provided evidence that contradicts this claim. Robinson (1965) stated that tamarisk was offered for sale to the public in California beginning in the 1850s. Apparently, tamarisk did not start to become invasive in the U.S. until about 1877 when collections of tamarisk started to appear in herbaria (Robinson 1965). The plant did not attract much attention in the United States until the 1920s, and its impact on ground water was not appreciated until years later (Robinson 1965).

HABITAT

Tamarisk can grow in many different substrates from below sea level to about 2100 m elevation (Hoddenbach 1990), although it grows mostly on fine-textured soils (Everitt 1980). Tamarisk is a facultative phreatophyte (Turner 1974), meaning that it uses but does not depend on ground water. Tamarisk occurs in areas where its roots can reach the water table, such as floodplains, along irrigation ditches and on lake shores. Plants usually grow where the depth to ground water does not exceed 3 - 5 m. Tamarisk forms dense thickets where the ground water lies from 1.5 – 6 m below the soil surface (Horton et al. 1960). Where ground water is deeper than 6 m, plants form an open shrubland (Horton and Campbell 1974). Tamarisks have a wide tolerance of saline or alkaline soils (Robinson 1965). Carmen and Brotherson (1980) found that sites with tamarisk in Utah had higher soil salinity and pH than sites without tamarisk. Brotherson and Winkel (1986) identified the major factors that contribute to tamarisk success as alkaline soils, available soil moisture, and sufficient disturbance of native vegetation to facilitate tamarisk invasion. Everitt (1980) stated that ideal conditions for first-year survival for tamarisk seedlings are on gently sloping riverbanks, or sandbars and siltbars where water levels slowly recede during the period of seed fall.

BIOLOGY – ECOLOGY

Stevens (1990) presented an overview of the biology and ecology of tamarisk based on studies in northern Arizona. He found that tamarisk was a highly fecund, relatively long-lived phreatophyte which is very tolerant of inundation, desiccation and nutrient stress. Tamarisk produces massive quantities of minute seeds that are readily dispersed by wind. Stevens (1990) found the seeds were viable for up to 45 days under ideal conditions during summer, and could complete germination within 24 hours following contract with water. Tamarisk seeds had no dormancy or after-ripening requirements. Tamarisk flowered in two flushes, one in April-May and another in late July in northern Arizona, presumably reflecting availability of spring snowmelt and summer monsoon moisture. Tamarisk flowered continuously under favorable environmental conditions but the flowers required insect pollination to set seed. Tamarisk seed lived for only a few weeks during the summer; and the few seeds that might survive over winter under cooler conditions did not appear to form a persistent seed bank (Stevens 1990).

Tamarisk will produce roots from buried or submerged stems or stem fragments (Merkel and Hopkins 1957). This allows tamarisk to produce new plants vegetatively following floods from stems torn from the parent plants and buried by sediment. Ideal conditions for first-year survival are saturated soil during the first few weeks of life, a high water table, and open sunny ground with little competition from other plants.

Tamarisk has two traits that might be exploited for its control. First, tamarisk seedlings grow more slowly than many native riparian plant species. Second, mature tamarisk plants are highly susceptible to shading (Stevens 1990)

Hem (1967) studied the salts present in leaves and stems of *T. pentandra* at locations in Arizona and New Mexico. He found that the total concentration of calcium, magnesium, chloride, and sulfate in the leaves generally ranged from 5 to 15% of their dry weight. About 10% of the total ionic concentration consisted of inorganic ions that could be readily washed off the leaves by rainfall.

RESTORATION POTENTIAL

Smith and Devitt (1996) concluded that riparian restoration efforts that involve removing dense stands of tamarisk without restoring historical flow regimes will not be successful without extensive follow-up management. Native cottonwood and willow species may fail to re-establish without intensive planting in areas where floods have been eliminated or where receding flood flows do not occur when short-lived cottonwood and willow seeds are produced. Another potential problem is the ability of tamarisk to increase the salinity of surface soil due to deposition of highly saline leaf litter. In areas subject to frequent flooding, increased soil salinity should be a fairly transient phenomenon. High salinities may persist, however, in higher terraces along rivers whose banks are dominated by tamarisk because floodwaters rarely reach these areas. This may make it difficult or impossible for native plants to colonize these areas once tamarisk is controlled. Another problem may be downcutting of stream channels downstream of dams. In such situations, surface water tables may decline to the point that cottonwood and willows can no longer survive or colonize. Wildfire may be a problem because tamarisk-dominated communities experience higher fire frequencies than native cottonwood-willow communities, eventually eliminating the fire-sensitive cottonwood and perhaps even the willows (Busch 1995; Busch and Smith 1993). A final problem may be lack of a thorough network of mycorrhizal hyphae in soils that have been dominated by tamarisk for many years (St. John 1997). Mycorrhizae are important for many native species and their absence or low abundance may impede colonization of desirable plant species.

