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Revegetation Strategies After Saltcedar (*Tamarix* spp.) Control in Headwater, Transitional, and Depositional Watershed Areas¹

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Abstract: The exotic saltcedar occupies headwater, transitional, and depositional watershed portions, and revegetation strategies can be quite different depending on these locations. Regardless of specific socioeconomic or biological needs (or both), sites must often be revegetated after control to avoid reinfestation or invasion by other exotic species. Where natural riparian hydrologic processes continue to function, natural regeneration can be used as an effective restoration mechanism. However, in altered river systems, harsh environmental site characteristics may occur that severely limit revegetation potential after control, particularly in depositional areas. Because of high costs associated with saltcedar control, revegetation, and follow-up management, specific treatment areas should be evaluated and prioritized based on revegetation potential. Specific consideration should be given to the establishment of sustainable plant communities for long-term exclusion of saltcedar and other exotics.

Nomenclature: Saltcedar, *Tamarix ramosissima* Ledeb. #³ TAARA.

Additional index words: *Acroptilon repens*, *Baccharis glutinosa*, *Distichlis spicata* (L.) DISSP, *Elaeagnus angustifolia*, ELGAN, imazapyr, *Lepidium latifolium*, perennial pepperweed, *Populus deltoides*, riparian restoration, Russian-olive, *Salix exicjua*, *Salix gooddingii*, saltgrass, triclopyr.

INTRODUCTION

During the 20th century, saltcedar became established within river systems of the southwestern United States (Brock 1994; DiTomaso 1998). Local elevation, soil, and topographic variants greatly influence saltcedar distribution and growth within specific watershed basins. Typically, in the headwaters or upper reaches of stream corridors, where cold temperatures limit growth at elevations greater than 2,100 m (DiTomaso 1998), saltcedar infestations are light with widely scattered plants (Brotherson and Winkel 1986; Everitt 1980). At middle elevations or transitional zones, saltcedar often occurs as a narrow belt along river edges within the confines of steep canyons and ravines. On low-lying floodplains saltcedar may grow densely in the understory of established native riparian forests or broadly across open areas as an impenetrable thicket (Crins 1989). Saltcedar also is widespread in many landscape positions away from river sys-

tems such as springs, seeps, lakes, playas, arroyos, dirt stock tanks, roadsides, railroad right-of-ways, residential areas, parks, and other upland situations.

Reasons for Saltcedar Control. Control strategies used within headwater, transitional, or depositional portions of a watershed are typically quite different. For example, in headwater areas, an eradication strategy may be emphasized to prevent further spread of saltcedar within a watershed. In the transitional zone, the goal may be to remove saltcedar from the rivers edge in order to enhance water flow and channel movement (Graf 1978). In depositional areas, saltcedar control objectives can vary widely and may include enhancing wildlife habitat (Anderson et al. 2004; Ellis 1995; Kerpez and Smith 1987; Taylor and McDaniel 1998), minimizing potential fire hazards (Busch and Smith 1995), facilitating better water management for agriculture (Weeks et al. 1987), regenerating native riparian communities (Howe and Knopf 1991; Taylor et al. 1999), or meeting other multiple-use needs (Horton and Campbell 1974). From a socioeconomic perspective, rural communities often place special emphasis on control to meet agricultural water needs, whereas urban areas identify recreation, fire prevention, flood control, or esthetics as important reasons for saltcedar control.

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³ Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

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Table 1. Saltcedar individual plant and large-scale control techniques, control costs, and plant mortality on the Bosque del Apache National Wildlife Refuge, New Mexico.

Control treatment	Cost	Control
	\$/ha	%
Individual plant treatments		
Cut-stump herbicide method ^a	3,952–6,175	60–80
Ground-based foliar herbicide ^a	99–741	97–99
Mechanical grubbing	99–741	97–99
Large-scale control		
Mechanical	1,729	97–99
Airplane Herbicide–Burn ^b	321	93
Helicopter Herbicide–Burn ^c	593	89
Airplane Herbicide–Shred ^{b,d}	988	97–99
Helicopter Herbicide–Shred ^{c,d}	1,260	97–99
Airplane Herbicide–Burn–Mechanical ^b	939	97–99
Helicopter Herbicide–Burn–Mechanical ^c	1,210	97–99

^a Duncan (2003).

^b McDaniel and Taylor (2003a).

^c McDaniel and Taylor (2003b).

^d With 2 yr of follow-up ground-based foliar herbicide treatment.

