Tamarisk or Saltcedar

Tamarix spp.

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Common Names and Synonyms

Athel tamarisk (*Tamarix aphylla* (L.) Karsten); French tamarisk (*Tamarix gallica* L.); Chinese tamarisk (*Tamarix chinensis* Loureiro); saltcedar (*Tamarix ramosissima* Ledebour, *Tamarix pentandra* Pallas, *Tamarix gallica* L.); smallflower tamarisk (*Tamarix parviflora* De Candolle, *Tamarix tetrandra* Pallas) (Baum 1978).

Taxonomy

Tamarix is one of four genera in the Tamarisk family and is represented by 54 species worldwide (Baum 1967). *Tamarix* taxonomy is somewhat disputed and authors generally include nomenclature different from each other (Allred 2002; Baum 1967, 1978; Crins 1989; DiTomaso 1998; Gaskin 2003; Martin and Hutchinson 1981; McClintock 1951; Welsh et. al. 1987). In addition to scientific synonyms listed above, Gaskin (2003) listed several more putative invasive taxa in the United States including *T. africana* Poir, *T. aralensis* Bunge, *T. canariensis* Willd., *T. juniperina* Bunge, and *T. tetragyna* Ehrenb. Most species with the exception of *T. aphylla* are regarded as weedy (DiTomaso 1998), and *T. ramosissima* is generally regarded as the most serious invasive species. The accepted common names of tamarisk and saltcedar are usually applied to many of the 90 species of the plant (Graf 1978), but in the southwestern United States the common names usually apply to *T. ramosissima* (Baum 1967) or *T. chinensis* (Allred 2002). Many taxonomists consider these to be indistinguishable and the same species, in which case *T. chinensis* is the proper nomenclature (Gaskin and Schaal 2003).

General Botanical Characteristics

Tamarix are shrubs or small trees 5 to 20 ft (1.5 to 6 m) tall with numerous brown or blackish basal branches or trunks. The bark on younger branches and saplings is reddish-brown or purplish. Leaves are scale-like, alternate, sessile or sheathing, with salt-secreting glands. Flowers are small, perfect, and subtended by a small bract (Allred 2002). Petals are white, pinkish, or reddish, and different colors often are found on the same plant or even the same flowering branch. Of the four principle invasive species, two (*T. gallica* and *T. parviflora*) flower mainly in spring, though they may also flower in summer, and two flower in both spring and summer (*T. ramosissima* and *T. chinensis*) (Allred 2002; DiTomaso and Healy 2003). Other than *T. aphylla* that has sheathing leaves, the other three species are not distinguishable by vegetative features.

Legal Status

Various Tamarix species are listed as noxious weeds in Colorado, Montana, Nevada, New Mexico, Washington, Oregon, Wyoming (Rice 2003; USDA NRCS 2002), and California (J. DiTomaso, personal communication).

Distribution and Occurrence

Origin and Distribution

Bowser (1957) speculated that Spanish explorers and conquistadors brought *Tamarix* to the New World between 1540 and 1750, however, there are no references or herbarium specimens to confirm the authenticity of this claim (Harris 1966). Eight species of *Tamarix* were first brought to North America in the 1800s from southern Europe or the eastern Mediterranean region (DiTomaso 1998). *Tamarix* species escaped cultivation and are now widespread on floodplains throughout the western United States (Christensen 1962; DiTomaso 1998; Robinson 1965). There are few river systems in Texas, Oklahoma, New Mexico, Arizona, Utah, Nevada, and California where *Tamarix* is not present (Brock 1994). *Tamarix* is continuing to spread northward into Oregon, Washington, Idaho, Wyoming, Montana, Kansas, Nebraska, North and South Dakota, and Canada (DeLoach 1991; Swenson and Mullins 1985) and southward into Mexico (Glenn et al. 1998). *Tamarix* is also found in Louisiana, Arkansas, Georgia, Mississippi, North and South Carolina, and Virginia (Rice 2003; USDA NRCS 2002).