MANAGEMENT REQUIREMENTS

Before embarking on a tamarisk control program, consult with federal, state, and local agencies to determine what permits, if any, may be required. For example, applying herbicides may require permits; certain herbicides may not be approved for use in or near open water; prescribed burns will likely require permits from the local air quality authority; the U. S. Fish & Wildlife Service may have jurisdiction if listed threatened or endangered species occupy the tamarisk habitat to be managed and a Section 404 permit may be required from the U. S. Army Corps of Engineers for mechanized control in aquatic areas (Stein 1996).

In addition, before using chemicals, managers need to understand and follow safety procedures. Workers using herbicides may need to wear protective clothing and my need face, eye and skin protection. Soap and water should be available on site to clean up after contact with chemicals.

Neill (1990) suggested that tamarisk control is most effective in canyons subject to intense flooding and at springs that are never flooded. Periodic flooding removes tamarisk plants in the active floodplain. Therefore, tamarisk control should be directed towards larger plants that occupy the higher terraces that are not flooded or are flooded very infrequently. Smaller plants in the active floodplain can be dealt with later and may be washed away by a scouring flood in the mean time. At springs, tamarisk plants should be eradicated so seeds are not produced to re-colonize cleared areas. Once eradicated, occasional follow-up should be sufficient to remove tamarisk plants that arise from seeds transported over long distances. Neill (1990) said that tamarisk control will be most difficult or impossible along rivers that flood enough to promote seed production and dispersal but not enough to dislodge established tamarisk plants.

Tamarisk should be controlled in natural areas or it will proliferate. Left uncontrolled, tamarisk can crowd out virtually all native vegetation. Proposing a contrary view, Brown and Johnson (1990) suggested that tamarisk habitat in Grand Canyon National Park, and perhaps elsewhere, is valuable for birds and ought to be reconsidered in regional management programs. They suggested that a mosaic of structurally diverse tamarisk habitats could be maintained along the Colorado River by releases of floodwaters from Glen Canyon Dam every 20 to 30 years.

MANAGEMENT PROGRAMS

Egan (1996) outlined a seven-step approach to site restoration and maintenance where tamarisk is involved. The following is modified somewhat from Egan's original list.

1. Identify factors that allow tamarisk or desirable species to invade and maintain themselves at a site, considering the entire watershed. Develop a long-term vision.
2. Plan a sufficiently large restoration site to allow natural processes that promote natural community diversity to operate.
3. Utilize natural processes such as floods and fire as well as deliberate control methods to further site restoration and maintenance.
4. Eliminate or reduce disturbances that undermine restoration and maintenance efforts.
5. Minimize recreation conflicts in the area, particularly as they influence disturbance at the restoration site.
6. Monitor site conditions on a regular basis. Revise objectives, strategies and tactics as needed.
7. Keep informed and maintain close contract with others involved in tamarisk control work.

Control of tamarisk often involves considerable cash and labor resources, which may exceed those available from any one source. de Gouvenain and West (1996) presented ideas for developing partnerships to control tamarisk that have been successful for BLM in California. They have been able to solicit modest cash grants and in-kind contributions from a variety of partners to accomplish projects that BLM would not have been able to complete alone. Interestingly, they have found prisoners to be hard workers and to be willing to put up with hot, dry conditions. Neill (1996) outlined his considerable experience with volunteers controlling tamarisk and provides a long list of tamarisk projects that have been undertaken in California partly or entirely by volunteers.

