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Proceedings

Saltcedar and Water Resources in the West

Symposium

July 16-17, 2003

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Contents

History and Biology of Saltcedar

HISTORY AND ECOLOGY OF SALTCEDAR (*TAMARIX*)

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Introduction

The goal of this review paper is to present a broad overview of the history, biology and ecology of the genus *Tamarix* (saltcedar). The intent is to provide the basic elements of this genus to 1) establish the basis for some of the known or perceived issues that exist relative to this group of plants, and 2) to set the stage for following presentations on specific aspects of the biology and ecology of the genus and efforts and approaches at management and restoration of ecosystems that have been impacted by members of this genus.

Taxonomy

Perhaps the first issue is to identify and characterize the subjects of interest. This is not a minor task, since total agreement does not exist on the number of species in the genus *Tamarix*, synonomy among the species, the taxonomic distinctions between species (Baum 1978), degree of hybridization between some species (Sudbrock 1993) or the phylogenetic position of the family Tamaricaceae (Spichiger and Savolainen 1997). In addition the exact origin of species introduced to North America is not certain, and the number and places of introductions are not well-documented. Also, the horticultural industry continues to import, propagate and disperse species in the ornamental trade. All of this simply creates a caution when considering the application of management to uncertain taxonomic and genetic variations. That is, variations in response of populations to management may be as much a matter of genetic differences as it is the environment they occur in or the method or technology of management applied; what works one place may not work elsewhere because subtle genetic differences may not be apparent based on the morphological or outward appearance of the population being treated. Recent comparisons of *Tamarix ramosissima* from Arizona and Montana indicate the great amount of phenotypic and genotypic variation in this species (Sexton 2000).

Between 8 and 10 species have been introduced into North America (Crins 1982, DeLoach *et al.* 2000). While complete agreement on nomenclature and number of species does not exist the most commonly available and used source for North America is the USDA, NRCS Plant Database which currently recognizes the following taxa:

Tamarix africana Poir.	African tamarisk
Tamarix aphylla (L.) Karst (*articulata* Vahl)	Athel tamarisk
Tamarix aralensis Bunge	Russian tamarisk
Tamarix canariensis Willd.	Canary Island tamarisk
Tamarix chinensis Lour.	Fivestamen tamarisk

(*pentandra* Pallas)	
Tamarix dioica Roxb. Ex. Roth	Tamarisk
Tamarix gallica L.	French tamarisk
Tamarix parviflora DC.	Smallflower tamarisk
(*tetrandra* auct. non Pallas)	
Tamarix ramosissima Ledeb.	Saltcedar
Tamarix tetragyna C. Ehrenb.	

History, Distribution and Introductions

The natural geographic range of approximatley 54 species of *Tamarix* extends from southern Europe across the Middle East, into North Africa and into India, Pakistan and China (Baum 1979). There are no species of *Tamarix* native to the New World. This is an ancient genus. Fossil charcoal from *Tamarix* twigs have been found in Israel that date to before 10,000 BC (Ley-Yadum and Weinstein-Evron 1994). Manna, an exudate, produced by the scale insect, *Trabutina mannipara*, is considered to be the biblical manna of the wandering Israelites (Ben-dov 1988). The name of the genus apparently comes from the Tamaris River in Spain (Di Tomasco 1998) or perhaps the Tamaro River in Nepal (Crins 1989).

Introductions to North America began in the early 1800s. First introductions were from the Middle East (Frasier and Johnsen 1991) and advertisements for ornamental sales occurred in the 1820s (Duncan and McDaniel 1997). Over time as many as 10 species were introduced. Introductions were primarily for the horticultural trade, soil erosion control, streambank erosion protection and windbreaks ((Brotherson and Von Winkel 1986, Di Tomasco 1998). The first noticeable invasions into western riverine systems occurred between 1890 and 1920 and from then until 1950 most riverine systems were affected. The predominant species involved in these invasions is generally agreed to be *Tamarix ramosissima*. Saltcedar occupies up to 1.5 million hectares of riparian areas throughout the western United States and the invasion continues (Brotherson and Field 1987, Clarke and Nelson 1996, Duncan 1997, DeLoach 2000).

Growth Habit, Life History Traits and Ecology

The genus *Tamarix* consists of small deciduous trees or shrubs that function as facultative phreatophytes and facultative halophytes (DeLoach 2000). Depending on species, they may reach large tree size, but most invasive species are multi-stemmed shrubs of less than 8 m that can grow 3 to 4 m in a growing season (Sisneros 1991). Leaves are alternate, sessile, small, punctate, scalelike with salt-secreting glands and are self-pruning during drought periods (Diggs *et al.* 1999). They have extensive root systems that easily extend to 3 m and lengths of 53 m have been recorded (Waisel, Eshel and Kafkafi 1996). They produce a primary root that extends to the water table and then profuse secondary root production may occur (Brotherson and Von Winkel 1986). Adventitious roots easily develop from submerged or buried stems. Thus, they can expand their range through vegetative reproduction from stems or rootstocks that become dislodged and are later buried in a mudflat (Kerpez and Smith 1987), or from the profuse production of up to 100,000 or more small seeds per plant that are wind or water dispersed (Stevens 1985). The plants are insect pollinated although some wind pollination may occur (DeLoach 2000) Due to their short-lived viability (less than 2 months), the seeds must come in contact with a moist substrate within a few weeks of dispersal. Seeds have no dormancy requirements and germinate in less than 24 hours. Actively growing plants produce a continual supply of seeds which can take advantage of suitable substrates when available during the growing season (Engel-Wilson and Ohmart 1978). New seedlings are highly susceptible to dessication and thus require a continually moist substrate for up to 4 weeks; one day of surface dessication can cause mortality (Kerpez and Smith 1987, Brotherson and Field 1987). Once established, however, seedlings can survive almost indefinitely in the absence of surface saturation.

Saltcedar plants are found on non-rocky silt loams and clay loams of high organic matter along streams, bottomlands, banks of drainages and washes and other wet environments in arid and semiarid regions. Disturbance of these habitats tends to favor establishment of these species. Disturbances that favor these species include clearing, plowing, overgrazing, and alteration of natural water flows; the construction of reservoirs, dams, river diversions, flow regulations and irrigation all disrupt natural flows. Saltcedar tolerates greater environmental extremes than associated native willows and cottonwoods and hence has an advantage over those species. They can grow on highly saline soil containing up to 15,000 ppm or more of soluble salts and under alkaline conditions. Mature plants are more drought tolerant than native species. They can function as facultative phreatophytes while associated native species are obligate phreatophtyes and hence more subject to mortality during extended droughts. Conversely, they can survive complete inundation of the entire plant for up to 70 days which would be fatal to most natives (Warren and Turner 1975). Mature plants are tolerant of fires and aggressively resprout following topkill.

Impacts and Invasiveness

The invasion by saltcedars is arguably one of the worst ecological disasters ever to befall western riparian ecosystems and they exhibit 10 of the 12 criteria of Baker (1974) that qualifies them as ideal weeds (DeLoach 2000). They are not only able to tolerate extremes of environmental conditions, but they also can dramatically alter the environments in which they grow, and by association affect the plants, animals, soils and hydrology of these areas. Examples of saltcedar reponses, tolerances and impacts, as summarized by DeLoach (2000) and others, are summarized below:

Direct responses and impacts:

Water consumption and hydrology alterantion-This is perhaps the primary area of concern relative to Saltcedar. Saltcedar apparently uses more water than native species which can result in depressed water tables, which in turn alters the onsite and offsite hyrology of the area (Horton 1976). Greater water use may be the result of 1) its ability to grow to the water table and continue to use water when some natives are unable to do so, 2) its development of a greater leaf area (more plants per unit area and/or more leaf area per plant) than native species, and 3) its being a facultative phreatophyte and having greater drought tolerance, which enables it to occupy greater areas away from the river or other water bodies and hence use more water (Gatewood *et al.* 1950, Sala *et al.* 1996, Cleverly *et al.* 1997, Smith *et al.* 1998). Later papers in this Symposium will expand on this topic.

Salinity tolerance and salt deposition-Saltcedar has the ability to grow in saline environments and to excrete salt from its leaves. This salt may fall directly to the soil or may arrive through leaf fall. In either case this increases the salt concentration in the soil surface which may inhibit the establishment and growth of other salt intolerant species (Shafroth *et al.* 1995, Smith *et al.* 1998). In addition little research attention has been directed toward this impact on soil organisms which could translate into alteration of other ecosystem processes.

Fire tolerance and litter dynamics-Native willows, cottonwoods and other species are often killed by fire. Saltcedar on the other hand is only topkilled by fire but actively resprouts to heights of up to 2 m in one growing season. It also produces greater quantities of leaf and woody debris which tends to favor fires. Its rapid regrowth following fire and its tendency to create conditions that favor fire adds to its ability to control and replace native species (Busch and Smith 1993, Smith *et al.* 1998).

Flood Tolerance-Generally mature saltcedars can survive greater durations and depths of flooding than most native species. Thus, once established they can persist under conditions that would result in mortality or reduction in abundance of many native species (Warren and Turner 1975). Saltcedar seedlings are not tolerant of submersion for long periods and flooding may be used to contro first year seedlings (Gladwin and Roelle 1998).

Herbivory tolerance-While native cottonwoods and willows, particularly seedlings, are often browsed by livestock and native ungulates, saltcedars are apparently not as readily consumed and if they are they are not greatly suppressed. In addition, as introduced species, saltcedars lack associated insect herbivores that could perhaps exert influence on these species and, if introduced, these insects may offer some potential for use in the biological control of saltcedar (DeLoach 2000).

As result of the morphological, physiological and ecological traits of saltcedar, this group of plants tends to be highly invasive and persistent once they have invaded. As a result they can significantly alter native plant and animal communities, and the fundamental ecosystem processes (hydrology, nutrient cycling, etc.) of the riparian and other wetland systems that they occupy. A shopping list of possible effects are include:

Plant communities-Composition and structure of riparian communities are greatly changed when invaded by saltcedar by altering abiotic factors and population interactions, e.g., competion, in the system.

Animal communites-As the plant community is altered and as ecological processes are changed, the animal community typically changes in composition.

Threatened and Endangered Species-As natural communities and abiotic factors are altered some plant and animal species are unable to maintain viable populations and their numbers decline and perhaps local extinctions occur.

Salinity-Surface soil salinity alterations alters plant and animal communities and ecological processes.

Channel alteration-Growth form, persistence and greater areal extent of saltcedar in some riparian systems can change the fundamental channel forming, sedimentation and physical/chemical processes of invaded riparian systems (Graf 1978).

Human Issues-Clearly changes in the above parameters create changes that influence water supply and quality, agricultural and municipal water use, recreation uses and other human uses and activities.

Saltcedar invasion has substantially impacted the natural ecosystems of riparian and other wet soil environments of many regions of the West. While purposeful, and in most cases well-intentioned, these introductions produced major changes, most perceived to be negative, that to a large extent were exacerbated by man's attempts to use, change and control the hydrology/watershed properties of these systems. To deal with this issue may take more than just developing methods of control of these plants. Many approaches have been applied to control these species including mechanical, chemical, pyric and biological, and varying combinations thereof, with varying but not universal success, and most are costly. Reestablished of natural hyrologic regimes may be necessary to truly make progress in reducing the impacts of these species. Both direct control and return of natural processes may be beyond the current ecological capacity of these altered systems and may not warrant the financial cost required. As water supply and other needs for resources from these systems become more acute, greater efforts will be required to determine if rehabilitation is reasonably possible and to develop more effective means to accomplish this restoration. A parting caveat is to suggest that simple, single-purpose solutions to complex problems rarely provide longterm, sustainable results, and at a minimum we should attempt to understand that which we choose to change so as not to make things worse than they may be in their current condition.

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DISTRIBUTION OF SALTCEDAR IN THE SOUTHWEST

Homer Sanchez and Patrick L. Shaver

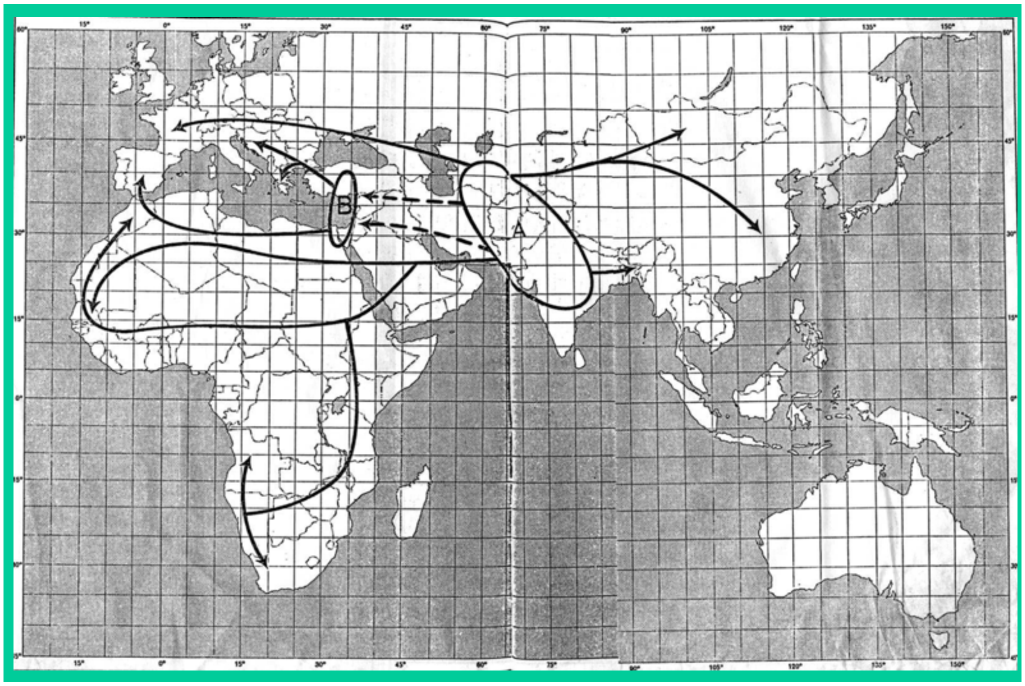
One of the most significant threats to global biodiversity is the invasion of exotic species into natural areas due to human activities and commerce (Clout. 1995). The invasion of saltcedar into desert wetlands of the southwestern United States certainly fits the criteria for causing significant threats to biodiversity. Saltcedar, in the genus *Tamarix*, family Tamaricaceae, is responsible for displacing as much as 50 to 60% of the native vegetation's on many of western riparian areas and almost completely eliminating the plant diversity of others.

Worldwide distribution

The genus *Tamarix* is comprised of shrub or trees native to arid, saline regions of Eurasia and Africa. Baum (1978) recognized 54 species in the genus *Tamarix*. The native distributions of these species range from southeastern Asia, to southern Europe and North Africa, with a few species in western and southern Africa (Fig. 1). The probable sites of origin for these species were the deserts of Iran, Afghanistan, Pakistan, south central USSR, and also in the eastern Mediterranean area.

Figure 1.

Origins of *Tamarix* (Baum 1978)

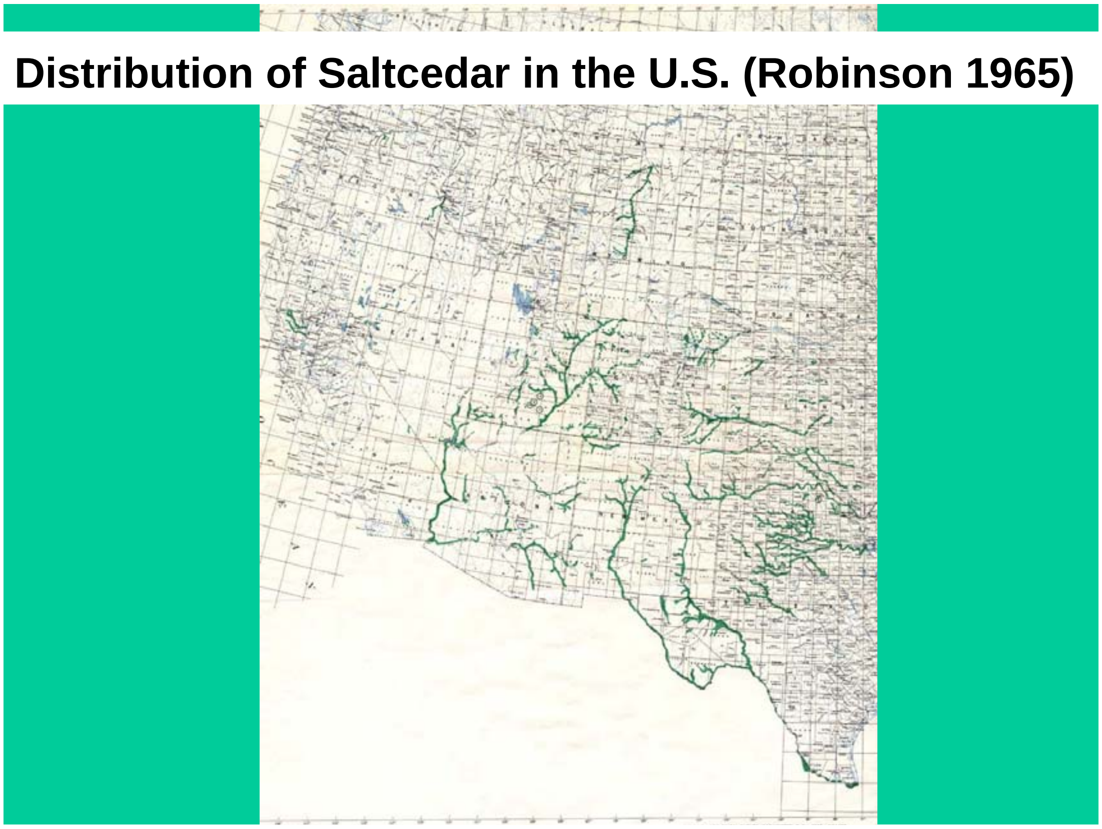


North American Introduction

Originally thought to have been introduced by the Spaniards, it is now believed that the first introduction of saltcedar to North America was made by nurserymen on the east coast of the United States in 1823 and by 1868, the U.S. Department of Agriculture began raising saltcedar. Saltcedar *(Tamarix sp.)* was planted as an ornamental plant in the United States during the late 1800's, however it is believed that the plant did not begin to escape until the 1870's. Tamarix was used widely, but not abundantly, in the southwestern United States, and in northern Mexico as a shade tree or as ornamental. During the early 1900's farmers began using this plant to control erosion (Everett 1980).

Saltcedar is an introduced shrub of North America where in 1965 it was estimated to occupy between 1 and 1.5 million acres (Robinson) (Fig.2). Considerable knowledge and professional opinion exist regarding the invasion of saltcedar across the southwest since the 1965 survey, but no national effort to monitor its invasion has occurred since 1965.

Figure 2. This 1965 study was the last intensive national inventory documenting of saltcedar movement nationwide.



Distribution of Saltcedar in the U.S. (Robinson 1965)

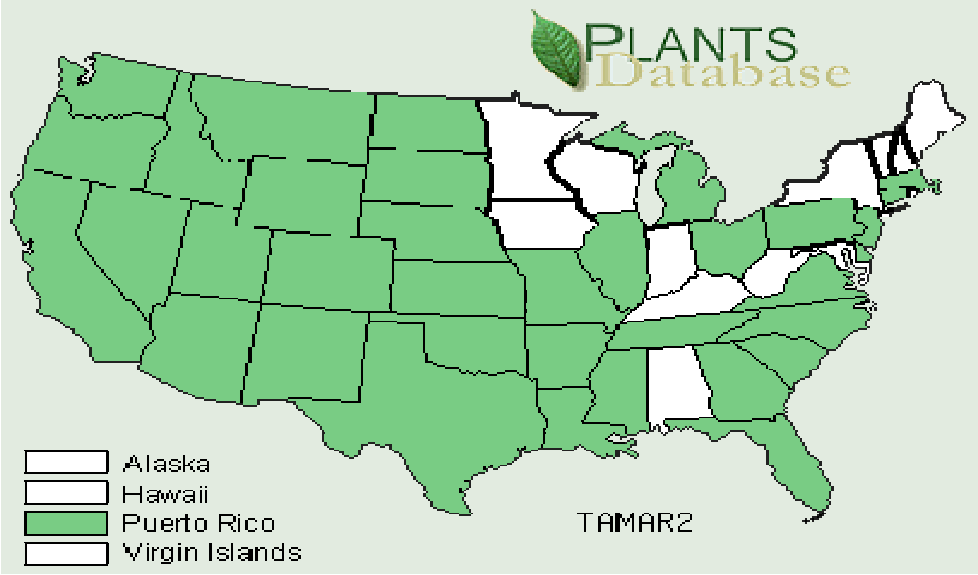
The ability of saltcedar to colonize riparian areas aggressively lead to it eventually being characterized as a troublesome plant or a "weed". (Baker 1974), and (Brotherson and Field

1987) developed a list of 13 characteristics that evidenced saltcedar being classified as one of our major weed problems.