Site Characteristics

Tamarix prevails in monospecific thickets where native plants have been eliminated (Busch and Smith 1995) and in early successional habitats such as recently scoured sandbars or in post-burn floodplain communities (Brotherson and Field 1987; Frasier and Johnsen 1991). It is also widespread in areas away from river systems such as springs, seeps, lakes, playas, arroyos, dirt stock tanks, roadsides, railroad rights-of-way, residential areas, parks, and other upland situations (McDaniel and Taylor 2003). Vegetation or habitat types most susceptible to *Tamarix* invasion include floodplains, riparian communities, seasonal wetlands, and lake margins (Johnson 1986). *Tamarix* is a ‘‘facultative phreatophyte,’’ a plant that grows best when there is an attainable source of groundwater, but can survive without a damp substrate.

Tamarix occurs in a variety of alluvial (river influenced) mixed soils on floodplains (Taylor and McDaniel 1998b). The plant typically occupies sites with silt loams and silt clay loams high in organic matter, intermediate moisture, high water tables, and little erosion (Brotherson and Winkel 1986). *Tamarix* can grow at elevations greater than 6,890 ft (2,100 m), but prefers saline soils below 1,640 ft (500 m) (DiTomaso 1998). Although there are no specific data on the range of temperature conditions in which *Tamarix* spp. survive, these species are found in hot, arid, desert environments to cold, high, mountain habitats.

Spread and Reproduction

Tamarix seeds are small with a tuft of hair on the end to aid in wind dispersal. These seeds can also float on water where they are deposited along sandbars and riverbanks (Brotherson and Field 1987). A single large *Tamarix* plant can produce 500,000 seeds/yr. Further information on biology, reproduction, and ecology of *Tamarix* may be found in DiTomaso (1998) and Carpenter (1998).

Ornamental plantings of *Tamarix* were made during the 1800s. *Tamarix* was sold by the Old American Nursery in New York in 1823, by Bertram’s in Philadelphia in 1828, and in the 1830s by several other nurseries (Robinson 1965). The oldest record of *Tamarix* in the western United States is in a nursery catalog from California dated 1856 (Robinson 1965). Harris (1966) speculated that *Tamarix* planted as an ornamental in parks and gardens formed the original stock in the southwestern United States. By the early 1920s, the plant escaped and was common in most major drainage systems in southwestern states (Clover and Jotter 1944; Harris 1966).

Once established, *Tamarix* spread rapidly from 1935 to 1955 (Christensen 1962).

Precise estimates of *Tamarix* spread and area infested are complicated by the observation that while it is increasing in some natural areas, it is declining in others because of agricultural, municipal, or other development (Graf 1978). Graf (1978) examined photo records of Canyonland National Park on the Colorado and Green River systems between 1925 and 1931. Spread rate was estimated at 12.5 mi/yr (20 km/yr), resulting in a 27% reduction in channel width. Based on aerial photo monitoring of a 280-mi (451-km) stretch of the lower Colorado River, *Tamarix* infestation increased by 20% from 1981 to 1994 (about 1.3%/yr) (Salas et al. 1996). *Tamarix* spread rate from Oklahoma to southern California, and from Colorado to Sonora, Mexico, was estimated at 3 to 4%/yr (DiTomaso 1998).

Tamarix was reported to infest about 10,000 ac (4,000 ha) of riparian habitat in the southwestern United States in the 1920s (Robinson 1965). By the 1960s, nearly 900,000 ac (360,000 ha) were infested. *Tamarix* continued to spread and infest 1.3 million ac (540,000 ha) (Gay and Fritschen 1979) in the 1970s. It occupied at least 1.47 million ac (600,000 ha) by 1987 (Brotherson and Field 1987; DiTomaso 1998). Area infested by *Tamarix* in 2003 was estimated at about 3.6 million ac (1.4 million ha) in 17 western states.

The aggressive spread of *Tamarix* in New Mexico and other areas of the Southwest is illustrated by its rapid expansion in the Pecos River valley. During a 3-yr period, *Tamarix* expanded from a few seedlings at Lake McMillan in 1912, to cover more than 600 ac (240 ha) along the watercourse by 1915. By 1925, infestations expanded to 12,300 ac (4,978 ha), and continued to increase to 57,000 ac (23,067 ha) by 1960 (Robinson 1965). Average annual spread rate in the Pecos River valley from 1912 to 1960 was about 25%. *Tamarix* now occurs along the river's edge and outer floodplains of the Pecos River from its junction at the Rio Grande northward nearly 800 mi (1,400 km) to the headwater area of Pecos, NM (McDaniel et al. 2000).