Barrows (1993) described a very successful tamarisk control program at a 10 hectare wetland site at the Coachella Valley Preserve in Riverside County, California. This project was initiated in 1986 and was completed in 1992, and required 5000 person-hours of labor and 30 gallons of herbicide. Labor was provided mostly by California Conservation Corps crews and Nature Conservancy staff and volunteers.

Table 3 contains a partial list of tamarisk control projects in the western U.S., and many more are underway. Managers are encouraged to contact experienced resource managers (e.g., BLM, USFS, USFWS, National Park Service, state wildlife agency, county weed control authority) in their area for information about local control programs.

Table 3. Selected management programs aimed at controlling tamarisk in the western United States.

Location	Methods of control	Effectiveness	Reference
Afton Canyon ACEC, CA	Burning & herbicide; cutting & herbicide	High High	Chavez 1996 Egan 1996, 1997 West 1996
Big Bend Nat'l. Park, TX	Cutting & herbicide	Low	Fleming 1990
Bosque del Apache NWR Complex, NM	Combinations of herbicide, mechanical control & burning	High	Taylor 1996
Canyonlands, Arches Nat'l Parks; Natural Bridges Nat'l. Mon. , UT	Cutting & herbicide	Moderate	Thomas et al. 1990
Coachella Valley Preserve, CA	Cutting & herbicide	High	Barrows 1993
Death Valley Nat'l. Park, NV	Mechanical & herbicide	High	Rowlands 1990
Grand Canyon Nat'l. Park, AZ	NA	NA	Sharrow 1990
Glen Canyon Nat'l. Rec. Area, UT	Cutting; burning	NA	Holland 1990
Guadalupe Mtn's. Nat'l. Park, TX	Cutting & herbicide; pulling	NA	Davila 1990
Joshua Tree Nat'l. Park, CA	Cutting & burning	High	Coffey 1990
Lake Mead Nat'l. Rec. Area, AZ	Cutting & herbicide; burning basal herbicide; mechanical	Unknown	Burke 1990 Luttrell 1983 Deuser 1996
Organ Pipe Cactus Nat'l. Mon., AZ	Digging	High	Mikus 1990
Petrified Forest Nat'l. Park, AZ	Cutting & herbicide; excavation	21-76% kill	Bowman 1990 Johnson 1985
Picacho State Rec. Area, CA	Cutting & burning	High	Jorgensen 1996
San Miguel River at Tabeguache Creek Preserve, CO	Cutting & herbicide	High initial kill	Willits 1994
Wupatki Nat'l. Mon., AZ	Cutting & herbicide	Moderate-High	Cinnamon 1990
Zion Nat'l. Park, UT	Cutting & herbicide	Moderate-high	Hays and Mitchell 1990

BIOLOGICAL CONTROL

Stevens (1990) stated that only six of the of the > 200 species of invertebrates known to occur on tamarisk in the U.S. were sufficiently common to be pests. Biological control would potentially kill tamarisk plants used in home landscaping and might reduce supplies of honey locally, as honeybees heavily use tamarisk. Landscapers and honey producers might oppose biological control programs.

In 1986, the U.S. Department of Agriculture's Agricultural Research Service (USDA-ARS) laboratory in Temple, Texas initiated a biological control program for tamarisk (DeLoach 1996). The goals for the program were to find and obtain insects that would damage *Tamarix ramosissima* without damaging native vegetation or *Tamarix aphylla*, the less invasive, evergreen species that is used for windbreaks and shade in the southwestern U.S. To date, two species of insect have been tested and proposed for release by USDA. One is a mealybug (*Trabutina mannipara*) from Israel and the other is a leaf beetle (*Diorhabda elongata*) from China. The leaf beetle defoliated tamarisks in greenhouse tests and the mealybug fed on twigs. DeLoach and Gould (1998) predict that these two insects may provide about 85% control of tamarisk and will take 3-5 years to control tamarisk at small sites and 5-10 years to control tamarisks in small to medium watersheds. Release of the two insects is pending resolution of whether the Southwestern Willow Flycatcher (*Empidonax trailii extimus*), which is listed as Endangered by the U.S. Fish and Wildlife Service, would be detrimentally affected by tamarisk control. The Flycatcher is known to nest in tamarisk dominated areas (USFWS 1993). In August 1998 the USDA requested permission from the U.S. Fish and Wildlife Service to release and monitor the impacts of one or both of these insects at thirteen sites in seven states in the western U.S. (CA, CO, NM, NV, TX, UT, WY; De Loach and Gould 1998). A decision had not been made as of late December 1998.