Reasons for Revegetation. Where saltcedar infestations are extensive and broad control measures are practiced to eliminate the plant, site stability can be significantly disrupted. Without special planning and care, saltcedar can rapidly reestablish or worse, areas are subject to invasion by other exotic species, such as perennial pepperweed (*Lepidium latifolium*), Russian knapweed (*Acroptilon repens*), and Russian-olive (*Elaeagnus angustifolia*). In such instances, long-term sustainable control is best accomplished through the establishment of native plant species with high competitive exclusion abilities after disturbance (Grime 1973). Native riparian woody species, including cottonwood (*Populus deltoides*), Goodings willow (*Salix gooddingii*), and coyote willow (*Salix exigua*), have rapid growth potential under low environmental stress and are able to competitively exclude saltcedar when seedlings are concurrently established after flooding (Sher et al. 2002). This ability is preempted, however, under harsher environmental conditions such as soils with high salinity and drought (Grime 1979; Sher et al. 2002). Although their competitive abilities have not been tested, native seepwillow (*Baccharis glutinosa*) and saltgrass (*Distichlis spicata*) may likely prove competitive on harsher sites after flooding (J. Taylor, unpublished data).

Plants selected for revegetation must be competitive with exotics for essential resources such as light, nutrients, and moisture. Outcomes are often based on resource supply and consumption rates. The better competitor may be the species that is more tolerant to a reduction in resource availability (Tilman 1980). Anderson et al. (2004) contends that sites with excessive salinity

cannot be revegetated effectively without costly soil amelioration. Currently, standard seed mixtures of fourwing saltbush (*Atriplex canescens*) and alkali sacaton (*Sporobolus airoides*) are used in areas of higher salinity, but knowledge of their competitive abilities is lacking (Taylor and McDaniel 2003). Research is ongoing to evaluate the adaptability of additional species in harsh riparian environments, which also may highlight their competitive abilities in the face of exotic invasions (Lair and Wynn 2002).

Integrating Saltcedar Control Strategies with Revegetation. Saltcedar control techniques and costs vary from individual plant control to large-scale control programs involving a combination of techniques (Duncan 2003; McDaniel and Taylor 2003a, 2003b) (Table 1). The extent of the infestation and its location within the watershed will determine whether individual plant or large-scale control programs are warranted. Managers should be especially cognizant of subsequent restoration processes, revegetation requirements, or both when selecting a control strategy (Figure 1). For example, a natural mechanism for the establishment of native riparian vegetation is periodic flooding, which provides scoured soil substrates for the germination of native, primarily aerially dispersed seed (Fenner et al. 1984). Although dams and other structures regulate flows in most southwestern river systems, flooding still occurs, but at lower intensities than historic events. Supplemental soil disturbance through mechanical saltcedar control may therefore be necessary to mimic flood disturbance for greater natural revegetation success in depositional areas (Taylor et al. 1999).

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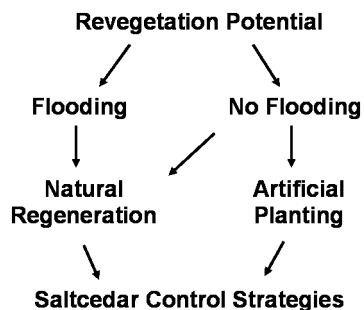


Figure 1. Revegetation potential and processes as a driving force in the selection of saltcedar control strategies on the Bosque del Apache National Wildlife Refuge, New Mexico.

Natural, primarily herbaceous, recovery after saltcedar removal also is possible where flooding no longer occurs. Sites with water tables near 1 m of the soil surface typically support meadow or grassland communities dominated by saltgrass and alkali sacaton (Groeneveld and Or 1994; Lindsey 1948). Natural recovery of these species has been noted on the Rio Pecos (Walthall 2004) and in other areas (Dudley et al. 2000) after saltcedar control where high connectivity between surface and groundwater predominates.

Where hydrologic connectivity is low, however, artificial plantings will be required to restore sites (Anderson et al. 2004; Dreesen et al. 2002; Taylor and McDaniel 1998). Saltcedar control strategies should therefore avoid the use of mechanical means that promote annual and perennial herbaceous weed establishment (McDaniel and Taylor 2003a). These weeds potentially compete with planted materials for light, nutrients, and moisture resources and can dramatically influence the success of revegetation efforts (Anderson et al. 2004).

Saltcedar Control and Revegetation in Headwater Areas. Headwater areas are usually the more pristine portions of a watershed. Flood pulses are generally unimpeded by dams, levees, or diversions for agricultural or municipal uses. Saltcedar infestations are usually limited to scattered stands or individual plants within robust, native riparian forests and meadows. Individual saltcedar plant treatments such as the cut-stump or foliar methods may need to be repeated during a 3- to 5-yr period to effectively eradicate infestations (Duncan 2003; Hughes 1965). Individual plant-grubbing techniques, such as front-end loaders equipped with stinger blades or extractors, also can be used; however, equipment access is often limited. Revegetation is seldom required in headwater areas because natural recruitment processes for native species are unimpeded after periodic flooding.

Saltcedar Control and Revegetation in Transitional Areas. Transitional areas often represent a gradation from scattered infestations occurring in upper reaches to more extensive stands occurring in lower depositional basins of the watershed. Area geomorphology is represented by steep intervening canyons, where the floodplain is narrow. The extent of native vegetation and exotic infestation is variable and is dictated by floodplain width. Eradication is often not a practical management goal. Although hydrologic integrity can be compromised in transitional areas, periodic flooding may still occur and its severity may be high because of floodplain confinement. The potential for native species regeneration after saltcedar removal may be high. Therefore, flood frequency, extent, and duration patterns for specific river systems should be evaluated to assess vegetation regeneration opportunities using natural processes.