Environmental and Economic Impacts

Livestock and Wildlife

The literature is void of research investigating the importance of *Tamarix* in diets of cattle (*Bos*), sheep (*Ovis*) and horses (*Equus*), but these animals have been observed to occasionally browse *Tamarix* foliage and remove seedling plants. When given a preference, livestock will select other native herbage and shrubs before grazing *Tamarix*. Goats (*Capra*) are currently being investigated as a biological tool for *Tamarix* control and are known to graze the plant heavily in special situations (K. Havstad, personal communication).

Tamarix provides limited food and shelter necessary for wildlife survival (Shrader 1977). Although some wildlife species successfully survive in *Tamarix*-dominated areas, most species are negatively affected by displacement of native riparian plant species and other habitat changes resulting from encroachment of *Tamarix*.

Some obligate riparian bird species can successfully utilize *Tamarix* (Ellis 1995). However, most of these continue to show preference for more diverse, native plant communities (Shrader 1977). Bird species include various doves (*Zenaida*), Gambel's quail (*Lophortyx gambelii*), other granivores (seed feeders), or other types of ground feeding birds. Because *Tamarix* seeds are too small to be eaten by most animals (Neill 1983), bird populations generally forage in nearby agricultural fields. Doves, particularly white-winged doves (*Z. asiatica*) and mourning doves (*Z. macroura*), are among bird species that utilize *Tamarix* (Anderson et al. 1977b). Although *Ta-*

marix provides nesting sites for doves, their populations are usually higher in native plant communities, especially mesquite (Shrader 1977), that provide more food (Kerpez and Smith 1987). The endangered southwestern subspecies of the willow flycatcher (*Empidonax trailii extimus*) will also nest in *Tamarix* when willows (*Salix*) are displaced (DeLoach et al. 1996). Other species, such as Gambel's quail, prefer honey mesquite (*Prosopis glandulosa*) and cottonwood (*Populus*) communities, but will utilize *Tamarix* for shelter, but not nesting (Shrader 1977). *Tamarix* invasion may be responsible for shifts in riparian bird populations in the middle Rio Grande (Yong and Finch 1997).

Although some riparian bird species have continued to breed in *Tamarix*-dominated habitats, breeding densities of these populations have declined. On the Colorado River, migratory and resident spring and summer breeding species show a declining trend in *Tamarix* use from west to east. These birds are largely restricted to cottonwood-willow communities (Hunter et al. 1988). The Bell vireo (*Vireo bellii*) on the lower Colorado River is nearly excluded as a breeding species, and summer tanagers (*Piranga rubra*) and yellow-billed cuckoos (*Coccyzus americanus*) are also in serious danger of elimination from the lower Colorado River due to *Tamarix* infestations.

The majority of birds, particularly riparian species, are more directly dependent on native plant communities (Ellis 1995; Hunter et al. 1988). Waterfowl, frugivores (fruit and seed feeders), and insectivores, usually abundant in native riparian vegetation, almost completely avoid *Tamarix* (Brotherson and Field 1987; Kerpez and Smith 1987; Shrader 1977). Many frugivores feed on the fruit of desert mistletoe (*Phoradendron californicum* Nutt.). This parasitic plant typically grows on native woody species (Cohan et al. 1978) and is uncommon on *Tamarix* (Haigh 1996).

When comparing total bird density and species diversity, *Tamarix* stands consistently had lower values than communities dominated by cottonwood, willow, and mesquite (Anderson et al. 1977b; Cohan et al. 1978; Engel-Wilson and Ohmart 1978; Hunter et al. 1988; Kerpez and Smith 1987). In one study, cottonwood-willow communities proved the most valuable to bird populations, followed by honey mesquite, desert wash, *Tamarix,* orchard, and arrowweed (*Pluchea sericea* [Nutt.] Cov.) (Anderson et al. 1977b). Along the Colorado River, native riparian areas sustained a density of 154 birds/99 ac (40 ha), whereas the *Tamarix*-dominated areas had an average of 4 birds/99 ac (40 ha) (Johnson 1986). Along the Pecos River in New Mexico, more birds were observed in 96 ac (39 ha) of cottonwood, willow, and mesquite communities than in 48,400 ac (19,600 ha) of *Tamarix* (Engel-Wilson and Ohmart 1978).