Saltcedar has the capacity to produce enormous numbers of seed. One mature plant can produce up to 500,000 seeds per season. These tiny seeds are extremely viable and are easily wind distributed due largely in part to their long hairs. Significant seed transport also occurs as they are carried and deposited along sandbars and riverbanks by water (Tomanek and Ziegler 1960). Seasonal fluctuations due to floods and droughts are major transport vehicles for saltcedar. Recent droughts in much of the southwest and specifically in Western and Central Texas has resulted in millions on seedling saltcedar becoming established as far east as Lake Buchanon, Texas, and possibly much further towards the Gulf Coast.

The rapid spread of saltcedar throughout the southwestern United States has been facilitated by large-scale modifications of environmental conditions associated with human activity ((Lovich and De Gouvenain) (Fig. 3).

Figure 3. NRCS Plants Database survey of states with Tamarix presence.



The damming of rivers and its resulting changes to natural flooding regimes and floodplain ecosystems greatly benefited the saltcedar species. Saltcedar is now found in a wide variety of climates and soils where human disturbances have created favorable conditions for its establishment (Brotherson and Field, 1987; DeLoach, 1989).

There are at least ten species of Tamarix occurring in the United States, at least six of which occur in Texas. Two species of saltcedar, *Tamarix chinesis* and *T. ramossima*, have escaped cultivation and rapidly invaded riparian areas of the western United States, especially during the drought years of the 30's and 50's (Christensen 1962, Horton 1977, DeLoach 1990). Five of the other eight species are not yet serious weed species and two of the species are only known as cultivated ornamentals. One species, T. aphylla, commonly known as Athel is an evergreen and grows to a large tree. This species is commonly found as either a windbreak species or is planted for shade in the United States and also in northern Mexico.

Table 1 below shows the selected list of potential causes and consequences of saltcedar invasion in desert riparian systems of the southwestern United States. The order of placement in each column is random and individual causes may lead to multiple consequences.

Table 1.

Causes	Consequences .
Diminished riparian flow rate	**stream channel modification**
Increased soil salinity	**diminished value of wildlife habitat**
Lowered water tables	**increased fire frequency**
Physical soil disturbance	**loss of biodiversity**
Irrigation	**increased evaporation**
Destruction of native vegetation	**decreased potential for native plants**
Deliberate planting	**elimination of salt-intolerant plants**

Saltcedar infestations often have profound effects on the geomorphology and hydrology of riparian systems. One of the most thorough studies of the impacts of saltcedar on the riparian dynamics was by Graf (1978). His research showed that saltcedar trapped and stabilized alluvial sediments causing an average reduction in channel width of 27% since the late 1800's on the Green River in Utah. Saltcedar infested riparian areas have a much lower value as wildlife habitat than do the areas of native vegetation they have displaced. The amount of losses to non-consumptive usage that can be attributed to saltcedar in New Mexico and Arizona is estimated to be as much as $45 million annually (DeLoach).

Unofficial accounts of saltcedar invasion show that Tamarisk species inhabit approximately 95,000 acres associated with Reclamation in the Lower Colorado River Basin. In New Mexico, saltcedar impacts an estimated 100,000 acres of the Pecos Basin, 100,000 acres in the Rio Grande and 250,000 acres statewide. Tamarisk is spreading at a rate of approximately 50,000 acres per year in the Western U.S. Numerous aspects (water supplies, maintenance, channel integrity and flooding, power revenue, habitat quality, etc.) of Reclamation water systems will continue to degrade if tamarisk keeps on spreading unabated. (Acreages above are estimates only and need further documentation)

An observation inventory from Oklahoma NRCS staff show that the entire western one-third of Oklahoma shows some presence of salt cedar. Approximately 86,000 acres in Oklahoma are infested with saltcedar. About half has canopies greater than 10% (Moseley 2003). Nevada NRCS reports heavy infestations of saltcedar with closed canopies and no understory vegetation occurring sporadically within major drainages specifically, the Colorado River and the Lake Mead area in northern Nevada below about 4500 feet elevation.

The 1982 NRI Texas brush Inventory shows that approximately 563,500 acres of saltcedar existed at that time. This USDA/SCS Inventory was the last complete effort to access the invasion of woody species statewide.

An observation inventory New Mexico NRCS staff shows the same explosive trend of saltcedar. During 1912 few saltcedar seedlings were noted around Lake McMillan, New Mexico. By 1915, approximately 600 acres were infested around the dam. By 1925, 12,300 acres of saltcedar were noted around the dam and down the Pecos River. By 1960, over 57,000 acres of saltcedar covered the region. (K. Allred 2002)

Conclusion

The continued invasion of saltcedar slowly eliminates riparian diversities. Numerous reports can be found to validate the species dominance. Great thickets, or bosques, of mesquite, and or cottonwoods formerly grew in many riparian areas of the southwest. Many of these thickets have been destroyed due in part to the saltcedars competitiveness and also in its ability to rob water from other woody species. A study by Busby and Schuster in 1973 measured the different vegetation types along the Brazos River of Texas from Possum Kingdom Lake to the headwaters. Aerial photographs from 1940, 1950, and 1963-68 were studied. Between 1940 and 1969, saltcedar had increased by 52.5% while the area in the riverbed and sandbars had decreased by 47.4%. This vegetational change has economic and environmental impacts that are not acceptable.

A number of recommendations have been made for the coordinated management of saltcedar. The partnerships between private landowners, and state and federal governments have led to excellent saltcedar control efforts in recent years. Successful saltcedar control can be accomplished, however much of the research reminds us that saltcedar alone was not the main cause for riparian degradation. Lowered water tables caused by pumping groundwater, vast land clearing, modifications of seasonal flows caused by dams, overgrazing, fire, and woodcutting have also contributed to the replacement of native plant communities, and the consequential degradation of habitats for many species of birds, and mammals.

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GROUNDWATER AND SURFACE WATER THRESHHOLDS FOR MAINTAINING *POPULUS-SALIX* FORESTS, SAN PEDRO RIVER, SOUTHERN ARIZONA

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Introduction

Stream diversion and groundwater decline from urban, agricultural, and industrial uses have contributed to the decline of many riparian phreatophytes in the southwestern United States. Consequences of declines in riparian forests include loss of habitat for animal species, many of which are endangered, and loss of scenic areas for recreation. Riparian vegetation loss also can contribute to increased flood peaks, sediment erosion, and channel widening. Many people value these forests and their functions, and thus there is considerable interest in restoring *Populus* spp. -*Salix* spp. (cottonwood - willow) forests to degraded river reaches and conserving those forests that remain. These restoration and management activities require knowledge of species' requirements for abiotic factors and processes including hydrologic regimes. They also require identifying hydrologic threshold values for desired attributes such as community structural traits and species abundances.

In addition to causing loss of *P. fremontii* and *S. gooddingii* (Fremont cottonwood - Goodding willow) stands, hydrologic changes to rivers have influenced the abundance of more drought tolerant species such as *T. ramosissima* (salt cedar). *T. ramosissima* was introduced to the United States in the late 1800's from Europe and Asia for ornamental, windbreak, and erosion control purposes. It has since spread to water courses throughout the United States and now covers at least 600,000 ha of floodplain habitat in 23 states (Di Tomaso 1998, Zavaleta 2000), including large expanses of former *P. fremontii* - *S. gooddingii* forest (Robinson 1965, Horton 1977). Stream diversion, ground water pumping, and flood flow alteration below dams have all contributed to this shift, allowing *T. ramosissima* to attain dominance in reaches with hydrologic conditions that are no longer favorable to *P. fremontii* and *S. gooddingii*. At some river sites, *P. fremontii* and *S. gooddingii* have declined because human-caused groundwater decline has produced conditions outside their tolerance range. At other sites, *T. ramosissima* may be contributing to loss of the *P. fremontii* - *S. gooddingii* forests by reducing water availability (Cleverly et al. 1997). Whether the mechanism is passive replacement or active displacement, there is a need to refine the hydrologic thresholds at which this shift in composition occurs.

We conducted this study to: 1) identify surface flow and groundwater depth and fluctuation thresholds for maintaining *P. fremontii-S. gooddingii* forests; 2) increase the understanding of how *P. fremontii*, *S. gooddingii*, and *T. ramosissima* population stand structure traits (size class diversity, canopy cover, basal area, vegetation volume, and stem density) vary with groundwater depth and fluctuation and surface flow permanency; and 3) assess how community structure traits vary across these hydrologic gradients. Although the results are specific to the San Pedro River, our goal was to generate models that can be tested on other rivers. Ultimately, we wished to provide information to river managers that would assist with their goal of conserving and restoring high density *P. fremontii-S. gooddingii* forests.

Research Approach, Study Sites, and Methods

Study area. We conducted natural field studies to measure abundance and structural traits of *P. fremontii - S. gooddingii - T. ramosissima* forests across spatial gradients of groundwater and surface water availability. The studies were conducted along the San Pedro River in southeastern Arizona, USA. The San Pedro arises in Sonora, Mexico and flows northward through the Chihuahuan and Sonoran Deserts to its confluence with the Gila River. Surface flow frequency and groundwater depth vary among sites due to geologic differences in depth to bedrock, proximity to tributaries, and proximity to sites of groundwater pumpage for agricultural, industrial, and/or municipal use. Field data were collected during 2000-2002 from 18 sites located along the San Pedro River from the International border to the confluence with the Gila River. Sites were selected to capture a range of hydrologic conditions along the San Pedro River and include ephemeral, intermittent, and perennial reaches. At each site, we established two transects that were oriented perpendicular to the channel and spanned the width of the floodplain, extending to the base of the *Prosopis-Sporobolus* (mesquite-sacaton) terraces.

Abundance, stand structure, and size structure. Vegetation patch types along the two transects at each site were classified using a rule-based system based on dominant woody species, canopy cover class, tree size class, and fluvial geomorphic surface. At one transect per site, 5 x 20 m study plots (long axis parallel to the river) were placed in stratified random fashion within discrete patches. Within each study plot, total stand and per species vegetation volume, canopy cover, canopy height, woody plant stem density, and woody plant basal area data were collected. Vegetation volume was measured using the vertical line intercept method (Mills et al. 1991). Canopy cover was measured using a spherical densiometer. Stem density was calculated by counting each live tree stem emerging from the ground in the study plots. Basal diameter of each stem was measured using a diameter tape or calipers.

Structure data were reduced to the site level (i.e., floodplain riparian zone) by weighting plot-level values by the percent of the floodplain of the respective patches. Importance values were calculated for *P. fremontii* + *S. gooddingii* and for *T. ramosissima* using the formula Importance Value = (relative basal area + relative canopy cover + relative vegetation volume)/3. The importance value represents a summary of the relative abundance at each site. To characterize size class diversity, *P. fremontii,* S. *gooddingii*, and *T. ramosissima* were arbitrarily broken into 5 cm diameter size categories. Total and per species number of size classes and mean stem densities per size class were calculated for each site.

Site hydrology. Data were obtained on groundwater depth and stream flow frequency. Two shallow piezometers were installed at the non-perennial sites and one at each perennial site. The intermittent-site wells were located approximately 1/3 and 2/3 of the distance between the channel and floodplain edge and the perennial wells were located approximately half-way between the channel and floodplain edge. Depth to groundwater, surface flow presence/absence, and river stage (depth at thalweg) were monitored monthly during water years 2001 and 2002. The groundwater surface across the floodplain was interpolated from the two well points at the intermittent transects and the river depth and well point at the perennial transects. River cross sections and floodplain transects were surveyed using a transit and stadia rod, to determine plot elevation above and distance from channel thalweg. Depth to groundwater was determined at each survey point and this information was used to estimate depth to the water table for each patch and to obtain a weighted average depth to groundwater for each site (weighted average = Σ [[depth to water table at each survey point] * [% of floodplain between adjacent survey point]]). Surface flow permanence at each site was calculated as the percentage of months during which surface flow was present over the two year period. Patch and site level groundwater depths were characterized as the average of the annual maximum depth to groundwater. A hydrologic rank for the sites was calculated as Rank = ([1-flow frequency]*maximum groundwater depth*water table fluctuation), where water table fluctuation equals the two year maximum January-June fluctuation in water depth in the well furthest from the stream edge at each site. The sites were divided into three hydrologic classes using the hydrologic rank scale and assigning breaks at 35% and 75% of the running mean.

Statistical analysis. Spearman rank order correlations and single and multiple regression were used to determine relationships between site- and patch-level vegetation abundance (dependent variables) and hydrologic variables (independent variables). One way ANOVA with post-hoc Tukey tests were used to determine differences in structural trait values (i.e. # 5 cm classes, maximum vegetation height, % shrublands, % woodlands, and upper stratum vegetation volume) between the hydrologic classes. Results from single- and multi-variate regression analyses between the importance value and hydrologic rank were used to determine hydrologic threshold values for three conditions of forest structure: 1) dominance of *T. ramosissima* trees/shrubs, 2) levels at which *P. fremontii-S. gooddingii* and *T. ramosissima* are co-dominant, and 3) levels where *P. fremontii* and *S. gooddingii* are the dominant pioneer tree species.

Results

Hydrology. Surface flow and groundwater levels during water year 2001 were above average due to a flood in October 2000 which maintained high levels of surface flow and groundwater for much of the water year. In contrast, water year 2002 was a particularly dry year. We used the mean of these two years to represent average long-term conditions. Sites ranged in flow frequency from 29% (i.e., stream water present in the channel about one-third of the time) to 100% (i.e., perennial flow). Sites ranged from 5.3 to 1.3 m in maximum depth to groundwater (i.e., average maximum value across the floodplain for the 2 year period), and from 0.05 to 1.5 m in maximum January-June ground water fluctuation. Hydrologic rank ranged among sites from -1.841 (dry) to -0.005 (wet). One site's hydrologic rank was identified as an outlier and removed from subsequent analysis. Three hydrologic classes were developed based on the hydrologic rank (Table 1).

<u>Population and community structure</u>. *P. fremontii* and *S. gooddingii* canopy cover, vegetation volume, basal area, and stem density increased with increasing flow frequency and decreasing depth to groundwater. In contrast, *T. ramosissima* structural variables decreased under wetter conditions. The number of *P. fremontii* and *S. gooddingii* 5 cm size classes increased at sites with higher flow frequencies but the number of *T. ramosissima* size classes was not related to the hydrology variables. As groundwater and flow frequency levels decreased and community composition shifted from *P. fremontii-S. gooddingii* to *T. ramosissima* dominated floodplains, there were also significant changes in community structural traits. Wetter sites had higher total stem size class diversity, vegetation volume above 8 m, and maximum vegetation height. Total canopy cover, basal area, and stem density did not vary as a function of site hydrology. The increase in upper canopy vegetation volume was reflected in the physiognomy of floodplain communities as wet sites had more woodlands and fewer shrublands than the dry sites. Tall woodlands and forests gave way to shorter shrublands at conditions drier than those of hydrologic class 2 (Table 1, Figure 1).

<u>Community composition thresholds</u>. Threshold values for the maintenance of *P. fremontii-S. gooddingii* forests were determined based on the relationships between importance values and hydrologic rank (Figure 2). Importance values for *P. fremontii* and *S. gooddingii* varied separately in relation to the hydrologic rank scale. However, because *S. gooddingii* consistently composed a small percentage (7.9 ± 7.1) of the overall importance value it was combined with *P. fremontii*. Hydrologic rank (HR) is a combination of flow frequency (FF), groundwater depth (GD), and groundwater fluctuation (GF); *P. fremontii* + *S. gooddingii* and *T. ramosissima* importance values were related to these three variables through the multi-variate regression equations: *P. fremontii* + *S. gooddingii* Importance Value = $56.5+(9.7*GD)+(73.8*FF)+(41.8*GF)$, $r^2=0.73$, $p<0.001$; *T. ramosissima* Importance Value = $43.5-(9.7*GD)+(73.8*FF)+(41.8*GF)$, $r^2=0.73$, $p<0.001$. Flow frequency, groundwater depth, and groundwater fluctuation threshold values were determined through regression equations with hydrologic rank, ($FF = 0.9+(0.3*HR)$, $r^2 = 0.57$, $p<0.001$; $GD = -2.4+(0.9*HR)$, $r^2 = 0.23$, $p = 0.03$; $GF = -0.4+(0.3*HR)$, $r^2 = 0.43$, $p<0.001$).

Based on the relationships between importance value and hydrologic rank (Figure 2), *T. ramosissima* was the dominant pioneer species at sites where groundwater depths were below 3.2 m, flow frequencies were less than 60%, and January-June fluctuation was less than 0.69 m. At groundwater depths above 2.9 m, flow frequencies above 73%, and January-June groundwater fluctuations of 0.56 m, *P. fremontii-S. gooddingii* stands dominate. When analyzed separately, each abundance metric (i.e. canopy cover, basal area, and vegetation volume) exhibited slightly different hydrologic thresholds at which dominance shifted from *P. fremontii - S. gooddingii* to *T. ramosissima* communities. To account for this variability in the threshold breakpoints, we assigned ranges for the threshold values that spanned the range of values observed in the relationships between each abundance trait and each hydrologic variable (e.g. *P. fremontii* basal area vs. depth to groundwater, or *P. fremontii* vegetation volume vs. depth to groundwater; Table 2). Below flow frequencies of 40-60% and groundwater depths of 3.2-3.8 m, and groundwater fluctuations of 0.59-0.75 m, *T. ramosissima* was the dominant pioneer species. *P. fremontii* and *S. gooddingii* should retain dominance as pioneer species at above 73-78%, and groundwater levels less than 2.4-2.9 m and groundwater fluctuations lower than 0.48-0.56 m. The species are co-dominant at flow frequency and groundwater depths and fluctuation ranges between these thresholds.

Discussion

Causes of shifts in species dominance. The groundwater depth threshold values (2.4-2.9 m) at which *P. fremontii-S. gooddingii* forests maintain dominance over *T. ramosissima* shrublands and woodlands along the San Pedro River are consistent with other values for rivers in the hot sub-tropical Sonoran desert biomes (Shafroth et al. 2000, Horton et al. 2001a,b). Our results integrate the environmental requirements for *P. fremontii-S. gooddingii* population maintenance across life stages from seedlings to adults. The values for stem density and size class structure reflect recruitment and mortality processes ranging from seedling establishment to adult survivorship. However, the results emphasize adult survivorship, as these requirements are usually less exacting than those for seedling establishment. *P. fremontii* and *S. gooddingii* size class diversity and stem density were low at dry sites, perhaps due to reduced germination rate and/or increased mortality of sensitive young age classes. At dry sites, groundwater depths may recede too rapidly following floods to sustain seedlings, resulting in recruitment success only in very wet years. Annual declines of 1 to 2.3 meters have caused mortality of *Populus* spp. and *S. gooddingii* saplings and trees (Shafroth et al. 2000). These values exceed the values for annual groundwater fluctuation (ca. 0.5 m) that we found to be favorable for *P. fremontii* and *S. gooddingii* maintenance. Low size class diversity at the dry sites may also occur because mortality thresholds for older plants are exceeded more frequently. The fact that the number of *T. ramosissima* size classes was not related to site hydrology could indicate that *T. ramosissima* is able to survive a wider range of conditions.

