This first page is a very small excerpt from the abstract on the following pages and outlines the reasons tamarisk eradication is so important to the success of Project Green. Tamarisk removal is the first step in reclaiming the native habitat.

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.

ELEMENT STEWARDSHIP ABSTRACT

for

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

Saltcedar
Salt cedar
Tamarisk

To the User:

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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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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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LAST UPDATED:
December, 1998

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