Restoration projects can have a dramatic effect on breeding bird populations in *Tamarix* stands. Anderson et al. (1977b) noted that the addition of one or more native tree species, even in small numbers, greatly enhanced overall attractiveness of an area to breeding pairs.

Bird species used both *Tamarix* and cottonwood habitats along the Rio Grande in central New Mexico, with three species using only *Tamarix* and six species using only cottonwood (Ellis 1995). Assuming the prediction by Howe and Knopf (1991) that *Tamarix* may completely replace cottonwood habitat along the middle Rio Grande in New Mexico over the next century, the richness of riparian bird species in that area is expected to decline.

Brown and Johnson (1989) argued that, while *Tamarix* 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 *Tamarix* along the lower Colorado River experienced higher heat loads than nests in multi-layered cottonwood forests that afford more shade. Brown and Trosset (1988) noted that the *Tamarix* community in Grand Canyon National Park developed after construction of Glen Canyon Dam. *Tamarisk* represented the ecological equivalent of native habitat for some riparian birds, and its presence enhanced breeding habitat for 11 species of birds.

With the exception of woodrats (*Neotoma* spp.) and the desert cottontail (*Sylvilagus audubonii*), native mammals are not known to widely feed on mature *Tamarix*. In some instances, young sapling growth is utilized by rodents and other mammals. When *Tamarix* was cleared from a 49-ac (20-ha) area along the lower Colorado River and replaced with native vegetation, the diversity of both birds and rodents increased significantly (Anderson and Ohmart 1985). In a study by Engel-Wilson and Ohmart (1978), mammals such as porcupine (*Erethizon dorsatum*) and beaver (*Castor canadensis*) had a high affinity for the cottonwood-willow habitats, but occurred in very low densities in *Tamarix*-dominated communities.

Insects

Willows and cottonwoods support a greater abundance of insect life than does *Tamarix* (Bailey et al. 2001; Neill 1983; Knutson et al. 2003). Principal insect species that thrive on *Tamarix* in the Southwest are cicadas (*Diceroprocta*) and European honeybees (*Apis mellifera*) (Horton and Campbell 1974). *Tamarix* provides an early source of pollen for overwintering bees (Kerpez and Smith 1987) and can be a beneficial species for honey production (Shrader 1977). Insect reproduction fluctuates dramatically on *Tamarix* compared with native riparian habitat (Carothers et al. 1976). Anderson (1994) studied the Apache cicada (*D. apache* Davis) in a native riparian community and a *Tamarix* stand along the lower Colorado River. He found that although cicadas were abundant in both communities, the insects emerged later in native cottonwood and willow-dominated communities when migrating and nesting birds were present. This change in temporal availability of a key food resource may help explain the low population of breeding birds in *Tamarix* communities.

Faster decomposition of *Tamarix* litter was associated with a twofold decrease in macro-invertebrate richness and a fourfold decrease in overall macro-invertebrate abundance relative to native cottonwood communities (Bailey et al. 2001). This study demonstrates that invasion by *Tamarix* affects leaf litter quality, which in turn affects stream macro-invertebrates. Thus, impacts on primary consumers and food web structure could affect higher trophic levels.

Plant Community

Tamarix density in riparian areas is generally higher than densities of cottonwood-willow or screwbean mesquite (*Prosopis pubescens*) that historically dominated riparian areas in the southwestern United States (Egan et al. 1993). In some sites, 70 to 80% of the total vegetative cover can consist of *Tamarix*. Such infestations lead to dramatic reductions in native indigenous woody and herbaceous plant composition and abundance (Engel-Wilson and Ohmart 1978; Hughes 1993; Lovich et al. 1994; Weeks et al. 1987).

Fire frequency, as well as other factors in *Tamarix* communities, has dramatically reduced native plant populations and hindered reestablishment of riparian species. When present in *Tamarix*-dominated communities, cottonwood populations often consist solely of mature or nearly mature trees. Because these communities lack a broad age distribution typical of vigorous reproducing populations, they are less able to spread and suppress *Tamarix* stands through shading (Shrader 1977). Along the Rio Grande, cottonwood regeneration has not occurred for 30 to 35 yr, partially because human interventions such as dams and other structures have suppressed natural flooding events necessary for seedling establishment. Consequently, riparian woodlands are aging and are expected to dramatically decline within the next 50 yr (Howe and Knopf 1991).