Several other insect species are currently in various stages of being tested.

CONTROL WITH BURNING

Tamarisk plants typically resprout vigorously after burning. However, burning followed by herbicide application to the resprouts can achieve excellent control in monotypic stands of tamarisk, as outlined in the "Control with Chemicals" section. Burning opens dense tamarisk stands and greatly reduces tamarisk biomass. Jorgensen (1996) recommended felling 20 to 25% of the largest tamarisk plants in stands several months prior to burning to create enough dry ground fuel to carry a fire. He also suggested using wildfires in tamarisk stands as an opportunity to begin tamarisk control, and following up the burn with herbicide treatment of the resprouts. Burning during the hottest part of the summer, when plants experience the greatest water stress, is likely to yield the best results. Chavez (1996), West (1996) and Egan (1996, 1997) used prescribed fire in Afton Canyon, California, to open dense stands of tamarisk for resprout treatment with herbicides. Duncan (1994) stated that repeated yearly burns can suppress tamarisk and kill some of the plants after 3 to 4 years.

Research by Busch and his colleagues in Arizona suggests fire is highly detrimental to native riparian forests. Busch and Smith (1993) noted that fire is a novel disturbance in southwestern US riparian forests. Furthermore, the dominant woody plant in many southwestern native riparian forests, Fremont cottonwood (*Populus fremontii* ssp. *fremontii*), does not re-sprout vigorously following fire, while tamarisk does. Busch (1995) concluded that the invasion of the alien tamarisk coupled with the novel disturbance of fire completely change southwestern riparian forests, based on his study of burned and unburned riparian forests along the lower Colorado River in Arizona. His results suggested that the native cottonwood – willow forest would be completely converted to tamarisk stands over the next several decades. Thus, burning does not appear to be a reasonable control method for tamarisk where it occurs as a component of native communities.

CONTROL WITH CHEMICALS

Foliar application to intact plants

Field studies in New Mexico by Duncan (1994) suggested that aerial application of the herbicide imazapyr (Arsenal®) alone or in combination with glyphosate (e.g. Roundup®, Rodeo®) is effective and practical for controlling tamarisk over thousands of hectares, particularly in dense stands where little on no native vegetation is present. Cost of aerial application of herbicide ranged from $70 to $90 per acre. Field trials along the Pecos River in New Mexico showed that fixed-wing aircraft could apply herbicide quite precisely, consistently following the 15 meter buffer line along the river bank. Several field trials have produced control rates of > 90% after one or two years. Alternatively, herbicide can be sprayed directly on tamarisk plants using truck-mounted equipment if stands are not too dense. This approach is appropriate where significant numbers of native trees and shrubs are interspersed with tamarisk plants. Duncan (personal communication) cautioned that sprayed plants should not be bulldozed or burned for two growing seasons, because disturbing the treated plants can induce some to resprout. Duncan and McDaniel (1996) have developed the following general guidelines:

- Focus treatment on young or regrowing tamarisk plants, because smaller plants are easier to kill than larger plants.
- Target areas previously plowed, mowed, burned or cleared, or areas where tamarisk appears to be invading.
- Target areas with tamarisk densities < 400 plants per hectare.
- While the optimal herbicide proportions have not yet been developed, a mixture of 0.5% (v/v) imazapyr and 0.5% glyphosate (v/v) plus 0.25% (v/v) nonionic surfactant give satisfactory results.

Kunzmann and Bennett (1990) stated that preliminary research indicates that the broad-spectrum herbicide imazapyr is the most cost-effective control technique known for tamarisk. However, they noted that more research is required to determine long-term effects of imazapyr on non-target plants and on other organisms.