Flow discharge and sediment load maintain a dynamic equilibrium in river systems (Knighton 1984). Upstream dams may retain sediment and result in downstream channel and bank erosion and increased channel bed incision (Graf 1978). Although periodic sediment flushing may ameliorate these conditions (Crawford et al. 1993), overbank flooding potential will be reduced, limiting natural revegetation processes. In such instances, artificial planting will be required to revegetate these areas. Where environmental stress is low, cottonwood and willow pole plantings have been used to reestablish extensive forests (Taylor and McDaniel 1998). Container seedlings of New Mexico olive (*Forestiera neomexicana*), silver buffaloberry (*Shepherdia argentea*), wolfberry (*Lycium andersonii*), and screwbean mesquite (*Prosopis pubescens*) have been widely used where water tables are shallow on the Rio Grande (Dreesen et al. 2002). Sites with low to moderate environmental stress have been successfully revegetated using rooted cuttings of honey mesquite (*Prosopis glandulosa*), velvet mesquite (*Prosopis velutina*), blue paloverde (*Cercidium floridum*), and quailbush (*Atriplex lentiformis*) on the Colorado River using drip-irrigation systems (Anderson et al. 2004).

The contrasting hydrogeomorphic conditions found in transitional areas will influence revegetation, and in turn, saltcedar control approaches. Where dense pockets of saltcedar exist within active portions of the floodplain and equipment access is possible, control programs that include a mechanical component may be desirable, whereas soil disturbance may not be appropriate where artificial plantings are required in the absence of flooding to avoid weed establishment. Mechanically

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shredding of standing saltcedar vegetation previously treated with herbicide (herbicide–shred treatments) (Table 1) can allow the removal of saltcedar vegetation aboveground, avoiding soil disturbance. Either program may be restricted in very narrow transitional areas where aircraft access, ground equipment access, or both are limited. Individual plant treatments would therefore be one of the few options available for control.

Saltcedar Control and Revegetation in Depositional Areas. Generally, the most extensive saltcedar infestations occur in depositional watershed areas. Hydrologic modification is most pronounced in these areas, effecting the potential for natural regeneration after saltcedar control (Auble et al. 1994). In areas where natural fluvial processes persist, hydrologic connectivity is high, and native seed sources are available, naturally regenerated native communities provide high competitive exclusion abilities after saltcedar removal (Sher et al. 2002; Stromberg 2001). In these instances, saltcedar control strategies should have a mechanical element to prepare seedbeds for natural regeneration (Sprenger et al. 2002). When mixed native and saltcedar cohorts are recruited, light disking in late summer can favor native seedlings over saltcedar because of inherent heavier native seedling root systems (Smith et al. 2002).

More often, however, hydrologic integrity is poor in depositional areas, resulting in low potential for native species regeneration. Such sites are either mixed stands of native and exotic vegetation or solid saltcedar monocultures. In mixed stands, the use of mechanical or broadcast herbicide for saltcedar control can be limited because of the need to preserve interspersed native herbaceous and woody vegetation. In such instances, the cut-stump treatment combined with chipping or shredding trunks and stems can be an effective control measure and also prevent wildfire, although costs are extremely high (Duncan 2003; Stuever 1997).

CONCLUSIONS

Sites in all watershed areas can be generally prioritized based on revegetation potential before initiating saltcedar control (Figure 1). Assessing revegetation potential must include the determination of key variables, including flooding potential and frequency and appropriate groundwater hydrology (Stromberg 2001). A soil survey is requisite for knowledge of soil texture, depth, and related salinity levels that ultimately influence replacement vegetation community types (Anderson et al. 2004; Sheets et al. 1994; Taylor and McDaniel 1998).

Table 2. Revegetation techniques and costs on the Bosque del Apache National Wildlife Refuge, New Mexico.

Revegetation technique	Cost
	\$/ha
Pole planting ^{a,b}	2,223
Tallpot-containerized stock ^{b,c}	6,669
Rainfall harvest ^{d,e}	17,784
Seeding ^f	296

^a Taylor and McDaniel (1998).

^b A total of 247 plantings/ha.

^c Dreesen et al. (2002).

^d Fenchel et al. (1996).

^e Thirty-one-meter rows with 1-m plant spacing and 37 rainfall harvest rows/ha.

^f Seeded with an Australian pitter seeder at the rate of 15.3kg/ha fourwing saltbush and 1.7 kg/ha alkali sacaton.

Where the control of dense saltcedar within areas of poor hydrologic integrity and elevated salinity is anticipated, managers must realize that some sites may have limited revegetation potential because of these harsh environmental conditions (Anderson et al. 2004). Considering the high costs for saltcedar control and revegetation (Tables 1 and 2), it is incumbent on resource managers to carefully select areas with high revegetation potential to provide long-term sustainable saltcedar control.

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