Rare, Sensitive, or Threatened Species

The federally endangered southwestern willow flycatcher (*Empidonax trailii extimus*) is known to nest in *Tamarix*-dominated areas (USFWS 1993). This subspecies of the willow flycatcher is widely distributed in scattered remnant populations across much of the area where *Tamarix* is invasive. Although it prefers to feed and breed in riparian woodlands dominated by native plants including willows, arrowweed, and *Baccharis* species, there has been concern that it might be further threatened if a biological control agent eliminated *Tamarix* over wide areas of the Southwest. Most scientists agree that even a highly successful biological control agent will not eliminate *Tamarix* and that where it is reduced, native plants favored by breeding and feeding birds are expected to establish (Lovich and de Gouvenain 1998).

Community Function

Fire Frequency: *Tamarix* is a fire-adapted species with more efficient fire recovery mechanisms than nearly all native riparian species (Anderson et al. 1977a; Busch and Smith 1993). Following fire, *Tamarix* is better able to utilize available soil moisture (Busch and Smith 1993), higher soil concentrations of mineral elements, and increased soil pH than native woody riparian species. This adaptation has likely been a significant factor promoting its rapid colonization of watercourses (Busch and Smith 1992, 1993; Wiesenborn 1996).

In native riparian plant communities dominated by cottonwood, willows, or mesquite, wildfires are infrequent (Busch and Smith 1993). In contrast, intervals between fires are considerably shorter in *Tamarix*-infested areas. It has been hypothesized that *Tamarix*, like other plant species that readily resprout, might have developed adaptive characteristics that enhance flammability of communities where they grow (Busch and Smith 1992). This can lead to replacement of cottonwood and willow that are not adapted to fire (Busch and Smith 1992; Kerpez and Smith 1987). In support of this, Anderson et al. (1977a) demonstrated that 21 of 25 *Tamarix* stands along the lower Colorado River burned within a 15-yr period. Fires burned 35% of *Tamarix*-dominated vegetation on the lower Colorado River floodplain between 1981 and 1992, compared to only 2% of communities of honey mesquite or screwbean mesquite during the same time period (Busch 1995). Increased incidence of fire in *Tamarix* stands has been attributed to substantial accumulation of leaf litter, as well as dead and senesced woody material (Busch 1995; Busch and Smith 1993; Kerpez and Smith 1987). Fuel buildup by *Tamarix* promotes fire every 10 to 20 yr in North American desert riparian settings (Lovich et al. 1994).

Hydrologic cycles: Robinson (1965) suggested that dense *Tamarix* stands could increase in areas inundated by floods. The extensive root system of *Tamarix* is more stable and resistant to erosion than most native riparian trees and shrubs. When stream channels are stabilized, they become more immobile and inflexible (Graf 1978), which progressively restricts channel width by increasing sediment deposition. Narrowing of the water channel increases the rate of water flow and the potential and severity of subsequent floods (Egan et al. 1993; Frasier and Johnsen 1991; Friederici 1995; Kerpez and Smith 1987). A *Tamarix*-infested area on the Gila River in Arizona had a 30% increase in water flow velocity and 13% increase in water depth (Great Western Research 1989). As the river recedes, *Tamarix* establishes itself further into the channel. This process continues until stream flow is severely reduced. *Tamarix* infestations increased on the Brazos River in northcentral Texas beginning in 1941. At this time, the mean width of the river channel along a 75-mi (121-km) stretch was 508 ft (155 m). By 1979, the mean width had been reduced to 217 ft (66 m). Narrowing channel width increased the incidence of flooding, as well as the area inundated by floodwaters (Blackburn et al. 1982). However, Everitt (1980) noted that while vegetation can promote local sediment deposition, the concept that vegetation over large areas can increase regional deposition of sediment is unfounded.

Soil Resources

It appears likely that *Tamarix* increases soil salinity. Numerous salts and minerals, both macro- and micronutrients, are excreted by *Tamarix* glands (Berry 1970; Bosabalidis and Thomson 1984; Dreesen and Wangen 1981; Kleinkopf and Wallace 1974; Storey and Thomson 1994; Thomson et al. 1969). Leaves and stems contain concentrations of soluble salts in the range of 5 to 15% (Hem 1967). These salts are absorbed by *Tamarix* from deeper soil layers, transported through the plant, and concentrated in the leaves. The salts are eventually deposited on the soil surface under the plant (Kerpez and Smith 1987) when deciduous leaves drop or following rainfall events. Consequently, salts are redistributed over time from deep within the soil profile to become concentrated on the soil surface of floodplains. Excessive surface deposits of salt can inhibit germination of other species (Egan et al. 1993), restricting competition for space and water with other under- or overstory vegetation (Brotherson and Field 1987).