Prescribed burning followed by foliar application of herbicide

This method is appropriate for larger areas, e.g., hundreds of hectares. It has been used successfully at BLM's Afton Canyon Area of Critical Environmental Concern in the Mojave Desert near Barstow, California. BLM began this program in 1991 in order to control tamarisk and restore riparian vegetation on 280 hectares of riparian habitat (Egan 1996, 1997). Costs of removing the tamarisk and restoring native vegetation ran from $1500 to $3000 per acre. The first attempt to ignite a tamarisk stand was unsuccessful, so they cut and stacked selected tamarisk plants to create dry fuel that would carry a fire. The subsequent fire burned the majority of the tamarisk stems and opened up the stands so follow-up work could be accomplished easily (West 1996). Resprouts were treated with triclopyr using hand-held equipment; Egan (1996) recommended the Pathfinder II formulation. As of 1997, tamarisk abundance had declined dramatically in the areas where it had been controlled (Egan 1997).

Cut-stump method

The cut-stump method is appropriate for modest-sized areas 2 hectares or smaller. Neill (1990, 1996) summarized the details of cut-stump herbicide treatments for tamarisk. Persons considering using the stump-cut method for the first time should read those articles. Neill cautioned that the effectiveness of treatments is highly dependent on the skill of the field workers – poor technique leads to poor results. Based on Neill's work, the triclopyr herbicides Garlon4® or PathfinderII® appear to be the best choices for killing tamarisk due to higher phytotoxicity, low toxicity to humans, lack of restriction, and cost comparable to the other herbicides when diluted as directed. These herbicides contain the same active ingredient, triclopyr. Garlon4® is diluted 1:3 (v/v) in the field with cheap vegetable oil while PathfinderII® is sold already mixed and diluted with vegetable oil. PathfinderII® also contains a dye, which makes it easier to distinguish stumps that have been treated from those that have not. Dyes such as colorfast® purple, colorfast® red and basoil® red can be added to Garlon4®.

Diluted, Garlon4® costs about $26 per gallon, while PathfinderII® costs about $30 per gallon. One gallon is sufficient to treat hundreds of cut stumps. Neill (1990, 1996) stated that 95% mortality can be expected with either of these herbicides, with lower mortality probably being the result of not cutting close enough to ground level and/or not treating the circumference of the stump completely. However, Howard (1983) found that cuts 15 to 30 cm above the ground surface were effective when using Garlon4® in the autumn. Neill (1990, 1996) noted that tamarisk plants are best located in the spring or summer when their pink flowers are visible, and that control during this period may be advisable even though the plants are less susceptible to the herbicide. Neither Garlon4® nor PathfinderII® is labeled for aquatic use; however, stumps located near but not in or over open water can be treated with these herbicides provided that none of the herbicide enters the water. Garlon3A, an amine-based, water-soluble formulation of triclopyr, may become registered for use over water in 1999 or 2000.

Neill (1990) summarized his four cardinal rules for tamarisk control using the stump-cut method, as follows:

1. Cut stems of tamarisk within 5 cm of the ground surface.
2. Apply herbicide within a few minutes of cutting.
3. Cut and treat the entire circumference of the stem cambium.
4. Treat any resprouted foliage between 4 to 12 months after the initial treatment.

Barrows (1993) outlined an ambitious and successful tamarisk control program at the Coachella Valley Preserve in California. He suggested cutting tamarisk stems with small chainsaws or shears as close to the ground as possible, then immediately (within one minute) applying herbicide to the cut stumps. This treatment worked best in the fall when the plants translocate nutrients from the leaves and stems into their roots. Herbicide was diluted in the ratio of one part herbicide to 2 or 3 parts water to cut costs, and the diluted herbicide killed tamarisk effectively. Barrows (1993) recommended backpack sprayers to deliver the herbicide because it was much easier on the person doing the spraying. However, others recommend using hand-held spray bottles in dense stands to avoid tangling the spray equipment in the tamarisk stems. Under actual control conditions, over half of the treated stumps eventually resprouted and required follow-up treatment. In dense stands of tamarisk, cut stems were stacked in brush piles that were heavily used by birds. Over a 5-year period, the brush piles decomposed to occupy about 10% of their original volume. Work crews used protective clothing, including hand, face, and eye protection, and as a safety precaution were provided with fresh water on-site to wash skin that accidentally came in contact with herbicide.

Willits (1994) found Garlon4® to be very effective at killing tamarisk along the San Miguel River in Montrose County, Colorado, on a Nature Conservancy preserve. In the fall, tamarisk stems were cut either with a chainsaw or a compound-action lopper, and the stumps were immediately sprayed with herbicide. Casual observations suggested an initial kill rate of over 90%.