San Pedro River vegetation composition shifted from *P. fremontii -S. gooddingii* to *T. ramosissima* dominated communities as groundwater and flow frequency levels declined between sites. This pattern is similar to those found by other researchers (Busch and Smith 1995, Cleverly et al. 1997) although there have been different conclusions drawn regarding the process producing the pattern. Questions remain as to the extent to which the compositional shift arises due to abiotic effects and differences between species in environmental tolerance ranges vs. biotic interactions in the form of interspecific competition that reduce water availability. When hydrologic conditions become unfavorable to *Populus* spp. and *Salix* spp., *T. ramosissima* may be capable of competitively reducing these species. *T. ramosissima* can extract large quantities of water from non-saturated soil, and has deeper roots, higher water use efficiency and tolerance of a wider range of groundwater fluctuation than *P. fremontii* and *S. gooddingii* (Busch and Smith 1995, Shafroth et al. 2000). While this greater tolerance to drought stress allows *T. ramosissima* to fare better under altered hydrologic conditions, research is showing that *T. ramosissima* is a poor competitor under conditions that are favorable to *Populus* spp. and *Salix* spp. survivorship (Sher et al 2002). The long term success of *Populus* spp. and *Salix* spp. does not depend on a single year of favorable conditions, but requires sustained conditions. Reducing *T. ramosissima* cover can be achieved by restoring environmental conditions favorable to *Populus* spp. and *Salix* spp. establishment and maintenance and

Functional significance of changes in community structure. Structural characteristics of the San Pedro River forest changed across spatial gradients of water availability in response to the effects of water availability on species or population structure, and in response to the effects of water reduction on shifts in species composition (Figure 1). Shifts in community composition from *P. fremontii - S. gooddingii* to *T. ramosissima* can affect animal species richness, diversity, and abundance if the structural characteristics of *T. ramosissima* stands differ greatly from those of *P. fremontii - S. gooddingii* stands (Ellis 1995). However, when structural characteristics are similar, *T. ramosissima* forests can have similar ecological functions to *P. fremontii* forests and even play a beneficial ecologic role in areas where broad-leafed deciduous species are absent or reduced (Brown and Trosset 1989). Because *T. ramosissima* generally has a lower canopy than *P. fremontii* and *S. gooddingii*, there were declines in total vegetation volume, upper canopy vegetation volume, and maximum canopy height as the relative abundance of *T. ramosissima* increased. Floodplain physiognomy patterns mirror the vegetation volume patterns through an increase in shrublands and decrease in woodlands at the drier sites.

Although *T. ramosissima* typically has more stems per individual plant than *P. fremontii* and *S. gooddingii*, we did not find total site stem density to increase at the drier sites. Increases in stem density can be ecologically significant because of resulting increases in near channel and floodplain roughness which can cause geomorphic adjustments such as bank stabilization, increased overbank flooding, excessive down cutting, and decreased channel migration (Graf 1978). While total stem density did not vary between San Pedro River sites, species stem density patterns were related to site hydrology. *T. ramosissima* stem densities were higher at the dry sites and *P. fremontii* and *S. gooddingii* stem densities increased at the wet sites. Perhaps these two trends balance each other to effect stem density patterns that are independent of site hydrology. An additional factor is the presence of *Baccharis salicifolia* (seep willow) which is a facultative shrub species that often occurs along channel margins and in the understory of *P. fremontii-S. gooddingii* forests. The abundance of *B. salicifolia* is contributing to the even distribution of stem densities across the hydrologic gradient. Further investigation is needed to assess whether increased *T. ramosissima* is having geomorphic effects on sedimentation, channel migration, overbank flooding, or channel down cutting as site become drier.

We did not observe changes in total canopy cover and basal area in relation to site hydrology. The method we used to measure canopy cover detected any vegetation above 1 m, where *T. ramosissima*, *P. fremontii*, and *S. gooddingii* can all be abundant. Total basal area did not vary, possibly because the basal area of the many small stems at dry sites equaled that of the fewer large stems at wetter sites. Relative and absolute *P. fremontii* and *S. gooddingii* canopy cover and basal area were lowest at the drier sites, as *T. ramosissima* abundance increased.

<u>Limitations with the threshold model</u>. A few caveats are associated with the hydrologic thresholds we identified. These thresholds are not actual predictive hydrologic values for conditions at which *P. fremontii - S. gooddingii* forests give way to *T. ramosissima* stands because we used a space for time substitution, where dry sites are assumed to represent future dewatered conditions. This assumes that plant communities are in equilibrium with current hydrologic and geomorphic conditions, although this may not be the case if there are lag-times associated with an increase or decrease in water availability. The two year period over which hydrology data were collected may not be representative of long-term conditions. While the thresholds are based on an average of a wet and dry year, there may be considerable variation in the long-term record which we were not able to incorporate. We also did not account for the

amount of water that *P. fremontii*, *S. gooddingii* , and *T. ramosissima* may be using from overbank flows, which could affect groundwater and surface water thresholds. Another limitation of our model is that we have variable levels of confidence in the threshold levels we identified. We have a high level of confidence in the groundwater depth and flow frequency threshold ranges because species importance values and individual abundance measures were strongly related to depth to groundwater and surface flow frequency. Although multiple regression analysis between importance values and all three hydrologic variables showed significant relationships ($r^2 = 0.72$, overall $p < 0.001$, GD $p = 0.07$, FF $p = 0.004$, GF $p = 0.04$), the single regression relationship between importance values and groundwater fluctuation was not as strong ($r^2 = 0.26$, $p = 0.04$) and few of the individual abundance variables were related to groundwater fluctuation. We therefore have somewhat less confidence in the groundwater fluctuation thresholds. More work needs to be done to validate the overall model, using additional sites on the San Pedro as well as sites along other southwestern rivers such as the Hassayampa, Bill Williams, and Rio Grande.

Biological and physical causes of site dewatering. Depressed groundwater tables and reduced surface flows have been an issue on the San Pedro River for decades and, while it is likely that *T. ramosissima* is not a direct cause of the altered hydrology, the presence of *T. ramosissima* may be contributing to the depressed groundwater tables. Dense *T. ramosissima* stands can use large amounts of water when groundwater is readily available (Sala and Smith 1996) and when water availability is limited (Busch et al. 1992). While many have interpreted results of evapotranspiration studies to indicate that *T. ramosissima* is able to desiccate floodplains by using large quantities of water, studies have varied in temporal and spatial scales and there are few studies that directly compare the species, making it difficult to draw definitive conclusions on relative water use.

Along the San Pedro, there are factors besides evapotranspiration that are causing surface flow and groundwater table declines. Decades of groundwater pumping and surface diversions for municipal, industrial, and agricultural uses have contributed to lowered alluvial and floodplain aquifer levels and decreased base flows along the river. (Jackson et al. 1987, Goode and Maddock 2000). In recent decades population centers within the San Pedro Basin have pumped alluvial groundwater at a rate exceeding its recharge from the regional aquifer. In apparent response to this pumping, base flows in the river and groundwater levels in the floodplain aquifer are continuing to decline.

Conclusion

Depth to groundwater, groundwater fluctuations, and surface flow frequency are influencing the ecological condition of San Pedro River floodplain forests. Canopy cover, basal area, vegetation volume, stem density and age class diversity of *P. fremontii* and *S. gooddingii* decreased at drier sites as *T. ramosissima* became more abundant. This shift in species composition was associated with changes in community structure and floodplain forest physiognomy. The presence of threshold values for various community structural traits underscores the importance of evaluating the structure and not just composition of hydrologically altered forests. Identification of hydrologic thresholds for the maintenance of tall dense *P. fremontii*-*S. gooddingii* stands emphasizes that restoring appropriate long term hydrologic conditions may allow these species to regain dominance without further human intervention.

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Table 1. Ranges, means, and standard deviations of hydrologic variables within hydrologic classes, arranged dry to wet.

Hydrologic Class (n)	Hydrologic Rank	Flow Frequency (%)	Groundwater Depth (m)	Annual Groundwater Fluctuation (m)
1 (4)	-1.84 - -1.11	29 - 67	5.34 - 2.72	1.52 - 0.35
	-1.43 ± 0.31	46 ± 18	3.85 ± 1.09	0.84 ± 0.51
2 (8)	-0.71- -0.08	33-96	4.09 - 1.63	0.64-0.30
	-0.30 ± 0.22	73 ± 21	2.66 ± 0.96	0.48 ± 0.10
3 (5)	-0.01 - -0.005	100	3.10 - 1.34	0.50-0.33
	-0.010 ± 0.003	100 ± 0	2.26 ± 0.73	0.42 ± 0.08

Figure 1. Distribution of community structural traits within hydrology classes (see Table 1 for description of hydrologic classes). Bar heights are means for each hydrologic class and error bars are standard deviations. Dissimilar error bar letters indicate a significant difference (ANOVA p<0.07) between the classes.

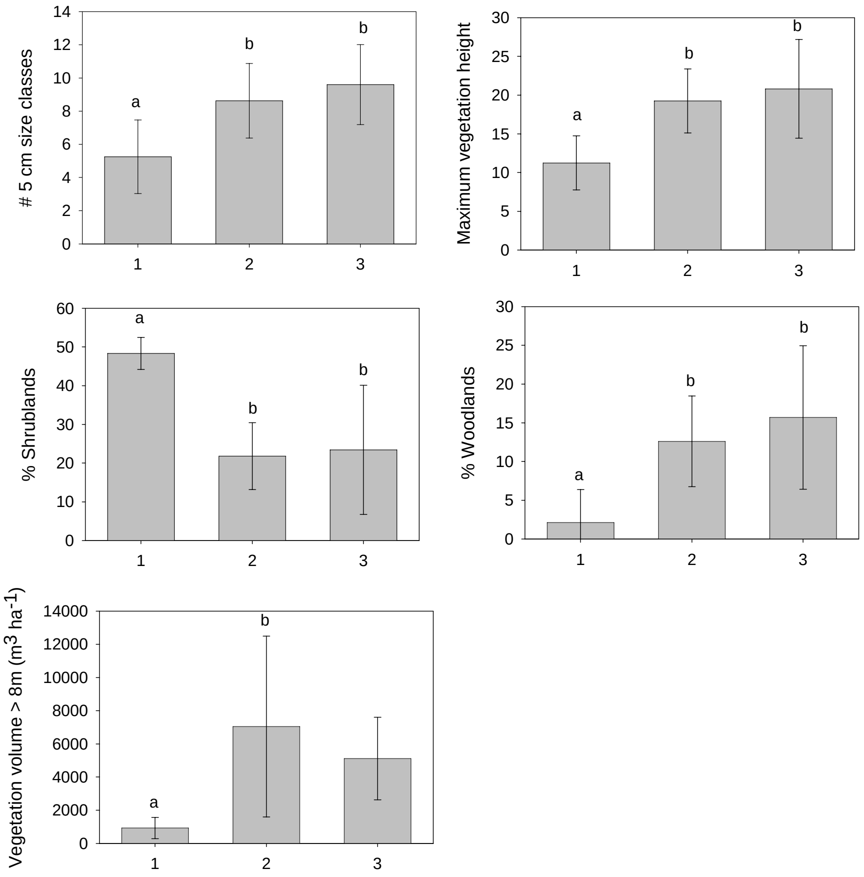
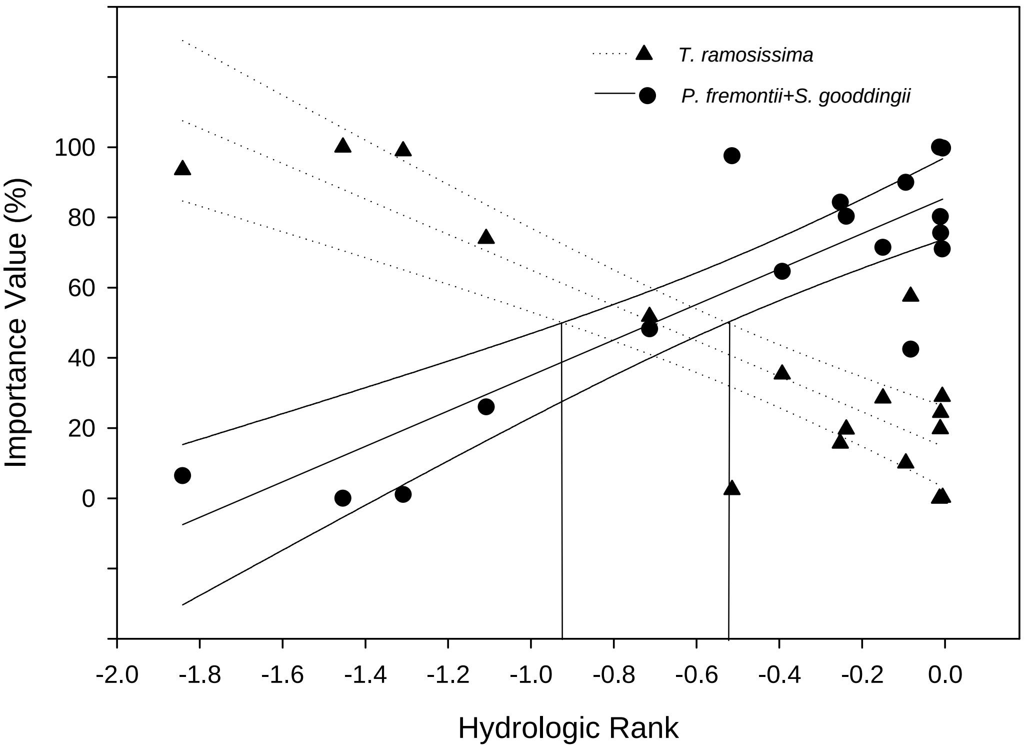


Figure 2. Hydrologic thresholds for the maintenance of *P. fremontii - S. gooddingii* stands along the San Pedro River. *T. ramosissima* IV = 14.5-(50.5*HR), r^2 = 0.75,p<0.001; *P. fremontii* + *S. gooddingii* IV = 85.5+-(50.5*HR), r^2 = 0.75,p<0.001. Thresholds were identified as the hydrologic rank value at which the 95% confidence interval curves intersect. Threshold values for flow frequency, groundwater depth, and groundwater fluctuation were calculated using regression equations with hydrologic rank (FF = 0.9+(0.3*HR), r^2 = 0.57, p<0.001; GD = -2.4+(0.9*HR), r^2 = 0.23, p = 0.03; GF = -0.4+(0.3*HR), r^2 = 0.43, p<0.001).



Flow frequency, groundwater depth, and groundwater fluctuation threshold values for associated hydrologic rank values.

HR	-0.92	-0.52
FF (%)	60	73
GD (m)	3.2	2.9
GF (m)	0.69	0.56

Table 2. Hydrologic threshold ranges for the dominance of pioneer tree and shrub species.

	Depth to groundwater (m)	Flow frequency (%)	Groundwater Fluctuation (m yr^{-1})
P. fremontii-S. gooddingii	2.4-2.9	78-73	0.48-0.56
Co-dominant	2-9-3.2	73-60	0.56-0.59
T. ramosissima	3.2-3.8	60-64	0.59-0.75

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Threatened and Endangered Species

Endangered Plant Species in Salt Cedar Habitats

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Plants form the very foundation of all life on earth—all organisms, including humans, rely on plants for the air they breathe and the food they eat. Plants are also the source of new medicines, fuels, fibers, fragrances, and agricultural products that have economic value and contribute to our overall well being. Yet, the plants that are so important to our own health and vitality—and to the health and vitality of the natural world around us—are vanishing at an alarming rate.

Recent estimates indicate that there are 223,000 known species of vascular plants on earth (Scotland and Wortley, 2003). Many plant species are still unknown to us, and new plant species continue to be discovered. As a result, there are widely different estimates of how many of the world's plant species are at risk of extinction. Global estimates place approximately 12.5 percent of the world's plant species at risk of extinction (Walter and Gillett, 1998). This estimate includes species in more than 350 families in 200 countries.

The United States is home to approximately 20,000 species of native plants (USDOI, Office of Surface Mining, 2003). Estimates place as few as 10 percent to as many as 29 percent of these species at risk of extinction (Center for Plant Conservation, 2002; Walter and Gillett, 1998). Compounding the problem is the fact that approximately 90 percent of these at-risk species are endemic to, or grow only in, the United States.

Texas is one of the most biologically diverse states in the country, with more than 5,000 plant species (Correll and Johnston, 1970). It ranks sixth in the nation in terms of the number of endangered species living within its borders, with 103 plant and animal species listed as threatened or endangered (TPWD, 2002), protected under the Endangered Species Act (U.S. Fish & Wildlife Service, 1998). Twenty-seven of these endangered species are plants. As in other parts of the country and the world, endangered plants in Texas continue to decline despite protection under the Endangered Species Act (Environmental Defense Fund, 1998). Of critical importance, however, is the fact that almost all of the plants on the endangered list in Texas occur nowhere else in the world. If they disappear from Texas, they will disappear from the earth.

In 1988, Texas was named by the Center for Plant Conservation (CPC) as one of five regions of the country that is a conservation priority. To date, the Texas Office of the U.S. Fish and Wildlife Service has developed recovery plans for all 27 plants on the Endangered Species List. Another 8-11 plant species have been identified as candidates for the Endangered Species List, and approximately 178 native plants are being evaluated for their threat potential (Poole, et. al., 2002). Implementation of the recovery plans has progressed on a steady schedule as time, staffing and funding have allowed.

A number of factors contribute to our flora's precarious situation. Urban development and road construction, agriculture and ranching, and habitat fragmentation and pollution contribute daily to the loss of habitat necessary to sustain our native plant communities. The introduction of aggressive, nonnative species which compete for, and take over space, food, water, and other resources native plants would normally use, force native species out of their natural habitat. Irresponsible collection of seed and entire by plants from the wild by gardeners, collectors, and retail companies adds to the decimation of entire plant populations.

Of the 27 federally listed plant species in Texas, two occur in saltcedar habitat: *Callirhoë scabriuscula* (Texas poppy mallow) and *Helianthus paradoxus* (Pecos or puzzle sunflower).

Dr. Sutton Hayes first collected Callirhoë scabriuscula on the Colorado River in the late 1800's (Dorr, 1994; USFWS, 1981). A member of the mallow family (Malvaceae), *C. scabriuscula* is a short-lived perennial, which can grow up to four feet tall. Blooming from late April to June, the flowers are produced in terminal racemes. The corolla is comprised of five, dark maroon petals which form a partially open cup with a darker maroon spot at the base. The reddish-purple anthers develop first followed by the red or pink stigmas (Amos, 2002). The above ground parts die back following seed dispersal. Basal rosettes appear in late August.

C. scabriuscula has been documented in Texas from ten small populations found in Coke, Mitchell, and Runnell counties (TPWD, 2002) (Figure 1). The US Fish and Wildlife Service listed it as endangered in January 1981 (USFWS, 1981).

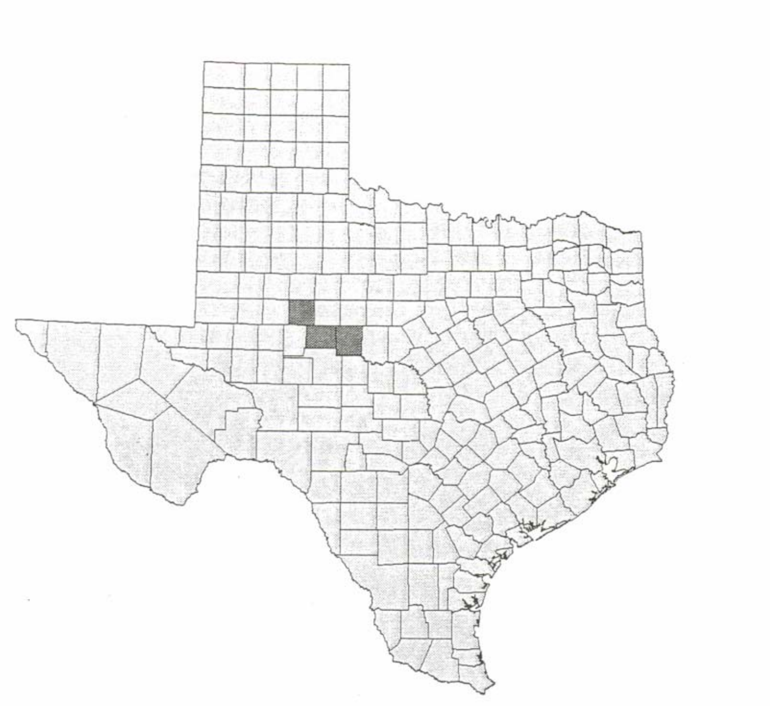

Figure 1. Counties with documented populations of *Callirhoë scabriuscula. Map courtesy of Texas Parks and Wildlife Department.*

C. scabriuscula is found growing in grasslands and open oak or mesquite woodlands of Colorado River terraces. Soils are mostly the deep loose sands of the Tivoli Series. Associated species include *Aphanostephus skirrhobasis*, *Cnidoscolus texanus*, *Oenothera engelmannii*, *Chloris cucullata*, *Phlox drummondii*, and *Mirabilis albida*.