Water Resources

In arid western states, competing interest for surface and groundwater is controversial (Morrison 1996). Within some river systems there is risk that the water needs of growing human populations may not be met (Waggoner and Schefter 1990). Evapotransporation (ET) or water use rates of *Tamarix* are among the highest of any phreatophyte evaluated in southwestern North America (Brotherson et al. 1984; Van Hylckama 1974; White et al. 2000), including native riparian trees (Busch and Smith 1995; Neill 1983). Its consumption of water can desiccate springs, drain pools, and even dry up perennial streams (Johnson 1986). *Tamarix* in heavily infested areas of the Southwest is estimated to consume almost twice as much water annually as the major cities of southern California (Friederici 1995; Johnson 1986).

Although total water usage was considerably higher in *Tamarix* stands than in areas with native woody riparian species, transpiration rates of individual plants have been shown to be similar to those of several herbaceous plants and co-occurring phreatophytes, including willows, cottonwoods, and mesquite (Anderson 1982; Sala et al. 1996). The difference between total *Tamarix* stands and native riparian habitat was attributed to greater leaf area index in *Tamarix* communities compared to any other riparian populations (Sala et al. 1996).

Tamarix is capable of drawing moisture from the saturated zones below the water table and from less saturated soils in areas with deeper water tables (Everitt 1980). Thus, the longer a community has been invaded by *Tamarix*, the greater the capacity to lower the water table (Brotherson et al. 1984). Robinson (1965) cited studies that indicate *Tamarix* has the potential to consume 4 ac-ft of groundwater annually. Estimates of water use by *Tamarix* in New Mexico, Texas, and Arizona were variable, reflecting variations in weather and environment, as well as difficulties in estimating ET rates (Weeks et al. 1987; White et al. 2003). Johns (1989) summarized data from various studies attempting to determine water usage by *Tamarix* (Gatewood et al. 1950; Gay and Hartman 1982; Van Hylckama 1974) and concluded that *Tamarix* water use ranged from 3 to 7.5 ac-ft/yr depending on depth to groundwater.

On the Middle Rio Grande at the Bosque del Apache National Wildlife Refuge, ET rates from a dense stand of *Tamarix* was reportedly 4.35 ft (1.35 m)/yr and 3.91 ft (1.2 m) during the growing season (April 5 to November 21) (Bawazir 2000). By comparison, a sparse stand of cottonwood used 2.97 ft (0.90 m)/yr and 2.62 ft (0.80 m) during the same growing season. In another study along the Rio Grande, ET rates from a dense stand of *Tamarix* were 3.5 to 4 ft (1.1 to 1.2 m)/yr, compared to a mature cottonwood stand with an extensive understory of *Tamarix* and Russian olive at 4 ft (1.2 m)/yr (Dahm et al. 2002). A mature cottonwood stand with a closed canopy had intermediate ET rates of 3.16 ft (0.98 m)/yr and a less dense *Tamarix* stand had the lowest ET rates of 2.4 to 2.43 ft (0.74 to 0.75 m)/yr.

Water consumption for *Tamarix* and for replacement vegetation was estimated following root plowing in the Pecos River floodplain between Acme and Artesia, NM. From 1980 to 1982, water use by *Tamarix* was about 11.8 in (0.3 m) greater than replacement vegetation (Weeks et al. 1987). In theory, this reduction in water use should have resulted in an increased base-flow of the Pecos River of 10,000 to 20,000 ac-ft/yr. However, clearing 21,500 ac (8,700 ha) of *Tamarix* by root plowing could not be used to verify base-flow gains. Hart (2003) estimated that *Tamarix* control by aerial spraying on the Pecos River salvaged slightly more than 36,000 ac-ft of water.