Bowman (1990) applied undiluted Garlon3A® herbicide to freshly cut stems of tamarisk in June and July at Petrified Forest National Park in Arizona, with an initial kill rate of 21%. Johnson (1985) achieved an initial kill of 76% using Garlon3A® at the Petrified Forest.

Cinnamon (1990) found that "frilling" cut stems and immediately applying Tordon® RTU to them was the most effective treatment, with initial kill ranging from 80 to 100%. He emphasized the need to grub around the bases of tamarisk plants to expose below-ground cambium and enhance uptake of herbicide by the plants.

Hays and Mitchell (1990) reported that cutting tamarisk stems and applying Garlon3A® herbicide killed 88% of the test plants in June treatments and 62% of test plants in February treatments. Although herbicide was applied the same day as the plants were cut, it is possible that herbicide application did not immediately follow cutting, thus reducing potential kill rates.

Rowlands (1990) reported satisfactory control of tamarisk in Death Valley National Park using a combination of mechanical and herbicide treatments. The herbicide used was Tordon® RTU. Burning was used occasionally to dispose of slash and to create access ways.

Basal bark treatment with herbicide

Neill (1996) reviewed the pros and cons of the basal bark method of tamarisk control. This method precludes the need to cut the tamarisk plants, resulting in major savings in labor and produces no tamarisk debris to haul away or burn. Disadvantages are the higher amount of herbicide required, up to five times that needed for stump-cut control, and lower mortality than with stump-cut. Neill (1996) noted that the basal bark method has been very effective at killing resprouts from debris piles left by a major flood. Jorgensen (1996) stated that basal bark application of Garlon4® was very effective on tamarisk plants with a basal diameter of less than 4 inches.

Carpet roller method
H. S. Mayeux with the USDA-ARS in Temple, Texas developed a carpet roller attachment for the front of a tractor. The roller is sprayed with herbicide, which is then applied to the tamarisk via the carpet roller as the tractor drives through the tamarisk stand. This method is an alternative in dense stands where desirable trees and shrubs are present. This method might also be useful in situations where standing water is interspersed with the tamarisk plants.

Table 4. Summary of herbicide information relevant to tamarisk control (Jackson 1996).

Herbicide Trade Name	Active Ingredient	Formu-lation	Signal Word	Aquatic Registration	Foliar Applic?	Aerial Applic?	Stump Cut?	Basal bark Application
Arsenal®	Imazapyr	IPA-salt	Caution	No	Yes	Yes	Yes	No
Garlon3A®	Triclopyr	Amine	Danger	No (applied for)	Yes	No	Yes	Yes
Garlon4®	Triclopyr	Ester	Caution	No	Yes	No	Yes	Yes
PathfinderII®	Triclopyr	Ester	Caution	No	No	No	Yes	Yes
Rodeo®	Glyphosate	IPA-salt	Caution	Yes	Yes	Yes	Yes	No
Roundup®	Glyphosate	IPA-salt	Caution	No	Yes	Yes	Yes	No

Sisneros (1991) reviewed herbicide control of tamarisk. Although this reference is a bit dated, it contains much information about toxicity, application methods, advantages and limitations of specific herbicides, and label data. He noted that Garlon® formulations are among the safest herbicides for mammals and other organisms, although Garlon4® is toxic to fish. Triclopyr, the active ingredient in all the Garlon® formulations decomposes rapidly after application, in less than one day in water and between 2 to 8 weeks in soil. Triclopyr will not kill grasses but it will kill native trees and shrubs.

CONTROL WITH CUTTING
A single cutting of tamarisk is ineffective, because tamarisks resprout vigorously. However, cutting combined with herbicide treatment can be very effective at controlling tamarisk, as noted above. Cutting tamarisk can reduce consumption of ground water, through reduction of transpiring leaves. Van Hylckama (1974) found that cutting tamarisk back from 3 m to 0.5 m reduced water consumption by 50%.

Burke (1990) found that scraping a site along the shore of Lake Mead with a bulldozer killed some tamarisk plants, but that many resprouted from roots that remained in the soil. Subsequent trampling from people and crushing by cars killed many of the resprouts. Also at Lake Mead, Luttrell (1983) found that a single cutting or burning would not kill tamarisk, but that repeated cutting and burning might kill the root system.