Threats to *C. scabriuscula* include its restricted habitat and habitat loss due to farming, pasture planting, sand mining, and urban development. Because it is such an attractive species, over collection in the wild also contributes to its decline (TPWD, 2002).

Helianthus paradoxus is a member of the Asteraceae or Sunflower Family and one of three species known to be the result of hybridization between *H. annuus* and *H. petiolaris* (Welch, 2003). It is an annual that blooms August through November, producing three-50 flower heads per stem. Each flower head consists of yellow ray flowers and red-purple disk flowers.

Known from only three sites in Pecos and Reeves counties (Figure 2), *H. paradoxus* is federally listed as threatened throughout its range (USFWS, 1999). Threats include loss and and/or alteration of habitat through lowering of the water table for agriculture, ranching, and urban water use, overgrazing, mowing, highway maintenance, and competition from nonnative invasive plant species, including saltcedar (USFWS, 1999).

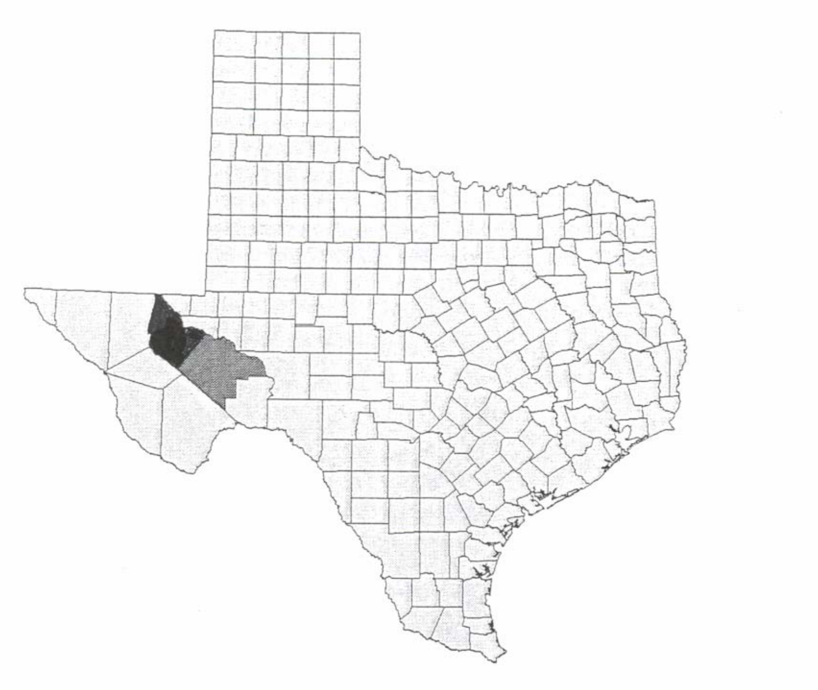

Figure 2. Counties with documented populations of *Helianthus paradoxus*. *Map courtesy of Texas Parks and Wildlife Department.*

H. paradoxus is restricted to the brackish waters and saline, calcareous soils around cienegas and other desert wetlands. Associated species include *Scirpus olneyi* (in wetter sites), *Sporobolus airoides* (in drier sites), *Distichlis spicata*, *Flaveria chlorifolia*, *Limonium limbatum*, and *Samolus ebracteatus*.

Because plants are such an integral part of the biological web of life, it is impossible to know the full ramifications of the loss of even one plant species. The loss of even a single plant species translates to the potential loss of genetic material for new medicines, and the sources of new foods, fibers, fuels and fragrances. Thus, it is critical that we not only save plants that are endangered, but also that we ensure the long-term survival of all native plant species and plant communities.

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PECOS PUPFISH: ONE PIECE OF THE PUZZLE

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Immersion in the details of assembling the animal collection and facilities of a new zoo exhibit - even one whose stated purpose is to spotlight partnerships for conservation – can allow one to be caught unawares by the amazing way that natural systems organize themselves. This was the Fort Worth Zoo team's experience as it prepared to exhibit Pecos pupfish *(Cyprinodon pecosensis)* in Texas Wild! that opened in 2001.

The zoo chose this pupfish species as an icon for west Texas conservation for several reasons. In Texas it is now found only in the Salt Creek tributary of the Pecos River. Historically facing habitat shrinkage during drought years, the pupfish now contends with hybridization from a related, introduced fish species the sheepshead minnow *(Cyprinodon variegatus)* and with habitat destruction caused by saltcedar's *(Tamarix ramosissimus)* alteration of the Pecos River drainage. So, the Pecos pupfish serves to carry the message to zoo visitors that whatever happens to wildlife ultimately happens to humans. In addition, by working with the Texas Parks and Wildlife Department (TPWD) and the US Fish and Wildlife Service (USFWS) to manage captive populations of pupfish it has successfully been kept off the endangered species list. Finally, and most to the point of this presentation, the zoo found itself in the ideal position of plugging into an existing conservation consortium.

In 1999, the Fort Worth Zoo knew it wanted to exhibit Pecos pupfish primarily as an educational species. Zoo aquarium curator Armin Karbach made contact with Dr. Gary Garrett of Texas Parks and Wildlife's HOH Research Station because he is TPWD's lead biologist on desert fishes. Karbach knew that the Pecos pupfish is listed as threatened in Texas and was being considered for federal listing as an endangered species. Texas Parks and Wildlife informed the zoo that a project was in the works to avoid listing by the US Fish and Wildlife service, in part by establishing several captive refugium populations. Further, they invited the Fort Worth Zoo to participate as one of the captive management sites; and the zoo readily accepted.

In June, 2000, Armin Karbach, Tarren Wagener, Fort Worth Zoo's Director of Conservation Science, and Stacey Johnson, Curator of Texas Wild! traveled to Pecos, Texas to collect the fish. Under the supervision of Dr. Garrett and Nathan Allan of the US Fish and Wildlife Service, approximately 800 fish were collected and divided between the Fort Worth Zoo and Bart Reid, a private shrimp farmer and project participant from the area. It was noted at the time that a drought was underway and both Garrett and Allan expressed concern that surface water was unusually scarce.

The Pecos pupfish is an opportunistic feeder, consuming nearly any available biological material in its habitat. It tolerates a very wide range of environmental conditions and has the reputation for thriving under conditions few other fish can tolerate. The pupfish collected for the zoo came from what appeared to be a shallow pool in an otherwise dry creek bed. However, subsequent visits to the site confirmed that the creek continues to flow as ground water even when none appears on the surface. Water quality parameters were measured from the collection site and they are recorded in the following table.

Parameter	Collection site	365 meters upstream
pH	8.1	8.3
Salinity (parts per thousand)	43.4	46.4
Temperature (ºC)	20.4	23.3

Moving surface water existed approximately 365 meters upstream, and the same measurements were taken there. It should be noted that seawater has a salinity of about 30 ppt (parts per thousand). The only other fish species seined from the site at that time were fewer than twenty plains killifish *(Fundulus zebrinus)*. As of this writing, the Fort Worth Zoo has maintained Pecos pupfish for three years, producing several generations of offspring. Continually refining the husbandry procedures, zookeepers have found that the species does best in a salinity of approximately 17 ppt, a much lower concentration than the 43.4 ppt found at the collection site.

In addition to serving as a holding institution against the need for wild reintroduction, the Fort Worth Zoo has maintained an active interest in habitat conservation for the species. Zoo staff views the Pecos pupfish as a potential flagship species for conservation of desert river ecosystems because the Texas Wild! exhibit emphasizes active participation in land management and conservation. To hold pupfish as a contingency for unforeseen events that might risk the species' survival is a privilege, but even as the animal managers returned from the collecting trip they discussed next steps to implement some kind of habitat restoration.

Two conditions appeared to be the biggest challenges to Pecos pupfish long-term survival: The first, and most difficult to manage is the introgressive hybridization with the sheepshead minnow, a closely-related species from the southeastern United States that seems to have been accidentally introduced to the Pecos River system in the 1980s by sport fishermen using them as bait. Rapid crossbreeding has limited pure Pecos pupfish to the Salt Creek drainage of the Pecos River in just twenty years. Hybrid pupfish are even found in the creek more than a mile upstream from the Pecos itself. The physical barrier of steep, permanent waterfalls has thus far safeguarded the remaining native fish. A similar situation exists for two known populations in New Mexico.

The second challenge, then, was to halt the degradation of the remaining habitat in Salt Creek. As mentioned previously, the state and federal biologists observed that the seasonal dry-out seemed earlier and more complete than usual, and they were concerned that the streams and seasonal wetlands could disappear completely. This would place the pupfish in grave danger of extinction in Texas. At first, discussion by zoo staff focused on protecting a small, selected wetland, or *ciénega*, via fencing it from free-range cattle, removal of introduced plants and installing a windmill. When informally proposed to TPWD, Dr. Garrett suggested that a windmill could produce unpredictable results given the already depleted ground water. However, he recommended making contact with the Natural Resource Conservation Service (NRCS) in Pecos to seek inclusion of this stream in an ongoing saltcedar eradication effort. Having been introduced as an ornamental tree and erosion control effort in the 1800s, saltcedar has impacted the entire riverbank ecosystem along the Pecos as well as consuming an enormous amount of water. This was the Fort Worth Zoo's introduction to the Pecos River Ecosystem Restoration Project.

In July, 2000, the District Conservation Officer for NRCS, Barney Lee, was enthusiastic about the zoo's participation but reported that the project's herbicide, *Arsenal*®, had a label restriction specifically prohibiting its use on Salt Creek in order to **protect** the Pecos pupfish from potential overspray. After consulting with biologists and chemists, the decision was made to request a waiver or outright removal of the restriction because the potential benefits of eliminating saltcedar outweighed the risks to the fish.

The Environmental Protection Agency's restriction on use of *Arsenal*® at Salt Creek was instituted at the request of the Texas Parks and Wildlife Department. Both Gary Garrett and Nathan Allan began exploring the necessary steps to request its removal at their respective agencies and with the Texas Department of Agriculture and the EPA. Preliminary indications were that it was possible, but unlikely before the September spraying dates. In a concerted effort between Dr. Garrett and the Fort Worth Zoo, the request to reverse the ban was shepherded through the approval process and, as a result, the herbicide was applied to Salt Creek in September 2000.

The zoo also signed on as a participant in the Pecos River Ecosystem Restoration Project and contributed funds toward the purchase of herbicide for use on Salt Creek. The contribution was matched by American Cyanimid/BASF with an equal amount of *Arsenal*® and North Star Helicopters' donation of air time to apply it. On Salt Creek, what had been planned as a twenty-acre application at one location became the eradication of saltcedar from the fish collection site downstream more than a mile.

Fort Worth Zoo animal staff from Texas Wild! have visited the site four times since September 2000. On foot, they have explored a large length of the draw from which pupfish were collected as well as a stretch of Salt Creek upwards from Red Bluff Dam. Although the upper portions of the draw dry out almost completely in the late summer and fall, water appears more plentiful during the spring of the year. Pupfish are apparent and plentiful in most locations, and have been observed each spring in areas that were completely dry the previous fall. The *ciénega* near the fish collection location had a large number of saltcedar trees encroaching on it before herbicide application, and the stream entering the stand of trees did not exit it. However, since application surface water again appears more plentiful and when flowing does continue on into the main draw. On the next visit, water quality conditions will be measured again for comparison to the original values taken while saltcedar thrived in the area.

Now that the immediate threat of catastrophic habitat loss has been pushed back, the zoo plans to pursue the objective of working with the landowners to protect additional patches of viable habitat and then connecting them. The longer-term challenge of reversing the trend toward hybridization downstream promises to be a more complex issue.

What began from the zoo's perspective as a small individual effort to work with a single species has been extremely rewarding. Rather than an attempt to begin a conservation effort, the Fort

Worth Zoo found a far-reaching and inclusive program already in place. Contributing its own specialized resources to the combination of public agencies, private companies and dedicated individuals the zoo realized its own aims and was able to add a bit of momentum to the project as a whole.

The Fort Worth Zoo could not be more pleased with the initial steps in Pecos pupfish conservation. The zoo has developed an exhibit to highlight a conservation story with direct implications for humans and wildlife. The species itself has, for now, been kept off the Endangered Species List. This is good for the fish and good for the landowners whose control over water rights and land management will not be impacted by federal regulation. Finally, and perhaps most important, the zoo joined in partnership with a diverse consortium of public and private interests whose goal of general ecosystem conservation can be a model for the future.

INSECTS ASSOCIATED WITH SALTCEDAR, BACCHARIS AND WILLOW IN WEST TEXAS AND THEIR VALUE AS FOOD FOR INSECTIVOROUS BIRDS: PRELIMINARY RESULTS

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Introduction

Saltcedars (*Tamarix* spp.) have become a dominant vegetation along many of the streams rivers and lakes in west and central Texas. While water use by extensive stands of saltcedar is a major concern, the replacement of native vegetation by saltcedar may also impact wildlife species dependent on native riparian habitats. The suitability of saltcedar as a nesting site and habitat for the endangered southwestern willow flycatcher, *Empidonax trailii extimus,* relative to its native nesting sites in willow and cottonwood, has been an important issue in developing a recovery plan and determining the role of biological control within the range of this endangered species. While the western willow flycatcher is not known from Texas, the wildlife value of saltcedar for other birds is of interest in Texas, especially when large expanses of saltcedar are killed by aerial application of herbicide or, possibly in the future, defoliated or killed by exotic insects released for the biological control of saltcedar (Milbrath et al. 2003, this symposium). While there are many biotic and abiotic characteristics important to habitat selection by birds, including suitability of nesting sites, shade, distance to water, etc, we chose to focus on the insect abundance and diversity in the saltcedar canopy relative to that in willow, *Salix interior*, and *Baccharis salicina.* Suitable prey and its abundance is important to insectivorous birds for feeding young and providing energy during spring and fall migration. Both willow and *Baccharis* spp. (seep-willow) are common along rivers and streams, irrigation and drainage canals and on flood plains in west Texas, and are found growing with saltcedar (Boldt 1989). Both willow and *B. salicina* are native plants, although *B. salicifolia*, also a native, is a undesirable phreatophyte and where it occurs in large stands it can compete for limited water resources (Boldt 1989).

We compared the abundance, biomass and diversity of insects and spiders associated with these three vegetation types once during the spring and once during the fall along three major river systems in west Texas. This report provides a preliminary analysis of the first year of what is anticipated to be a three year study. As programs expand in Texas to control saltcedar through chemical and biological control tactics, results of this study should help anticipate effects of removing large stands of saltcedar on the associated insect fauna and the insectivorous birds in the riparian habitats of west Texas.

Methods

This report summarizes the insects and spiders associated with saltcedar, willow and *Baccharis* from collections taken during the spring and fall at two sites in West Texas in 2002 and a third site in 2003. Study sites were: 1) Canadian River at Lake Meredith, Lake Meredith National Recreation Area, north of Amarillo, TX, 2) Lake Thomas, Upper Colorado River, near Big Springs, TX and 3) Rio Grande River, near Candelaria, TX. These three study sites were selected because they represent three major river systems in Texas impacted by saltcedar, the Canadian, Colorado and the Rio Grande, and provide a north/south transect of riparian systems in west Texas. Also, these sites are along the central flyway, a major route for birds migrating between the US, Mexico, and Central America (Shackelford 2002 et al.).

At each site, monotypic stands of each of the three vegetation types were sampled to avoid movement of insects between vegetation types that would likely be more common in mixed stands. Four plots, approximately 15-20 meters square, were sampled within each vegetation type. Sampling consisted of cutting an 18 inch length of terminal branch with pruners and immediately beating the branch terminal inside a white, five gallon plastic bucket. The bottom of the bucket had been replaced with a large plastic funnel. Insects and spiders dislodged from beating the branch were funneled into a plastic jar fitted to the base of the funnel. Thirty stems were sampled from a site and the captured insects were killed and preserved by the addition of 80% ethanol to the collection jar. Five sites were sampled per plot for a total of 600 stems per vegetation type on each sample date. Insects and spiders were sorted and identified to order, family and, in most cases to species. The abundance of these taxa was determined and arthropod diversity was calculated using Menhinicks' diversity index (Magurran 1988). Biomass was determined by drying a subsample of each taxon in an oven at 75 Celsius for 48 hours and weighing the dried specimens with an electronic balance.

Sites were sampled once in the spring, to correspond with the spring migration and nesting season, and once in the fall to correspond with the fall migration. During 2002, the site at Lake Meredith was sampled on June 25 and September 11 while the site at Lake Thomas was sampled on May 8 and September 18. The site on the Rio Grande River was first sampled on March 26, 2003. For this paper, only the data collected in the spring at each site is presented.

Insect Abundance

Insect abundance, as percent of total specimens collected, is shown for the three vegetation types from samples taken in March, May and June at the sites of Lake Thomas, Rio Grande and Lake Meredith, respectively (Figs. 1-3). The greatest number of specimens was collected on saltcedar at each location. However, the fauna on saltcedar was predominately *Opsius stactogalus*, a leafhopper (Homoptera). This leafhopper was apparently introduced with saltcedar into the US and is one of the few herbivorous insects found on saltcedar (DeLoach 1996). This single species represented 88-94% of the total specimens collected from saltcedar at the three sites.

The relative abundance of different insect taxa on willow and *Baccharis* varied by site. At Lake Meredith, the most northern location, Hymenoptera, primarily ants, were the most abundant insect on both willow and *Baccharis*. Spiders and walking stick insects (Orthoptera) were also common on *Baccharis*. The only caterpillars (Lepidoptera) were found on willow and represented 1% of the total specimens.

At Lake Thomas, Hymenoptera were again the most abundant insect but both ants and wasps were common. A total of 40 different species were recorded from *Baccharis*, and included Coleoptera (beetles), Diptera (flies), Hemiptera (true bugs), Orthoptera (grasshoppers and walking sticks) and Homoptera (leafhoppers). A total of 44 species of insects were identified from willow, and include all of the orders present in *Baccharis*. In addition, caterpillars (Lepidoptera) were more abundant on willow than on Baccharis and none were collected from saltcedar.

At the site on the Rio Grande, a very small Lepidopteran caterpillar (Gelechiidae) was the most abundant species on *Baccharis* and averaged 1.3 larva per stem sample. Hymenoptera collected on *Baccharis* were primarily ants. Spiders were the most abundant group collected on willow, while several species of leafhoppers (Homoptera), beetles (Coleoptera) and ants were also common. These samples were collected in late March and willow and saltcedar had only recently leafed out. Insect populations were probably just beginning to increase, and a later sample date may have provided a large number and diversity of insects.

Insect Diversity

To date, species diversity has been determined only for the collections from Lake Thomas on June, 2002. Due to the very large number of *Opsius* leafhoppers present in saltcedar, the total number of individuals collected from saltcedar was more that ten fold greater than the number collected from *Baccharis* or willow (Table 1). However, willow and *Baccharis* had about twice as many species of insects as did saltcedar and as a result had a higher diversity at both the family and species level (Table 1).

Table 1. Species abundance and diversity among insects and spiders collected from the foliage of *Baccharis*, willow and saltcedar at Lake Thomas, TX. June 25, 2002.*

Vegetation	Total Individuals	Total Species	Diversity-Family	Diversity-Species
Baccharis	449	40	1.038	1.888
Willow	932	44	0.819	1.441
Saltcedar	11,985	22	0.128	0.201

* Menhinicks' diversity index (Magurran 1988).