Evapotranspiration measurements from a dense stand of *Tamarix* along the lower Colorado River in Arizona (using the Bowen ratio measurement system) ranged from 0.08 in (2 mm)/d in the spring and fall up to 0.5 in (13 mm)/d in midsummer (Gay 1986). Total ET for the growing season (March 23 to November 11) was estimated to be 66 in (1,680 mm).

Peak ET rates for *Tamarix* [0.43 in (11 mm)/d] were compared to winter wheat (*Triticum* spp.) [0.31 in (8 mm)/d], cotton (*Gossypium* spp.) [0.35 in (9 mm)/d], and alfalfa (*Medicago sativa*) [0.35 in (9 mm)/d] during the growing season in Arizona (Gay and Hartman 1982). Water use by *Tamarix* began with bud burst in early April [0.11 in (2.9 mm)/d], and reached a peak of about 0.43 in (11 mm)/d near the summer solstice in late June.

Economics

A comprehensive economic analysis estimated ecosystem services lost to *Tamarix* invasion in the western United States (Zavaleta 2000). Values lost from *Tamarix* included irrigation and municipal water, flood control, hydropower, wildlife habitat, and river recreation. Dove hunting and sedimentation were considered benefits provided by *Tamarix* in the analysis. Based on estimates of 1.16 million ac (0.47 million ha) to 1.6 million ac (0.65 million ha) infested, the presence of *Tamarix* in the western United States will cost from $7 billion to $16 billion in lost ecosystem functions over the next 55 yr. This loss amounts to an average of $6,300 to $10,000/ac ($15,600 to $24,600/ha) of land infested with *Tamarix*.

Zavaleta (2000) also estimated costs (in 1998 dollars) of a regionwide *Tamarix* eradication program including evaluation, control, revegetation, and monitoring. The 20-yr cost of a hypothetical eradication and revegetation program was estimated at $3,006/ac ($7,428/ha). Long-term benefits outweighed costs by $3,312 to $6,975/ac ($8,184 to $17,235/ha) or $3.8 billion to $11.2 billion across the entire region (assuming a 0% discount rate). The resulting benefit:cost ratio for the eradication program lies in the range of 2.1:1 to 3.3:1.

Economic feasibility studies to estimate costs and benefits of *Tamarix* control have been conducted for some western U.S. waterways (Great Western Research 1989). Horton and Campbell (1974) estimated water savings (difference between *Tamarix* use and native vegetation use) resulting from *Tamarix* control on the Colorado River were as high as 3 ac-ft/yr. It has been estimated that 568,000 ac-ft/yr of water are lost along the Colorado and that water lost by *Tamarix* from the Bonneville Unit of the Central Utah Water Project had an estimated cost of $27 million annually (Brotherson and Field 1987).

Tamarix clearing is accomplished using a combination of herbicide, burning, and mechanical control techniques. Complete land restoration costs range from $1,852 to $3,200/ac ($750 to $1,300/ha) on extensive floodplain areas on the Bosque del Apache NWR along the Rio Grande (Taylor and McDaniel 1998a). For *Tamarix* control alone, a combination of herbicide and burning cost from $114 to $225/ac ($46 to $91/ha) with expected control around 92% (McDaniel and Taylor 2003). Root plowing plus raking cost ranges from $300 to $700/ac ($121 to $283/ha) with plant control exceeding 97%. *Tamarix* infestations intermixed with remnant stands of desirable trees, shrubs, or herbaceous cover are cleared with cut-stump treatments on a contractual basis averaging between $2,000 to $2,500/ac ($809 to 1012/ha) (Taylor and McDaniel 2003).

Value and Use

Tamarix habitats have been found to provide shelter and roosting for some avian species, the most important of which are white-wing and mourning doves (Anderson et al. 1977a). However, *Tamarix* areas have low forage value, which forces doves to use nearby fields for food supply (Kerpez and Smith 1987). The plant provides an early source of pollen for overwintering bees (Kerpez and Smith 1987) and can be a beneficial species for honey production (Shrader 1977).

Tamarix was introduced partially to stabilize soils and mitigate stream bank erosion. In 1925, the New Mexico Extension News reported that *Tamarix* would be planted at the head of arroyos near Silver City to slow flow of water and reduce erosion. This perceived benefit resulted in increased flooding in many areas of the West (Graf 1978; Egan et al. 1993; Frasier and Johnsen 1991; Friederici 1995; Kerpez and Smith 1987).

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