Coffey (1990) reported that Joshua Tree National Park did not use herbicide to control tamarisk, which grows primarily around isolated springs. Rather, they planned to cut tamarisk plants and burn the slash in the winter when seeds are not present on the plants. In the one burn conducted, all tamarisk was reportedly killed. Coffey (1990) noted that the success of burning may reflect the very dry conditions under which the tamarisk plants were growing.

Root plowing has been used to control tamarisk. It is important that the root plow cut the tamarisk root crowns well below the soil surface, e.g., 0.3 - 1.0 m. Root plowing works best during hot, dry conditions that help dry the cut roots. Root fragments left in the ground will often resprout after root plowing, necessitating follow-up treatment, either with hand-grubbing resprouts or spraying them with imazapyr or triclopyr. Root plowing is appropriate for large, dense stands that have little or no native vegetation and where prescribed burning and/or aerial application of herbicide is not feasible. Root plowing was used to clear about 5000 hectares of tamarisk along the Rio Grande River in central New Mexico (Weeks et al. 1987).

Cinnamon (1990) tried cutting tamarisk stems with a weed-eater, followed by application of triclopyr herbicide to the cut stems, but found this method ineffective. Small stems became tangled in the weed-eater and the person following the weed-eater could not locate all the cut stems to treat with herbicide.

CONTROL WITH GRAZING, DREDGING AND DRAINING

Tamarisk is able to extract water from deeper in the soil profile than the native species of cottonwood and willow. Therefore, draining and dredging that lead to local declines in water table depth could promote tamarisk at the expense of desirable native plants, rather than discourage tamarisk.

Cattle (and probably goats) will eat tamarisk, but grazing alone is probably not a feasible control method. However, goats might be able to control dense stands of tamarisk where little native vegetation is present, particularly if the stands are cut or burned first, with goats eating the regrowth.

CONTROL WITH MOWING, DISKING AND PULLING

Mowing might be a useful way to reduce the volume of tamarisk prior to treatment with herbicide, especially in relatively level sites where prescribed burning is not feasible. Hand pulling can be an effective way to control tamarisk in situations where the plants are small, where access is difficult, or where herbicides cannot be used. For example, hand pulling has been used to control new tamarisk plants around isolated desert springs in national parks after the larger tamarisk plants have been killed.

CONTROL WITH PLASTIC SHEETING

I found no references to controlling tamarisk with plastic sheeting. It does not appear to be a promising control technique due to the relatively fragile nature of plastic coupled with the periodic flooding that occurs in typical tamarisk habitat.

MONITORING REQUIREMENTS

A key shortcoming of many tamarisk control programs is the failure to systematically assess the efficacy of control efforts. Without such data, it is impossible to objectively gauge the value of control efforts.

There are several elements of a typical monitoring program. First, management objectives must be developed. For example, how much tamarisk is to be eliminated over what area? Second, monitoring objectives must be prepared based on the management objectives. For example, what is the minimum amount of change that you want to be able to detect and how sure do you want to be of detecting it (Elzinga et al. 1998)? Third, contingency plans must be developed and ready to be implemented in case monitoring indicates the management objectives are not met. The objectives will serve as the basis for a monitoring plan that sets forth in considerable detail the actions to be taken.

Tamarisk monitoring programs would likely involve documenting the presence, absence or abundance (e.g., canopy coverage) of tamarisk in key locations such as springs. In addition, abundance data for desirable plants could be useful if the control method might have adverse effects on those species. Certain animal species might be monitored if increases or decreases in their populations were management objectives.

Once control measures are initiated, the success or failure of the control measures should be monitored. The particulars of the monitoring program would be dictated by the management and monitoring objectives. Considerations such as the number, dispersion, size, shape, and location of sampling units; response variables for which data will be collected; frequency of data collection; whether temporary or permanent sampling units will be used; methods of data analysis; and storage protocol for data need to be considered. A useful reference for developing monitoring programs is the Bureau of Land Management's Technical Reference titled "Measuring and Monitoring Plant Populations" which was developed in conjunction with the U. S. Forest Service and The Nature Conservancy (Elzinga et al 1998).