Insect Biomass

Large insects, such as caterpillars and beetles, contribute more biomass to the diet of birds relative to smaller insects such as fleahoppers and small flies. Biomass of individual insect groups and the abundance of these groups can be used to estimate their contribution to the diet of birds, once the food preference of the birds is known. To date, biomass data have been calculated for the samples collected in June, 2002 at Lake Thomas and are summarized as dry weight (grams) for all specimens by order in Fig. 4.

Willow had the greatest biomass of four of the seven major orders recovered in these samples. Large numbers and the large size of immature and adult leaf beetles, *Chrysomela texana*, were primarily responsible for the large biomass of Coleoptera present on willow. The large biomass of Lepidoptera was a result of caterpillars, primarily Notodontidae and Geometridae. Sawfly larvae (Tenthredinidae), in addition to ants, contributed to the high biomass of Hymenoptera in willow. *Baccharis* hosted the greatest biomass of Orthoptera. The single greatest biomass was found in saltcedar and was due to the great numbers of *Opsius* leafhoppers present exclusively on this host.

Value of Insects and Spiders as Prey for Birds

The value of saltcedar, willow or *Baccharis* as hosts of insect prey for birds will depend not only on the abundance and biomass of the insect fauna, but also the food preferences of the bird species of interest. To illustrate the application of these data, results presented herein are compared to food preferences of the southwestern willow flycatcher as reported by Drost et al. (1998). Working in Arizona and Colorado, these authors identified 11 different insect orders from the stomach contents of southwestern willow flycatchers. The most common orders present in stomach contents were true flies (Diptera), bees and wasps (Hymenoptera) and true bugs (Hemiptera.). These three orders represented 51% of the identifiable remains. Other common prey were leafhoppers (Homoptera), dragonflies and damselflies (Odonata), caterpillars (Lepidoptera) and winged and wingless ants (Hymenoptera). As measured as frequency of occurrence (for all of the birds in the sample, how many of them contained that prey taxon), bees and wasps (flying Hymenoptera), flies (Diptera) and true bugs (Hemiptera) were the most frequent, in that order. The frequency of occurrence for dragonflies (Odonata) and caterpillars (Lepidoptera) ranked higher than they did in total numbers.

Drost et al. (1998) also compared diet of birds occupying sites dominated by willow, saltcedar, or a mixed riparian vegetation. Significant differences in diet were observed between mixed riparian and saltcedar sites for caterpillars (Lepidoptera), which represented 8% of prey items in birds from mixed riparian sites and 3 % from saltcedar sites. This is consistent with our data from Texas showing the absence of caterpillars in saltcedar and their presence in willow and *Baccharis* (Fig. 1-3). These authors also reported significantly more bees and wasps (flying Hymenoptera) from the saltcedar sites (25%) relative to the mixed sites (13%). It will be necessary to further categorize our data into non-flying (ants) and flying (bees and wasps) Hymenoptera to determine how well they correspond to these differences in diet among sites. Overall, these authors concluded that richness of prey taxa as reflected in food samples was lower in saltcedar than in the native habitats in Arizona and Colorado. This conclusion is consistent with our data on insect abundance in saltcedar, native willow and *Baccharis* in the sites sampled in Texas.

These authors also compared the diet composition of eight young birds (nestlings or recently fledged birds) to 30 adult birds in willow and mixed riparian habitats. There was no significant effect of age on diet, but the authors observed that the power of the test was low. Recognizing the absence of statistical difference, a comparison of the two diets (Fig. 5) shows caterpillars (Lepidoptera) and dragonflies (Odonata) were more common in the diet of young birds than adult birds, while the reverse was true for Hymenoptera.

The prey items recorded from these birds in this study varied widely in size and consequently in their contribution to the energy needs of the birds. As biomass estimates for the various taxa identified from stomach contents were not available, Drost et al. (1989) estimated the volume of each identified prey item as a percent of the total volume of material. The ranking and percent volume was: bees and wasps (31%), caterpillars (23%), flies (10%), true bugs (6%) and ants (5%). They concluded that most of the bees, wasps and caterpillars were relatively large, and as they represented a large volume of the diet, presumably were of greater value in the bird's diet.

While saltcedar hosts few, if any caterpillars, it hosts a great number of *Opsius* leafhoppers. While individual leafhoppers are small, the total biomass is great due to their abundance (Fig. 4). Are these insects an important diet of any riparian bird species? Again referring to Drost et al. (1998), leafhopper species (Homopteran) represented 4% of the identified remains in stomach contents of western willow flycatchers from willow and mixed riparian habitats, and 18% in birds from saltcedar sites. Most if not all of the Homopteran in flycatchers from saltcedar were *Opsius*. In general, flycatchers and in particular *Empidonax* species infrequently prey on leafhoppers and other Homopterans, as cited in Drost et al. 1998.

The data on insect abundance reported herein for saltcedar represents samples from foliage only and excludes sampling of saltcedar blooms. Saltcedar blooms were sampled separately when present because saltcedar blooms attract large numbers of pollen and nectar feeding bees, wasps, flies and other insects. Thus, while saltcedar does not host the immature stages of these insects, the blooms attract and concentrate these insects which can then be exploited by flycatchers and other birds. The abundance of bees and wasps at saltcedar blooms probably contributed to the greater abundance of these insects in the stomach contents of willow flycatchers in saltcedar habitats relative to willow (Drost et al. 1998). DeLoach et al. (2002) discusses the abundance of pollen and nectar feeding insects during bloom in saltcedar and the absence of caterpillars on the use of saltcedar by the endangered southwestern willow flycatcher.

The insects feeding on saltcedar in New Mexico have been reported by Liesner (1971) and Watts et al. (1977) and the herbivore community on saltcedar and willow in the Grand Canyon of Arizona was described by Stevens (1985). DeLoach and Tracy (1977) reviewed the arthropods specializing on cottonwood and willow, and Boldt and Robbins (1989) detailed the phytophagous insect fauna of *Baccharis salicifolia* in the southwestern US. Data from our project will add to this data base by comparing insect abundance between saltcedar and native vegetation at the same time and location and at various times of the year. We hope the results on insect abundance, diversity and biomass will better quantify the arthropod communities inhabiting the canopy of these plants. These data coupled with published data on bird diets should provide insight into the relative value of these plants as hosting insect prey important to specific riparian birds.

Acknowledgment

This project was conducted in cooperation with the National Consortium for Biological Control of Saltcedar and with support from a USDA-CSREES grant under the Invasive Species Initiative.

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Figure 1. Insect abundance in three habitat types: Lake Thomas, TX. May 2002.

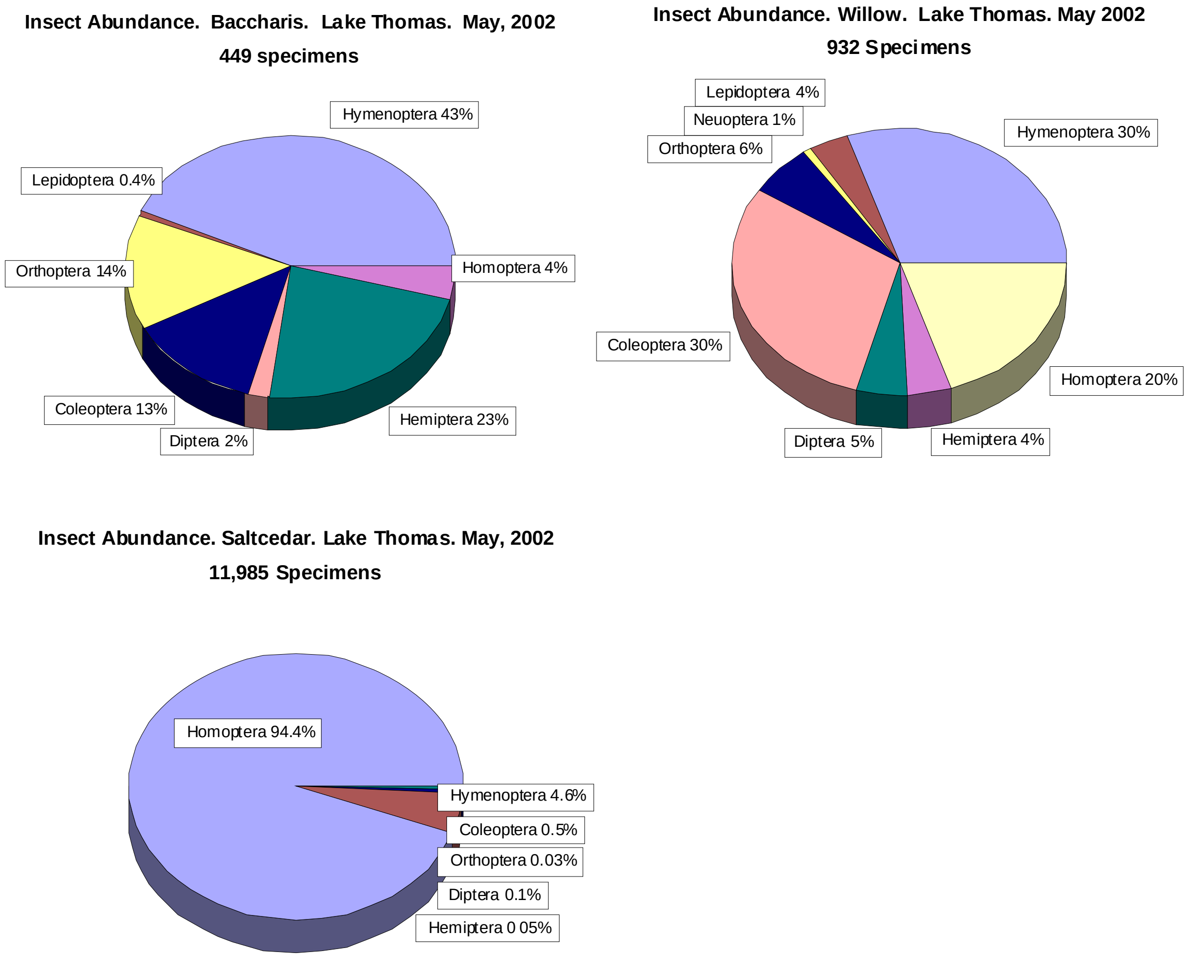
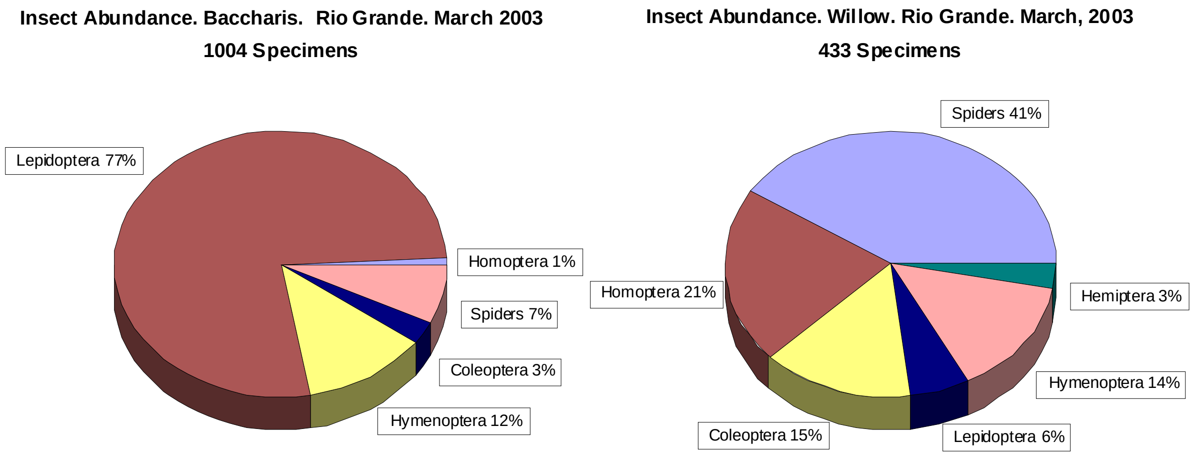


Figure 2. Insect abundance in three habitat types: Rio Grand, TX. March 2003.



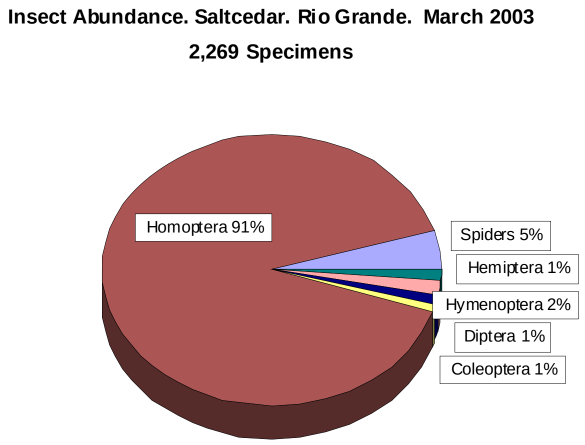


Figure 3. Insect abundance in three habitat types: Lake Meredith, TX. June 2002.

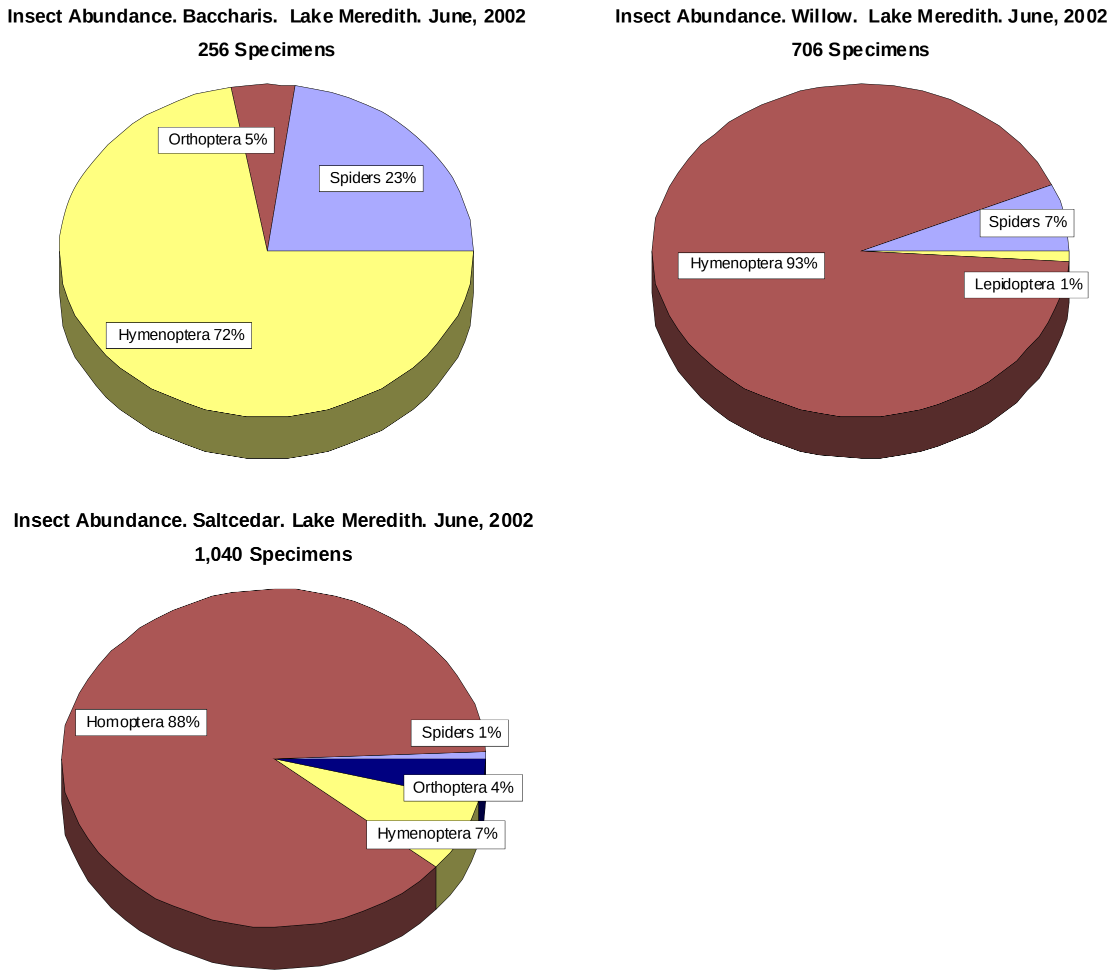


Figure 4. Dry Weight of Total Insects Collected from Three Habitat Types: Lake Thomas, TX, May 2002

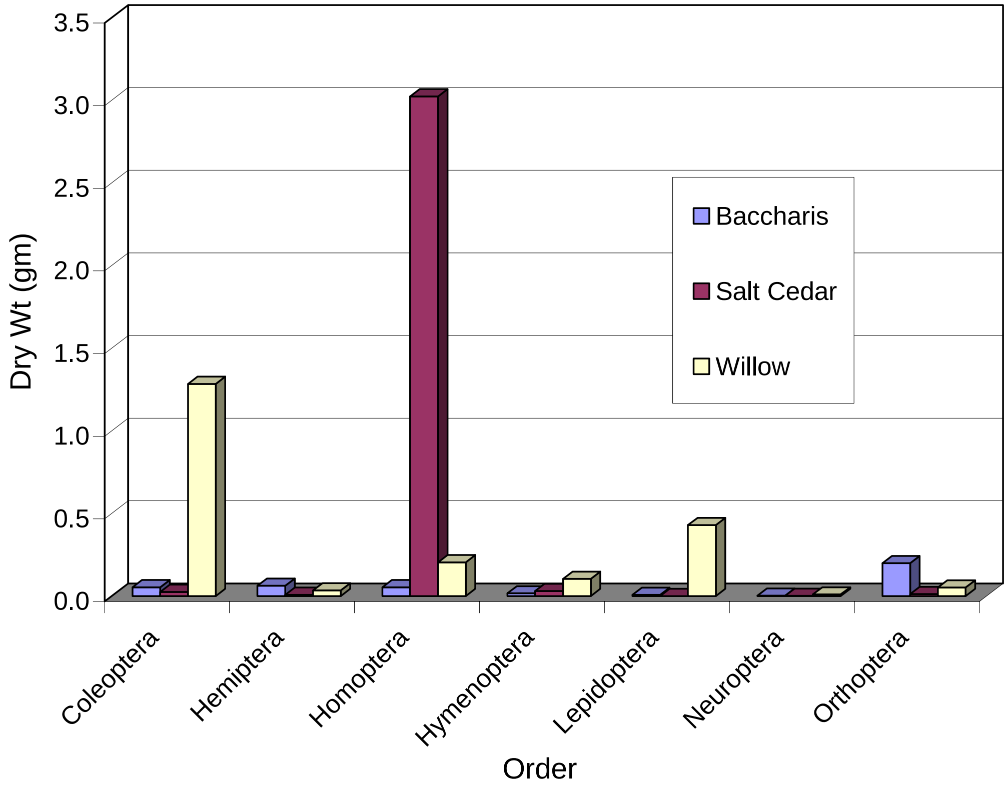
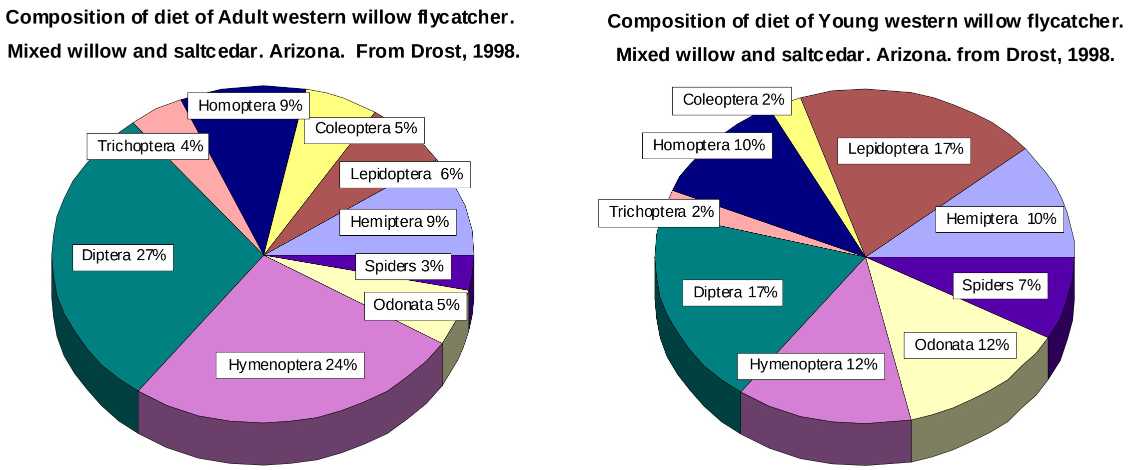


Figure 5. Diet composition of adult and immature Western willow flycatcher. Mixed willow and saltcedar (Drost 1998).



Water Use and Saltcedar

WATER USE BY SALCEDAR AND ASSOCIATED VEGETATION ALONG SELECTED RIVERS IN TEXAS[1]

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Introduction

Saltcedar (*Tamarix spp.*) and associated species are phreatophytes that occur in the flood plains of streams, rivers and lakes in the Southwestern United States and many parts of semi-arid regions of the world. Phreatophytes, unlike terrestrial species, rely heavily if not exclusively on shallow water tables and are not directly dependent on rainfall except for replenishing the shallow groundwater table and for flooding to allow establishment.

Attention has focused on control of saltcedar for the last 40 years to potentially help meet water demand for human use. Saltcedar is also noted for its invasiveness, often to the demise of native riparian species, and for altering the hydrology of streams and rivers. "The combination of high leaf gas exchange rates, growth when water is abundant, drought tolerance and, especially, the maintenance of a viable canopy under dry conditions are characteristics that help explain the ability of *Tamarix* spp. to thrive in riparian ecosystems … subject to large interannual fluctuations in water availability" (Horton, et.al. 2001). Saltcedar is also more tolerant to fluctuations in the water table than *Populus* and *Salix* spp. (Shafroth, et at. 2000).

Until recently, control was marginal and very expensive. With the approved state special use labeling of Arsenal© herbicide for aquatic situations and its effectiveness on saltcedar, effective control is now obtainable. However, the question remains as to where and when control should be applied to best benefit man and the natural riparian ecosystem.

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Numerous studies have reported estimates of water use and evapotranspiration (ET) by saltcedar and associated species. The term evapotranspiration is often used interchangeably with water use by plants; however, it includes evaporation from the soil/water surface and transpiration from plants. Contrary to popular press saltcedar trees do not use “200 gallons of water per day per tree.” Water use depends on many factors that are site specific for each riparian complex system. Evapotranspiration (ET) rates vary based on ground water availability, stand density, weather conditions, soil characteristics and depth to groundwater (Davenport, et al. 1982). Hoddenbach (1987) in reporting “a single large [saltcedar] plant absorbing 200 gallons of water per day” indicated a potential transpiration of “7.2-acre-feet [of] water, depending on water table depth/stages of growth.” ET estimates do not identify the amount of water that will be available following saltcedar control since soil/water evaporation and transpiration from replacement vegetation will still occur. Understanding how various factors can affect water use as well as ecosystem impacts is critical to making proper decisions for specific riparian situations. The literature is inadequate for proper interpretation or modeling of these factors to accurately predict ET, actual water salvage, or ecosystem responses from alternative management regimes. Site specific information is needed to understand differences and extrapolate results to specific situations.

This paper will focus on how various factors affect water use by saltcedar; compare water use estimates for saltcedar; and present results from on-going studies being conducted by the authors in Texas.

Factors Affecting Water Use by Riparian Species

A number of factors affect the amount of water use (ET) by riparian species. Phreatophytes are similar to a series of shallow wells with root systems into the water table. As the phreatophytes “pump” water throughout a diurnal cycle and over the year, the water table directly reflects the amount of withdrawal, inflow, and outflow. When ET exceeds inflow a cone of depression occurs (daytime) and when recharge exceeds ET the cone of depression decreases or disappears (nighttime). Rapid changes in inflow or outflow directly affect the observed diurnal cycle. This diurnal fluctuation has been widely recognized and reported to be primarily due to ET from riparian vegetation in unconfined aquifers (Laczniak, et al., 1999; Maidment, 1993; Tromble, 1977; Troxell, 1936; White, 1932; etc.).

Phreatophytes are known for their high water use compared to terrestrial species. As long as water is readily available there is no need to conserve. However, some species have “drought” adaptations and can survive when water tables are inaccessible or limited. The amount of water utilized from the water table is determined by the length of the growing season, species, leaf area, root distribution, stand characteristics, depth to the water table, salinity of the ground water, specific yield of the saturated soil profile, hydraulic conductivity of the water table soil profile, recharge rate of the water table, distance to a surface water source, PET, and other sources of water (unsaturated soil profile and precipitation percolation). These factors will be discussed in the following sections: ground water recharge, depth to the water table, effects of salinity, vegetation characteristics, and atmospheric conditions.

Ground Water Recharge

Water available for ET from a riparian ecosystem is determined by a water source interacting with site specific geological and hydrological features. The amount of water available over time is a function of the storage capacity of the saturated soil profile, recharge (inflow) and discharge (includes outflow and ET). The elevation of the water table (hence depth to water for vegetation) depends on the distance to and elevation of the water source for recharge, substrate soil texture and stratigraphy, topography of the flood plain, and water transmissivity of the subsurface materials. Stream segments vary considerably at each location within a basin that crosses several geological, topographic, soil, vegetation, climate and man-made situations. In addition, many rivers and streams have been altered by upland and riparian management practices, water withdrawal and discharges, dams and channelization. Many private ownership floodplains have been converted to agricultural uses with further attempts to reduce flooding. Often stream hydrographs show increased intensity and frequency of floods in existing channels and floodplains. Impoundments and regulated releases can have decreased flows resulting in less water recharge to the floodplain/shallow water table. In some cases this decreased flooding has reduced damaging effects on vegetation and allowed establishment of riparian species, such as on the Canadian River near Canadian, Texas (Figure 1).

Riparian vegetation occurs within the floodplain of a stream or lake. Often these streams become incised through vertical cutting until a more resistant geological substrate is encountered, further increasing the depth to the water table and reducing surface flooding of the natural riparian zone. Once the stream is incised, riparian vegetation is often restricted to narrow bands along the channel and oxbows are isolated, such as on the Pecos River near Mentone, Texas (Figure 1). Where the water table is deep and flooding is infrequent, riparian vegetation may be restricted to the immediate channel or only persist as pockets where conditions allowed

Figure 1. Study sites on the Canadian (top), Colorado (middle) and Pecos (bottom) Rivers in Texas where water use is being estimated from monitoring wells with and without control of saltcedar and associated vegetation.

them to establish and develop deep root systems to the water table, such as on the Colorado River above Lake Thomas in Borden County, Texas (Figure 1).

A floodplain is composed of unconsolidated material from the drainage basin through erosion and deposition processes over time. This material is normally “easily eroded, and the stream can adjust its depth, width, length (meandering) and to some extent, slope to satisfy demands of discharge and load" (Fairbridge, 1968) unless restricted by man-made structures or natural events. Progressive erosion and deposition as the channel meanders within its geological boundaries results in various layers of sediment, original subsurface materials, channels and alluvium with riparian vegetation at different stages of establishment and complexity. The various deposits are not continuous and vary considerably with depth and distance from the stream channel(s) and along the length of the stream.

The soil texture of the water table strata directly affects the amount of free water (specific yield) (Figure 2), hydraulic conductivity and rate of flow into, away from or parallel to the water source. Gravels and fine sands allow rapid transport of water along a hydrologic gradient and have the highest amount of free water. More water is available for plants to transpire in a given period of time when recharge rates are high. Conversely, the slower the recharge rate the greater the "cone of depression" below the root zone. This could result in plant water deficits and increased stomatal resistance. Little information is available to characterize the substrata along most stream and river segments, thus extrapolation of results from studies at one location is highly speculative for other stream segments.

Depth to Water Table

Soil characteristics and depth to the water table significantly affect evaporation (Sosebee, 1975). "The depth to which water is depleted from soil through evaporation is about [4 inches] for clay and about [8 inches] for sands…If the soils are saturated and in constant contact with a free water surface…, upward movement of water through the soil is continuous and quite rapid and evaporation rates are quite high". Sosebee citing Veihmeyer (1964) indicated that evaporation can be comparable to the transpiration rate for an irrigated crop. Very shallow water table situations would have high soil/water evaporation and transpiration from grasses and other resultant vegetation following control of saltcedar. The Canadian River near Canadian, Texas is an example where the water table is at the soil surface or within a foot of the surface most of the year; hence, "water savings" from control would be a smaller percentage of original ET than for the Colorado or Pecos River sites (Figure 1).

A shallow water table fluctuates in relation to the recharge from the stream or surrounding landscape and diurnal ET. Phreatophytes are adapted to extend root systems into the capillary fringe and into upper parts of the water table where free water is readily available (Figure 3). White (1932) noted that the fluctuations in groundwater monitoring wells varied in amplitude with the amount of water discharged from the zone of saturation by ET. He also noted that the amount of the daily rise and fall is a function of the texture of the material in the belt of fluctuation, which controls the capacity of the material to give up water under the pull of gravity after being saturated. A change in the water table elevation from one soil profile to another directly affects the specific yield and hydraulic conductivity which would directly affect ET.

Water tables can fluctuate considerably due to seasonal and annual changes in inflows as well as fluvial processes (Shafroth, et. al. 2000) and transpiration by riparian vegetation. Plant roots tend to accumulate near the surface of the water table (figure 3) and can be flooded or stranded by rapid fluctuations. A water table decline of 3.6 feet from the previous year level of 2.8 feet resulted in 92-100% mortality of *Populus* and *Salix* saplings, whereas, 0-13% of *Tamarix* stems died (Shafroth, et. al. 2000). Riparian plant survival depends on the “magnitude of groundwater decline relative to the pre-decline distribution of roots, rate of decline, duration of decline, ability of the plant to grow new roots to adjust water demand (e.g., via physiological and morphological adaptations), plant age and size, transpirational demand, and importance of other sources of water (e.g., precipitation) to the overall plant water supply” (Shafroth, et al. 2000). “Plant response is likely mediated by other factors such as soil texture and stratigraphy,

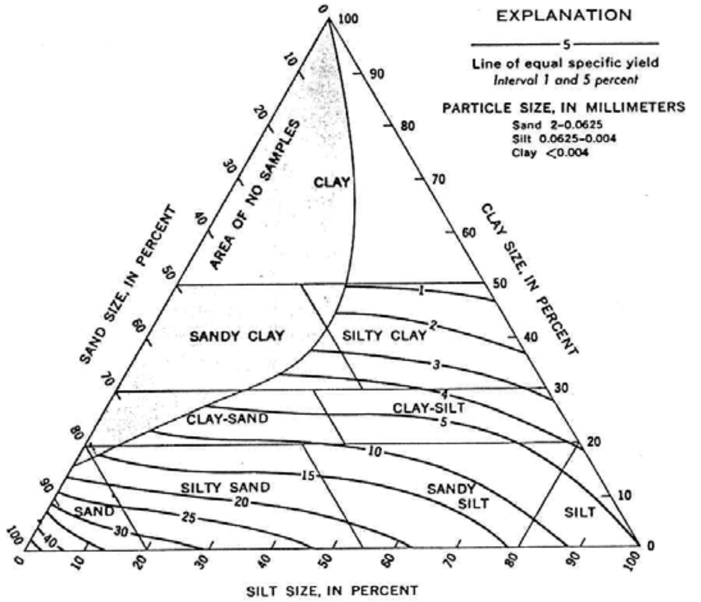

Figure 2. Soil classification triangle showing relation between particle size and specific yield (Johnson, 1967).

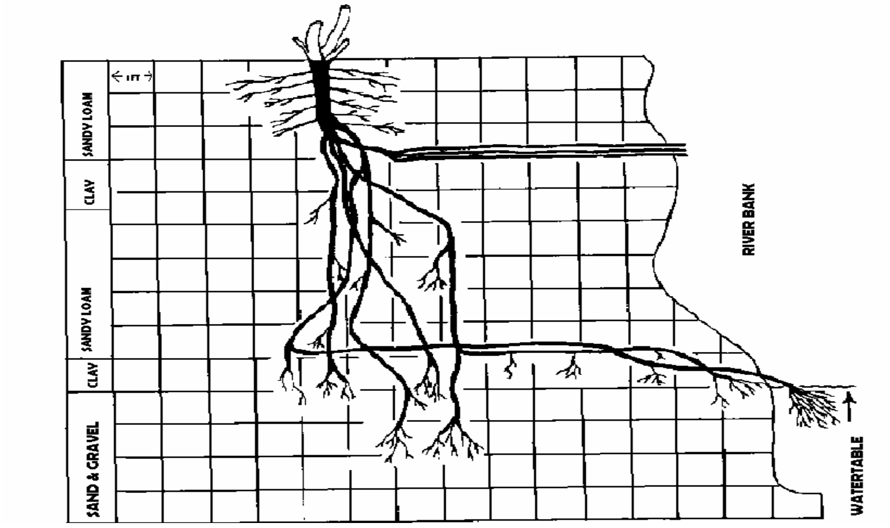

Figure 3. Root systems of saltcedar extend to the water table, capillary fringe and the water source when close to a stream channel (Gary, 1963).

availability of precipitation-derived soil moisture, physiological and morphological adaptations to water stress, and tree age." Gary (1963) found saltcedar roots could adapt themselves to favorable soil moisture conditions. Where the water table was deep, saltcedar produced long taproots and the branch roots were vertical in nature. The branch roots occupied the areas immediately above the groundwater table. When the water table was high, saltcedar developed a taproot and secondary roots that occupied all zones of the soil profile above the water table. Busch, et al. (1992) found that saltcedar not only gets water from the water table but is capable of getting it from unsaturated alluvial soils. This evidently gives saltcedar a competitive advantage over some native phreatophytes that are not able to survive when water levels are low or non-existent.

The distance from the water source and depth to the water table directly affect water use. Devitt, et al. (1997) found that sapflow decreased in saltcedar as the water table and soil water declined (lysimeters placed at desert edge, river edge and open stand). "Daily sapflow totals… [leaf area basis] were higher for the plants growing along the river's edge, with midday hourly values significantly higher when a water table was present." As the water table dropped, sapflow decreased at the river's edge and open stand. Water use by a dense saltcedar thicket in Arizona varied from 7.43 ft/yr with a depth to the water table of 4.9 ft and to 2.8 ft/yr with a depth to the water table of 8.8 ft (van Hylckama 1970). He concluded that saltcedar may thrive with a lower water table but water use will be considerably lower. Thus, considerable differences in water use by individual plants can occur across the riparian zone. The water table along a river decreases in elevation with distance from the river (increasing depth from the soil surface) unless water is moving from the landscape into the stream (Figure 4).

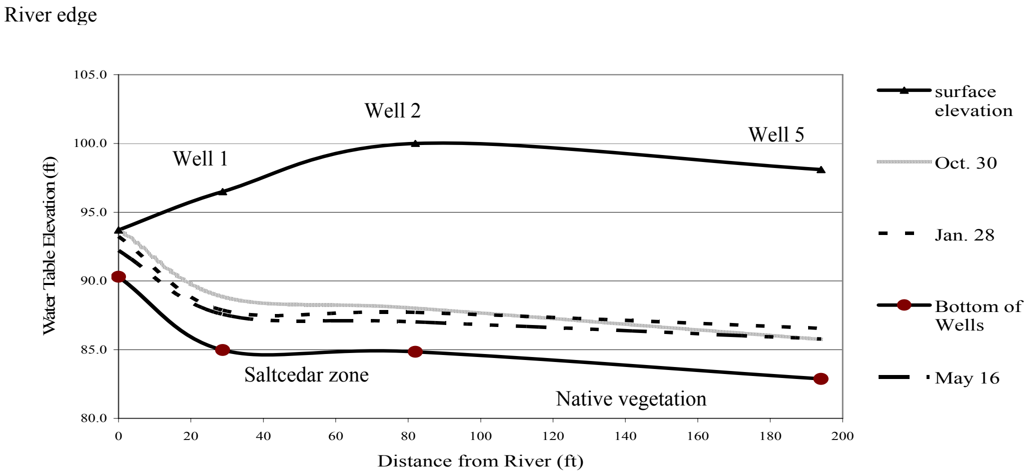

Figure 4. Water elevation in wells located on the Pecos River, site A during 2002.

Numerous researchers (Anderson, 1982; Laczniak, et al.,1999; van Hylckama, 1974; Tromble, 1977; Sala, et al. 1996; King and Bawazir, 2000; White, 1932; and others) have noted the diurnal trends in shallow groundwater levels. Most of these authors have attributed this fluctuation primarily to local evapotranspiration. Tromble (1977) concluded that "the change in static head [in transpiration wells] over a day is attributed to ET from vegetation surrounding the well." Laczniak, et al. (1999) also noted that the "magnitude and timing of the fluctuation differs with well depth, vegetation and soil conditions, climate, and distance from a surface water source." Tromble (1977) explained the hydrograph (Figure 5): "at the lowest point (A) on the curve, the inflow and outflow of water are about the same; both high, and at the highest point on the curve (B) recharge and transpiration are at a minimum. When outflow is greater than inflow (D) transpiration is high and when inflow is greater than outflow (C) transpiration rates are lower for the day. The recharge stopped at point (B) because the water level had reached the static head. The nighttime peak (B) and the daytime low (A) decrease over time due to water loss from evapotranspiration from the shallow water table or flow from the system."

Effects of Salinity

As a soil becomes progressively saline it becomes more difficult for a plant to extract water from the soil/water profile. This is caused by lower osmotic potential that increases the solution entropy and forms associations between water molecules and the solute. This creates water stress in plants as solute content of the soil/groundwater increases and the ability of the roots to take up water decreases. Saltcedar utilizes active uptake of salts to increase ability to absorb water from saline situations and exudes salt that is observed on their leaves to reduce toxicity.

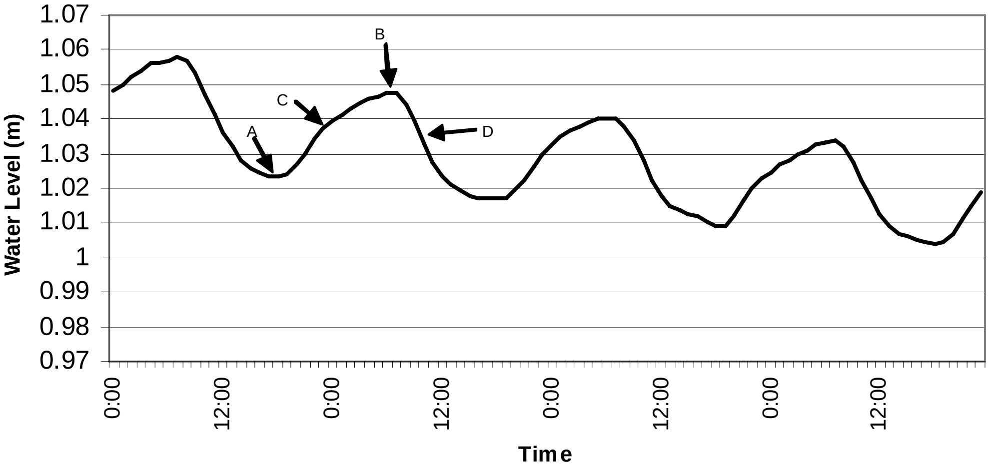

Figure. 5. Diurnal fluctuations of groundwater table with inflection points (Tromble, 1977).

There have been several studies on the effects of salinity on saltcedar's growth and water use. Kleinkopf and Wallace (1974) reported that as levels of NaCl increased from 640-12800 ppm that rates of transpiration did not change significantly. Van Hylckama (1970) reported that after flushing tanks back to original levels of salinity the flushed system saltcedar used 90 inches of water compared to the non-flushed system, which used 45 inches of water. Cumulative water use averaged 118 inches/yr (6400 ppm at 77°F) compared to 20 inches/yr (25600 ppm at 77°F). Vandersale (2001) also showed a decrease in transpiration with increasing salinity levels from 500 ppm to 4000 ppm. Carman and Brotherson (1982) found that saltcedar occurred on sites with soluble salt concentrations ranging from 700-15000 ppm and Russian olive occurred on sites with soluble salt concentrations ranging from 100-3500 ppm.