MONITORING PROCEDURES

Everitt et al. (1996) developed a procedure using data collected with standard video from a fixed-wing aircraft in conjunction with a geographical information system (GIS) and a global positioning system (GPS) to map locations of tamarisk infestations along rivers. Managers could use such data to develop regional maps of tamarisk occurrences to help identify areas where monitoring and management would be most fruitful. The aerial images could also be used to monitor future contraction or expansion of tamarisk occurrences. Data from large areas could be obtained relatively inexpensively using this approach.

MONITORING PROGRAMS

I found little published information on monitoring programs. It appears that many management programs aimed at controlling tamarisk involve little or no systematic attempt to assess the efficacy of control treatments. Where monitoring has been attempted, it has usually been designed to assess the percentage of tamarisk clumps that are killed by the treatment(s). Descriptions of monitoring programs are typically very sketchy with little or no information provided about management or monitoring objectives, contingencies in case objectives are not achieved, sample sizes, sample allocation, frequency of data collection, etc. Several managers noted the absence or uncertainty of funding to support monitoring programs. It appears that many land managers would plan and initiate monitoring programs for tamarisk control if funds were available.

A notable exception to the general lack of monitoring is the work of Egan and his colleagues in BLM (Egan 1997; Egan 1997; West 1996; Chavez 1996) at the Afton Canyon Area of Critical Environmental Concern (ACEC) near Barstow, California. They established goals for the project: control alien plants; restore critical native plant community elements over 280 hectares of degraded riparian habitat; and improve the proper functioning condition rating of the Mojave River (which flows through the site) from non-functioning to functioning at risk. Managers developed two monitoring approaches for tamarisk. They established a total of six permanent, 2 m x 2 m photoplots across young, medium and old age tamarisk stands. In the photoplots, they visually estimated cover of tamarisk, bare soil, grass/forb and standing dead classes. Data were collected prior to treatment, shortly following treatment, after a flood (year 2), and during the second and fifth growing seasons following treatment. Egan and his colleagues also established six permanent transects, each 400 to 800 m long, which spanned the riparian area. Along each transect, they positioned between 113 and 178 frames, each 0.5 m x 0.5 m, in which they collected cover data of key riparian species. Data were collected two years prior to treatment and in the second and fifth growing seasons following treatment. Egan (1997) presented the data graphically featuring mean values across years for various response variables, and painted a compelling picture that burning followed by spraying of the resprouts with herbicide had successfully controlled tamarisk (Egan 1997).

RESEARCH NEEDS

Bennett and Burke (1990) suggested several areas for research on the ecology of tamarisk:

- Determine the present distribution of tamarisk.
- Determine the susceptibility of native riparian vegetation communities to tamarisk invasion.
- Determine how to restore native vegetation in areas invaded by tamarisk.
- Determine the autecology of tamarisk species in the US, focusing on reproduction, seed viability, phenology, and ecological amplitude.
- Determine the synecology of riparian communities invaded by tamarisk, with particular attention to soils, birds and mammals.
- Develop a standard protocol for testing herbicide effectiveness
- Determine effectiveness of herbicide control under various conditions.
- Compare the effectiveness of mechanical, herbicide and combination control programs.
- Develop a biological control program.

Brown and Johnson (1990) suggested that the relatively high value of tamarisk habitat in Grand Canyon National Park and elsewhere needs to be confirmed. Determining and rationalizing patterns of biodiversity that occur with and without tamarisk was also suggested.

Everitt (1980) suggested an interdisciplinary approach to understanding tamarisk. Issues warranting attention included the relative water use by tamarisk and native riparian communities; relationships between tamarisk invasion and alteration of hydrologic processes; relationships between tamarisk and changes in channel width, sedimentation, flow velocity, and flood hazard.

Van Hylckama (1974) stated that a satisfactory way was needed to express water use in relation to tamarisk stand density, thus being able to predict water use from measurements of selected attributes of vegetation (and a few other climatological and meteorological factors). Possibly, recent work of Gay (1990) might be an appropriate solution. Sala et al. (1996) suggested comparative studies of water use by different riparian communities; they also suggested research on structural data from riparian communities (leaf area index, aerial extent, plant species composition) and how this relates to water use in monotypic stands of deep-rooted plants (phreatophytes), like tamarisk.

Studies of the impacts of tamarisk control, particularly biocontrol, on native plants and animals are also needed.

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