Saltcedar has shown resistance to salinity changes in excess of 19200 ppm, while other woody shrubs (i.e., *Salix*) succumbed to the change (Smith, et al. 1998). Tomanek and Ziegler (1962) found that transplanted saltcedar seedlings can withstand salt contents up to 4000 ppm but at 2500 ppm the seedlings are stressed. Busch and Smith (1995) found that saltcedar was likely to be tolerant to a relatively high degree of salinity and water stress and these adaptations benefited the plant in these environments.

Vegetation / Stand Characteristics

Carman and Brotherson (1982) found that the highest stand densities of saltcedar occurred where water tables were close to the surface. "Consumptive use of water by dense stands of vegetation …is not necessarily directly proportional to the density of the stand. [ET] from within dense stands of vegetation is often much less than that on the periphery of the stand" (Sosebee, 1975). Davenport, et al. (1982) found that evapotranspiration by saltcedar plants ranged from 0.09 inches/day for a sparse stand to almost 0.62 inches/day for a dense stand. Sala, et al. (1996) found the key factors controlling water use by *Tamarix ramosissima, Pluchea sericea, Prosopis pubescens, and Salix exigua,* under moderate to high water tables included leaf area index (LAI) and stand density. They concluded that feedback mechanisms could reduce transpiration rates:

> under ample water availability, transpiration rates of *Tamarix ramosissima* measured on either leaf-area or dry-mass bases were no greater than those of sympatric native phreatophytes. Dense *Tamarix* stands can lose very high amounts of water under high evaporative demands, and this water loss tends to increase as individual leaf area increases. Such high rates of water loss in dense *Tamarix* stands may trigger feedback mechanisms due to the creation of a surface boundary layer that decreases vapor pressure deficit at the leaf level, resulting in reduced peak transpiration rates. However, strong advective conditions combined with high LAI would tend to compensate for this boundary layer effect, resulting in stand ET rates that can be almost twice as high as PET during certain times of the year.

Saltcedar is a deciduous warm season plant. It leafs out in late spring and drops leaves in the fall following frost. The length of the growing season directly affects the total water use for the year and differs between years. Water use changes as the plant foliage progresses from young to mature to senescence. Van Hylckama (1970) found that when 50% of the transpiring surface of saltcedar was removed there was only a 10% to 15% decrease in the amount of water used. White (1932) observed that groundwater fluctuations in monitoring wells occurred with leaf emergence and ceased when freezes caused defoliation. King and Bawazir (2000) observed saltcedar budbreak in New Mexico beginning about April 5, 1999 and by April 17 budbreak was >50% for the trees. Senescence of leaves started from about late September and by November 1 was >50%, complete senescence was obvious by November 21.

The ecophysiological attributes (functional traits) of cottonwoods (*Populus* sp.), willows (*Salix* sp.), mesquite (*Prosopis* sp.), and saltcedar are different (Smith, et al. 1998). Saltcedar is highly tolerant to water and salinity stress and has higher water use efficiency than cottonwoods, willows and mesquite. The peak transpiration rates (on a leaf area basis) for saltcedar and mesquite are moderate while cottonwoods and willows are high. However, on a stand basis saltcedar has the highest peak transpiration rate.

Atmospheric Conditions

ET should be directly related to the evaporative capacity of the atmosphere as the primary driving force; however, other factors alter soil/plant/water responses to atmospheric conditions. ET is complex "because the rate of water vapor loss depends on the amount of solar radiation reaching the surface, the amount of wind, the aperture of the stomates, the soil water content, the soil type, and the type of plant" (Ward and Elliot, 1995).

The majority of ET takes place during the daytime and during the growing season. King and Bawazir (2000) showed a dense stand of saltcedar used 4.35 ft/yr and 3.91 ft during the growing season. Seasonal atmospheric conditions affect the amount of water use. Anderson (1977) stated that "exchange of water vapor between the plant canopy and the atmosphere depends upon air and leaf temperatures, atmospheric humidity, aerodynamic or boundary layer resistance, and leaf diffusion (stomatal) resistance." He found that saltcedar stomatal resistance increased as leaf temperatures increased between 57^0F and 122^0F. Under full sunlight at 86^0F and 45 % relative humidity, he found that saltcedar twigs transpire a mass of water greater than their own fresh mass each hour. Van Hylckama (1969) discovered that saltcedar was temperature sensitive and it reduced water use on hot afternoons.

An oasis effect occurs when plants grow in situations where the surrounding landscape/vegetation/atmosphere increases the riparian water use due to higher advective energy than found in a forest/stand situation. Van Hylckama (1974) considered this a problem when using individual plant lysimeters (wells) to monitor water use for extrapolation to large stands. Dugas and Bland (1989) reported that a 44% increase in latent heat flux occurred for soybeans when the bordering soil surface was dry vs. when it was wet. Dugas, et al. (1991) considered this edge effect the result of energy advected from bordering dry conditions. Most riparian situations in the arid southwestern U.S. occur as narrow bands or pockets of riparian vegetation surrounded by dry desert which would increase water use. Large stands of riparian vegetation are often associated with Federal / State ownership or the floodplain of a lake. Along rivers in Texas, most floodplains are privately owned and have been converted to agricultural production with narrow bands of riparian vegetation existing along the stream/river channel.

Estimated Water Use for Saltcedar and Other Riparian Species

The estimated water use by saltcedar varies depending on method of measurement, location of study and other factors (Table 1). Anderson (1977) stated "It is clear that the plants are not just wicks in the ET equation. Failure to treat stomatal resistance as a variable in attempts to predict ET from meteorological data and stand characteristics may result in significant overestimates." Goodrich, et al. (2000) identified several factors critical to coupling riparian ET with groundwater models: 1) plant water sources (groundwater, surface runoff, precipitation, or vadose zone) must be identified as well as their seasonality and depth to groundwater, 2) the typical riparian corridor geometry (relatively high forest, narrow, long, and sinuous) along the alluvial floodplain precludes use of classical micrometeorological flux measurements, 3) a number of integrated experiments were needed to characterize various parameters at points in time, and 4) spatial extrapolation over the entire corridor requires a number of assumptions for components and uniform meteorology over the entire corridor. "None of these measurements provide ET estimates over the entire growing season for the entire riparian corridor."

On-going Studies – Canadian, Colorado and Pecos Rivers in Texas

The three sites currently being studied in Texas by the authors are different river hydrology/vegetation situations (Figure 1). The Colorado and Pecos River situations are losing streams (water from the river moves into the landscape most of the year). The Canadian study site occurs in an old channel (slough) of the river. The Canadian site has freshwater subsurface flow from the landscape to the study site, a very shallow water table and very rapid subsurface flow parallel to the river. The saltcedar stand on the Colorado River is not influenced directly by river surface flow, rather has a gradual subsurface flow approximately 20 + feet below the soil surface parallel to the river. Within year well water table levels fluctuated within a 3 foot range for all the sites studied. Sites A and B on the Pecos River are different: site A is located above a weir in the river and near the bottom of a floodplain with old channels to the east, site B is more directly affected by the river than site A and is above the floodplain and old channels that influence site A.

Vegetation at the Canadian site has nearly a 100% woody plant cover dominated by willows, Russian olive, saltcedar, cottonwood, etc. with large basal diameters and a dense understory (Figure 1). Saltcedar dominates the woody vegetation with very little understory at the Pecos and Colorado sites. Due to the shallower water table and frequent flooding grasses occur in openings at the Pecos sites while understory at the Colorado site is rainfall driven.

Table 1. Estimated annual water use by saltcedar (*Tamarix sp.*) in the Southwestern United States (Hays, 2003).

Reference	Location	Method	Values reported converted to feet/growing season (180days)
Meterological			**Evapotranspiration**
Gay and Fritschen (1979)	NM	Bowen ratio	4.9
Devitt, et al. (1998)	NV	Bowen ratio	3.6
King and Bawazir (2000)	NM	Eddy covariance	3.9 (230 days)
Luo (1994)	NM	Blaney-Criddle	3.0
*Bureau of Reclamation (1995)	CA	Mirco-meteorological	2.6
**Weeks et al. (1987)	NM	Energy budget	3.0
Lysimeter			**Evapotranspiration**
van Hylckama (1974)	AZ	Evapotranspirometer	5.2
Davenport, et al. (1982)	CA	Drums	5.2
**Bureau of Reclamation (1979)	NM	Non-weighing lysimeter	3.0
**Grosz (1972)	NV	Tanks	2.0
Gay and Fritschen (1979)	NM	Lysimeter	4.6
Plant Measurements			**Transpiration**
Sala et al. (1996)	NV	Stem-heat-balance	6.6
Wells			**Evapotranspiration**
Inglis, et al. (1996)	NV	Wells	4.3
Watershed			**Evapotranspiration**
**Culler et al. (1982)	AZ	Water budget	3.3

*As cited in Lines and Bilhorn (1996). **As cited in Johns (1989).

Soil textures and specific yields for the water tables were very different for each of the study locations and wells. Sand was the dominant soil texture for all depths at the Canadian location. This resulted in a specific yield of 41.3% for the treated slough and a specific yield of 39.5% for the untreated slough. Sandy clay loams dominated the water table zone for the Colorado site with specific yields of 15.7% and 15.0% for the treated and untreated areas, respectively. Sand dominated the water table zone at both sites A and B at the Pecos location. Specific yields varied from 37.7% to 35.0% at Site A for the saltcedar zone. At site B specific yields were 32.5% to 33.8% for the saltcedar zone.

Water salinity differed among study sites and situations. Salinity on May 14, 2002 at the Canadian site was 1400 ppm for the river, 400 ppm for the upland, 2500 ppm for the untreated slough and 800 ppm for the treated slough. On May 15, 2002 salinity at the Colorado site was 200 ppm for the river, 4100 ppm for the treated saltcedar area, and 7500 ppm for the untreated saltcedar area. At the Pecos River on May 16, 2002 site A had salinities of 4900 ppm for the river, 6400 ppm for treated saltcedar 29 feet from the river, 6300 ppm for the outside edge of the treated saltcedar (82 feet from the river) and >10000 ppm for the native vegetation well approximately 212 feet from the river. At site B on the Pecos the river on May 16, 2002 salinity was 6000 ppm for the river, 6100 ppm in untreated saltcedar 30 feet from the river, 7000 ppm for the outside edge of the untreated saltcedar (97 feet from the river), and >10000 ppm for the untreated native vegetation area (197 feet from the river).

Estimated Water Use by Saltcedar and Associated Vegetation in Texas

The drawdown-recharge method of calculation was used to estimate water use from hourly measurement of diurnal fluctuations of the water table (Hays, 2003). This method assumes little evapotranspiration occurs during the nighttime (21:00 to 8:00 hours) and that the period from the low point of the water table during daylight hours to the nighttime high can be used to calculate a recharge rate for the drawdown period. This method requires a drawdown and recharge diurnal cycle; hence, days when the water table rapidly rises or falls through out the diurnal cycle were excluded from the calculations. A standardized procedure-analysis software program is being developed and will be available via the web later this summer.

Water use varied considerably between river locations, sites within locations, years and treatment (Tables 2, 3, and 4). The highest water use was observed on the Canadian River, 11.5 and 13.8 feet for the growing season (April through October, 2001) before control treatments were applied in September 2001 (Table 2). During the growing season following treatment, water use declined to 5.2 feet (well 3) for the area treated the previous September. The water table remained high through out the study period. Control was near 100% for all vegetation except grasses in the slough. High soil/water evaporative losses would be expected for this situation due to the sand soil and very shallow water table. Total brush control reduced ET to 45% of expected (a potential savings of 55% or 6.3 acre-feet (2,052,855 gallons) until reestablishment occurs. The highest daily/monthly use occurred in June and July for both years.

The Colorado River location is an isolated patch of saltcedar created approximately 15-20 years ago when the water district attempted to remove salinity from Lake Thomas by pumping water to an evaporation pond. These saltcedar became established and maintain a root system to the water table approximately 20 feet below the surface. The area is surrounded by dry cultivated fields and an arid landscape. Over the three year period of study the water table declined in the summer and rose during the winter; however, each year the water table was lower than the previous year at the beginning of the growing season. The water table is influenced by subsurface flows from the upper part of the basin and landscape. Water use was considerably lower than other study locations for all years studied (Table 3). In 2000 prior to treatment, water use varied from 1.1 to 2.8 acre-feet for the growing season (April through October). Herbicide application to well 1 resulted in 50% mortality with numerous root sprouts by the end of the 2001 growing season. This resulted in a water use of 0.51 acre-feet (48.7% compared to the previous year for the site). The untreated site had similar water use to the previous year (2.69 acre-feet). The potential water savings was 0.54 acre-feet (176,546 gallons) the first growing season. Drought conditions prevailed throughout the study period and apparently affected water use in 2002 where the untreated site only used 0.58 acre-feet. Some recovery of saltcedar on the treated site slightly increased water use during 2002 to 0.54 acre-feet similar to the untreated site.

The Pecos River sites also experienced drought during 2002 due to the lack of water in Red Bluff Lake. Irrigation water was frequently released during the pretreatment period (2001) but not released during 2002 and apparently releases are not planned for 2003. River water was present through out the study but during 2002 it was several feet lower than the previous year.

Table 2. Estimated evapotranspiration (ft) from saltcedar and associated vegetation from monitoring wells located on the Canadian River in Texas.

Canadian River*		2001	2002	2001	2002
Well 3	Month	Ave. daily (ft.)	Ave. daily (ft.)	Month (ft.)	Month (ft.)
	April	0.0140	0.0054	0.4190	0.1619
Arsenal	May	0.0554	0.0236	1.7186	0.7331
applied	June	0.0852	0.0374	2.5563	1.1228
Sept.	July	0.0985	0.0203	3.0532	0.6298
2001	August	0.0636	0.0276	1.9709	0.8563
	September	0.0482	0.0269	1.4470	0.8081
	October	0.0119	0.0288	0.3693	0.8917
	Average	**0.0547**	**0.0245**	**1.6478**	**0.7434**
	Standard Error	0.0023	0.0009		
	95% Confid. Interval	0.0007	0.0019		
	Total			**11.5343**	**5.2038**
Canadian River*		2001	2001	2002	
Well 4	Month	Ave. daily (ft.)	Month (ft.)	Logger	
	April	0.0524	1.5712	Malfunctioned	
	May	0.0683	2.0483		
Untreated	June	0.1032	3.0953		
	July	0.1030	3.0895		
	August	0.0592	1.7764		
	September	0.0454	1.3612		
	October	0.0295	0.8850		
	Average	**0.0815**	**1.9753**		
	Standard Error	0.0027			

	95% Confid. Interval	0.0053			
	Total		**13.8269**		

Several of the wells were dry during the year; hence only the wells closest to the river are reported (Table 4). Water use varied from 9.5 to 10.2 acre-feet for the 2001 growing season. Herbicide treatment was applied to site A at the end of the 2001 growing season. Nearly 100% control of all vegetation was observed at the end of the 2002 growing season. Due to drought, water use for the untreated site dropped to 4.0 acre-feet (39% of the previous year). The treated site had 1.0 acre-feet of water use during 2002 (10% of the previous year). Potential water savings even during drought was approximately 75% (2.6 acre-feet); however, when there is little water available there is also little to save by brush control. Due to drought, recovery of vegetation was minimal.

A lysimeter study of the effects of salinity and depth to the water table was conducted during the 2002 growing season. Cuttings were rooted in the greenhouse and transplanted to PVC tubes equipped to maintain constant water levels and salinities during the study. Results are currently being analyzed. Preliminary analysis shows that both salinity and depth to the water table affected water use (Table 5). Approximately 50% less water was used when the water table was at 5.7 feet compared to 1.6 feet across salinities. Salinity effects were variable.

Table 3. Estimated evapotranspiration (ft) from saltcedar and associated vegetation from monitoring wells located on the Colorado River in Texas.

Colorado River*		2000	2001	2002	2000	2001	2002
Well 1	Month	Ave. daily (ft.)	Ave. daily (ft.)	Ave. daily (ft.)	Month (ft.)	Month (ft.)	Month (ft.)
	April	NA	0.0050	0.0043	NA	0.1497	0.1301
Arsenal	May	0.0062	0.0039	0.0040	0.1922	0.1220	0.1240
applied	June	0.0056	0.0041	0.0057	0.1695	0.1225	0.1724
Sept.	July	0.0060	0.0035	0.0035	0.1852	0.1072	0.1078
2000	August	0.0073	0.0024	0.0031	0.2273	0.0048	0.0062
	September	0.0052	0.0017	NA	0.1567	0.0034	NA
	October	0.0040	0.0020	NA	0.1245	0.0039	NA
	Average	**0.0055**	**0.0039**	**0.0044**	**0.1759**	**0.0734**	**0.1081**
	Standard Error	0.0002	0.0002	0.0002			
	95% Confid. Interval	0.0004	0.0004	0.0004			
	Total				**1.0554**	**0.5136**	**0.5405**
Colorado River*		2000	2001	2002	2000	2001	2002
Well 2	Month	Ave. daily	Ave. daily	Ave. daily (ft.)	Month (ft.)	Month (ft.)	Month (ft.)

		(ft.)	(ft.)				
	April	NA	NA	0.0052	NA	NA	0.1552
Untreated	May	0.0203	0.0185	0.0040	0.6282	0.5737	0.1248
	June	0.0125	0.0255	0.0059	0.3748	0.7638	0.1757
	July	0.0131	0.0148	0.0040	0.4060	0.4574	0.1236
	August	0.0180	0.0065	0.0026	0.5590	0.2030	0.0053
	September	0.0177	0.0106	NA	0.5295	0.3188	NA
	October	0.0087	0.0122	NA	0.2683	0.3781	NA
	Average	**0.0150**	**0.0139**	**0.0047**	**0.4610**	**0.4491**	**0.1169**
	Standard Error	0.0004	0.0006	0.0002			
	95% Confid. Interval	0.0008	0.0012	0.0004			
	Total				**2.7658**	**2.6949**	**0.5845**

Conclusions

Several factors apparently affected water use (ET) on the Canadian, Colorado and Pecos Rivers during 2000-2002: depth to the water table, soil texture and specific yield, salinity of the ground water, vegetation characteristics, and drought conditions. The first year following herbicide control of saltcedar and associated vegetation ET was reduced approximately 50% to 75% depending on location, 6.3 acre-feet, 0.54 acre-feet (with drought effects), and 2.7 acre-feet (with drought effects) on the Canadian, Colorado and Pecos Rivers, respectively. Actual water savings should be higher on the Pecos and Colorado River situations following recovery of native riparian vegetation than on the Canadian River where a shallow low salinity water table will result in high use by native species. The differences in water use observed in this study and in the literature verify that more site specific information is needed to properly predict ET and water savings following riparian restoration along entire river segments and lake situations. Saltcedar acreages, soil surveys, stand density measurements, etc. along river and lake systems does not provide enough information to identify which ET values to use for the many different riparian situations, thus estimates for entire river/lake systems are based on very general assumptions and the bias of the proponent for or against control.

Table 4. Estimated evapotranspiration (ft) from saltcedar and associated vegetation from monitoring wells located on the Pecos River in Texas.

Pecos River **		2001	2002	2001	2002
Site A	Month	Ave. daily (ft.)	Ave. daily (ft.)	Month (ft.)	Month (ft.)
Well 1	April	0.0102	0.0077	0.3073	0.2319
	May	0.0690	0.0102	2.1402	0.3160
Arsenal	June	0.0755	0.0031	2.2653	0.0929
applied	July	0.0690	0.0068	2.1402	0.2097
Sept.	August	0.0465	0.0039	1.4423	0.1208
2001	September	0.0286	0.0000	0.8591	0.0000
	October	0.0100	0.0000	0.3106	0.0000
	Average	**0.0441**	**0.0045**	**1.3521**	**0.1388**
	Standard Error	NA	NA		
	95% Confid. Interval	NA	NA		
	Total			**9.4650**	**0.9713**
Pecos River**		2001	2002	2001	2002
Site B	Month	Ave. daily (ft.)	Ave. daily (ft.)	Month (ft.)	Month (ft.)
Well 1	April	0.0115	0.0222	0.3465	0.6648
	May	0.0607	0.0239	1.8823	0.7407
Untreated	June	0.0279	0.0160	0.8364	0.4790
	July	0.0454	0.0184	1.4081	0.5700
	August	0.0600	0.0240	1.8590	0.7445
	September	0.0692	0.0084	2.0757	0.2526
	October	0.0579	0.0161	1.7955	0.4994
	Average	**0.0475**	**0.0184**	**1.4576**	**0.5644**
	Standard Error	NA	NA		
	95% Confid. Interval	NA	NA		
	Total			**10.2035**	**3.9510**

* Canadian and Colorado River estimates developed by White using described error procedure.

** Pecos River estimates developed by Hart and McDonald using slightly different procedures for error correction. A standardized procedure is being developed and will be applied to all values.

Table 5. Effects of salinity and depth to the water table on water use by young saltcedar during 2002 (Schmidt, personal communications).

	Depth to Water Table (feet)			Average Daily Water Use
Salinity (ppm)	1.64	3.28	5.74	(ft per plant)
0	0.063	0.034	0.030	0.038
1250	0.054	0.053	0.034	0.048
2500	0.039	0.041	0.022	0.035
5000	0.080	0.035	0.024	0.045
7500	0.039	0.038	0.011	0.031
Average Daily Water Use (ft/plant)	0.051	0.041	0.025	0.039

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SIMULATING WATER USE BY SALTCEDAR WITH THE EPIC MODEL

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Abstract

Simulation models for the water balance of areas near rivers or lakes dominated by saltcedar *(Tamarix* spp.) should accurately describe plant development and the soil hydrology for different soils and climate regimes. For this study, we worked with version 9200 of the EPIC (Environmental Policy Integrated Climate) model, applying it to saltcedar and grasses at three sites in arid regions of Texas. The model simulates plant water use and the water table depth fluctuations as well as salinity effects. For this paper, we demonstrated how different densities of saltcedar, with and without accompanying grasses, contribute to water loss at sites on the Pecos, Colorado, and Canadian rivers.

Abbreviations: ALMANAC (Agricultural Land Management Alternatives with Numerical Assessment Criteria model); EPIC (Environmental Policy Integrated Climate); LA! (leaf area index); RUE (radiation-use efficiency).

Introduction

A robust model capable of realistically simulating plant water use of salt cedar and grasses would be a valuable as a tool to assess impacts of saltcedar removal on water use along rivers in arid regions. The EPIC model 9200 version described herein is capable of providing estimates of plant water use and water table fluctuations. A similar project was conducted in Australia, simulating how long-term tree growth affected water use and water table depths (Silberstein et aI., 1999). The EPIC model we used continues to be improved, with improvement in plant parameters and work on simulation of water table depth. This model can be a valuable tool to integrate what we know about physical and biological processes, showing gaps in knowledge where further research is needed.

The end product is a tool to assess water use with trees and grasses using NRCS, USGS, and NOAA data. Resulting revegetation by more shallow rooted grasses and by native cottonwood or willows could also be simulated to look for net changes in water use. Our objective in this study was to demonstrate the capability of EPIC 9200 (Williams et aI., 1984; Williams et aI., 1989) to simulate water use at three sites in Texas.

This model shares plant parameters for woody species and native grasses with the ALMANAC model (Kiniry et aI., 1992b). ALMANAC realistically simulated native grass productivity on a diverse group of soils and in diverse climatic conditions in Texas (Kiniry et aI., 2002). ALMANAC was used to simulate Alamo switchgrass productivity at several locations in Texas (Kiniry et aI., 1996). Both EPIC and ALMANAC simulate plant growth using Leaf Area Index (LA!) and radiation use efficiency (RUE). In the case oftrees competing with grasses, the amount of light the trees intercept is calculated first, with the grasses having the remainder available to them. This EPIC model can simulate two plant species competing for light: water, and nutrients. Soil inputs can be easily derived from the NRCS Soils 5 Data Base. Required inputs, daily maximum and minimum temperatures, solar irradiance, and rainfall are readily available from many sites.

Materials And Methods

General Model Description

The EPIC 9200 model (Figure 1) simulates the water balance (including the water table depth), salinity, the nutrient balance, and the interception of solar radiation. The model simulates plant water use by trees and grasses from the soil and the water table, provided the water table is within the rooting depth of the plant species. The model has a daily time step. It simulates plant growth reasonably and is implemented easily. Some important modifications were made to enable more realistic simulation of the hydrology at the three sites.

Firstly, plant transpiration was increased by 67% over what the EPIC model normally simulates, in order to account for effects of advected energy from adjacent arid areas, as described in Arizona by Dugas et aI.(1991). This response has also been demonstrated in central Texas by Dugas and Bland (1989).

Secondly, while not reported herein, diurnal fluctua.!ions in water table were simulated from the daily value for transpiration from the daily value of water table before recharge, to give a maximum range of fluctuation each day. The value of daily transpiration was divided by 0.41, assuming 41 percent soil porosity, to calculate the daily fluctuation of water table.

Next, maximum range of water table depths over the season were set for each site. Water table fluctuations are calculated based on an assumed value for maximum ground water storage of 100 mm for all three sites. This affects how a water table rises after a rain. The value for the parameter for ground water storage loss was set to 0.2 mm per day for all the sites. We also allowed river flow rates or lake levels to affect ground water using values from adjacent bodies of water.

Light Interception

EPIC simulates light interception by the leaf canopy with Beer's law (Monsi and Saelri, 1953) and the LAI. The greater the value of the extinction coefficient k, the more light win be intercepted at a given LAI. The trees were allowed to intercept the light first, with the grasses having the remaining light available to them.

The fraction of incoming solar radiation intercepted by the leaf canopy is
Fraction = 1.0 - exp (-k * LAI) (1)

Preliminary results of Schmidt (thesis in progress) indicate k values of 0.35 for cottonwood and willow and 0.75 for saltcedar

Leaf Area Development

Accurate prediction of light interception depends on realistic description of leaf area. Values for saltcedar LAI are being developed from ongoing work by Schmidt Likewise, simulation of light interception also requires accurate description ofleaf area production and decline. The model estimates leaf area production up to the point of maximum leaf area for the growing season using Eq(2). The model generates a curve that is forced through the origin and through two points, asymptotically approaching y=1.0. The s-curve function takes the form:

$$F = X / (X + \exp (Yl - Y2 * X)) \qquad (2)$$

where F is the factor for relative LAI, X is the fraction of heat units from planting to maturity, and YI and Y2 are the s-curve coefficients generated by EPIC. For each day, the fraction of total heat units that have accumulated is determined, denoted as SYP. The sum of heat units is zero at planting in the establishment year and at tiller emergence in subsequent years, and is maximum at maturity. The s-curve describes how LAI can increase, under nonstress conditions, as a function ofSYP.

Biomass Production and Partitioning

Biomass growth is simulated with a RUE approach (Kiniry et aI., 1989). Values for RUE have been previously derived for many crops (Kiniry et al., 1989; Manrique et aI., 1991; and Kiniry et aI., 1992). For grasses, we have used RUE values ranging from 1.8 to 5.0 g per MJof intercepted photosynthetically active radiation (Kiniry et aI., 1999).

The maximum rooting depth defines the potential depth in the absence of a root-restricting soil layer. Soil cores from plots at Temple in 1994 indicate that grass roots varied in depth among the species, with switchgrass roots extending to 2.2 m (Kiniry et aI., 1999). For saltcedar, we assumed a deep maximum rooting depth to assure that plants could extract water from the water table. For the Pecos River site, we only simulated saltcedar. We assumed grass roots extended to 2.0 m at the other two sites.

Demonstration Data Sets

The three locations simulated represent three conditions where saltcedar is pJresent along a river. We simulated one soil at each site. These were: a Harkey soil at the Pecos River site in Loving County; Colorado soil at the Colorado River site in Borden County; and a Lincoln soil at the Canadian River site in Hempstead County. Mean annual rainfall values were 28 cm at the Pecos River site, 50 cm at the Colorado River site, and 55 cm at the Canadian River site.

Model Evaluation

Data Sets

At the Pecos River site, we simulated different plant densities of saltcedar without grass. The appropriate soil parameters for each site were used and the weather data was the measured daily maximum and minimum air temperatures, and rain from the nearest weather station. We ran simulations for 25 years at the Canadian River site, 32 years at the Colorado River site, and 18 years at the Pecos River site, based on number of years of river flow or lake level data. Daily solar radiation was the mean for the month for twenty years at each site.

Results And Discussion

Water table fluctuations for five years showed seasonality at all three sites (Figure 2). The fluctuations depended on rainfall, water use by trees, and adjacent river flow rates or lake levels. Using these, along with adjustment of ground water storage capacity and maximum and minimum water table depths, gives the model versatility in simulating the water table at different sites near rivers or lakes.

The dependence of both seasonal and mean daily plant water use (transpiration) for June through August are demonstrated for the Pecos River site with different tree cover (LA!) (Table 1). With a LAl of only 0.5, seasonal and mean daily plant water use were only 17%/ofthe value with a high LAl of5. Values increased with each increment ofLAl up to LAI of 4. All these assume trees are extracting water from the water table.

For the Colorado River and Canadian River sites, seasonal plant water use and mean daily water use were less than the Pecos River site with high LAl. This is partly due to the lower tree cover at the two latter sites and partly due to different atmospheric demand for water" At the Pecos River site, the mean annual potential evapotranspiration was 2309 mm, while at the Colorado River site it was 2260 and at the Canadian River site it was 2010. Previous methods of estimating water use by saltcedar have ranged from as low as .6 m per year in Nevada (Johns 1989) to as high as 4.05 m in Texas(Hays 2002), so these annual values are reasonable and within the range of values from other methods of estimating water use.

The EPIC model shows promise as a tool for simulating water use by saltcedar and other plants at sites along rivers and lakes in arid sites in Texas. The data sets developed here can be used as starting points to derive data sets for sites with similar soils, grass species, and weather, providing users with examples of realistic values for soil and plant parameters. Using NRCS soils data, NOAA weather data, and stream flow or lake level data, we can efficiently estimate plant water use for different plant cover of trees or grasses and show relative differences in water use between different plant covers.

Acknowledgments

The model and data sets described herein are available to users at no charge. Users wanting these models and data should contact the senior author.

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Table 1. Mean annual and mean daily (June through August) plant water use (transpiration) (mm) as estimated by the EPIC model, for the Pecos River site with different plant cover (LAI) of saltcedar and for the Colorado and Canadian River sites with representative plant cover.

	Tree LAI:	**0.5**	1	2	3	4	5
Pecos River	Mean Annual mm yr^{-1}	377	688	1286	1889	2203	2260
	(Percent of highest)	(17)	(30)	(57)	(84)	(97)	(100)
	Mean Daily mm d^{-1}	2.5	4.7	8.8:	13.0	14.8	14.7
	(Percent of highest)	(17)	(32)	(60)	(88)	(100)	(100)
Colorado River Mean Annual mm yr^{-1} (LAI=1.0 for trees and 1.0 for grass)					1060		
	Mean Daily mm d^{-1}				7.1		
Canadian River Mean Annual mm yr^{-1} (LAI=0.5 for trees and 3.0 for grass)					1404		
	Mean Daily mm d^{-1}				12.2		

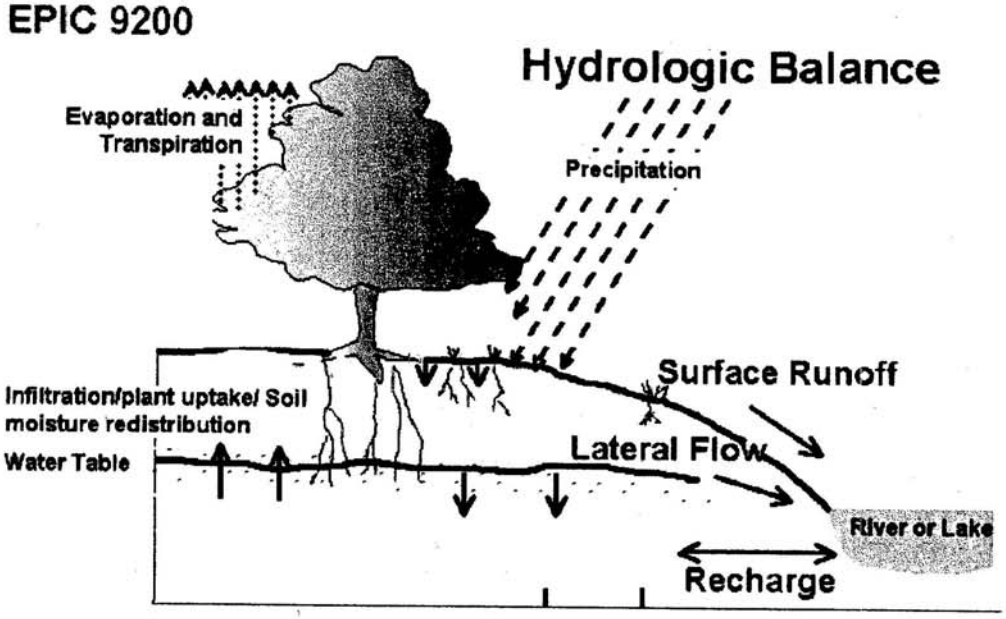
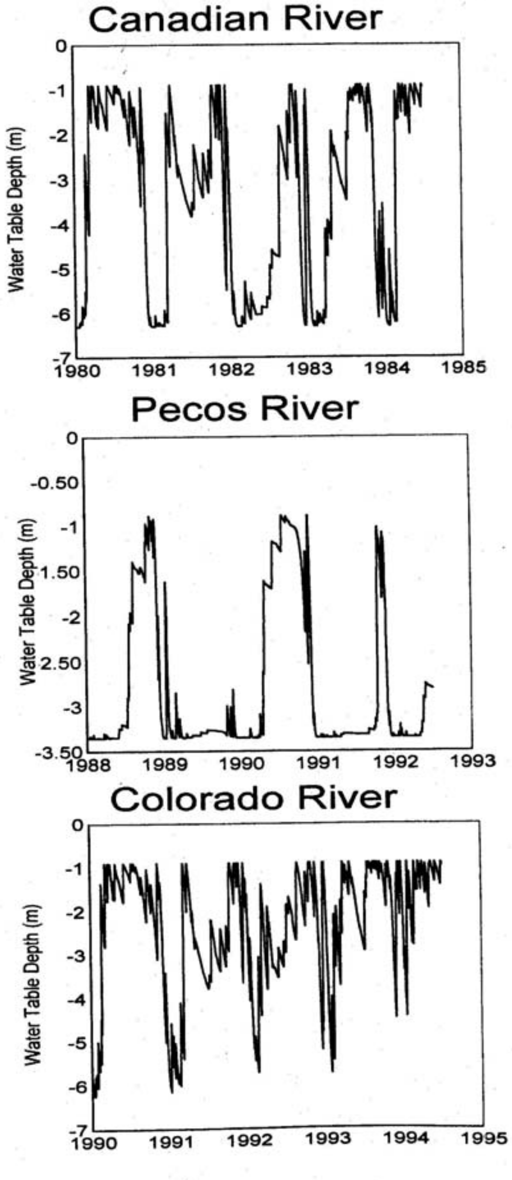

EPIC 9200
Hydrologic Balance
Evaporation and Transpiration
Precipitation
Surface Runoff
Infiltration/plant uptake/ Soil moisture redistribution
Water Table
Lateral Flow
River or Lake
Recharge

Figure 1

Figure 2


Canadian River
Water Table Depth (m)
0
-1
-2
-3
-4
-5
-6
-7
1980
1981
1982
1983
1984
1985
Pecos River
Water Table Depth (m)
0
-0.50
-1
-1.50
-2
-2.50
-3
-3.50
1988
1989
1990
1991
1992
1993
Colorado River
Water Table Depth (m)
0
-1
-2
-3
-4
-5
-6
-7
1990
1991
1992
1993
1994
1995

Saltcedar Management

TOXICOLOGY AND ECOTOXICOLOGY AND SUMMARY FOR IMAZAPYR (ARSENAL® HERBICIDE)

BASF Corporation

Introduction

Imazapyr (the active ingredient in ARSENAL herbicide) has been registered for terrestrial use in the US since 1985. Currently the EPA is reviewing imazapyr in the form of ARSENAL herbicide for the proposed aquatic use to control undesirable floating and emergent aquatic vegetation. A registration decision is expected from the EPA in 2003 for the proposed aquatic use. Hundreds of scientific studies have been conducted to support the current terrestrial and proposed aquatic uses of imazapyr. The use of ARSENAL herbicide as described in the Texas 24(c) label for the control of saltcedar should not result in any unreasonable risk to human health or non-target organisms such as birds, fish and aquatic invertebrates. Below is a brief summary of the mammalian toxicology and ecotoxicology studies that have been conducted in support of imazapyr.

Toxicology

Imazapyr, the active ingredient in ARSENAL herbicide, inhibits a plant specific enzyme (acetohydroxyacid synthase, AHAS) that causes the plant to stop growing and slowly die as its food and energy reserves are exhausted. With perennial woody species, such as saltcedar, potential regrowth from the root system must be prevented if long term control is to be achieved. Because of imazapyr's relatively slow mode of action and favorable chemical properties, it quickly enters the target plant, circulates throughout the plant and ultimately is concentrated in the growing points of the plant, including the root system., thus preventing regrowth. Imazapyr has no known biological activity in animals and imazapyr is considered to be essentially non-toxic to mammals. Imazapyr is not a mutagen, terratogen, carcinogen nor is imazapyr an endocrine disrupter. Imazapyr itself is a weak acid, and as such it can cause eye irritation. As the formulated product, ARSENAL herbicide (23% imazapyr) can cause temporary eye and skin irritation, but once the product is further diluted for spraying, irritation is not a concern. Table 1 summarizes the acute toxicological values for imazapyr and ARSENAL herbicide.

When ARSENAL herbicide is used as directed for saltcedar control on the Texas 24(c) label then the imazapyr residues that can be expected to occur in surface waters as a result of applications made to saltcedar growing along the water's edge should cause no unreasonable risk to human health.

Ecotoxicology

Both technical grade imazapyr (the active ingredient in ARSENAL) and ARSENAL herbicide were found to be practically non-toxic to birds, fish and aquatic invertebrates, and only slightly toxic to algae and diatoms. Laboratory studies to evaluate the bioaccumulation potential of imazapyr have been conducted with bluegill sunfish, grass shrimp and Eastern oysters. The steady-state bioconcentration factor determined in each of these studies was less than 1.0, indicating low potential for bioaccumulation in aquatic organisms. The low bioaccumulation potential of imazapyr was confirmed in two aquatic field dissipation studies and a freshwater clam field accumulation study, where results demonstrated minimal accumulation of imazapyr in crayfish, several species of fish, and clams.

A theoretical worst-case risk assessment, which incorporates estimated environmental concentrations based on U.S. EPA's worst-case criteria, indicates that applications of ARSENAL for aquatic vegetation management will not result in an unreasonable risk to the environment. Tables 2-7 summarize the available ecotoxicology data for imazapyr and ARSENAL herbicide.

Table 1. Mammalian acute toxicological values for imazapyr and ARSENAL herbicide

Toxicity Test	Sex	Imazapyr	ARSENAL herbicide
Rat Oral LD_{50}	M/F	>5000 mg/kg	>5000 mg/kg
Rabbit Dermal LD_{50}	M/F	>2148 mg/kg	>5000 mg/kg
Rat Acute Inhalation	M/F	No mortality or abnormality in 4 hours at 5.1 mg/L of air	No mortality or abnormality in 4 hours at 5.0 mg/L of air
Rabbit Eye Irritation	M	Irreversible irritating	Irritating with complete recovery within 7 days
Rabbit Skin Irritation	M	Not irritating	mildly irritating
Guinea Pig Skin Sensitization	M	Not sensitizing	Not sensitizing

Table 2. Summary of the avian toxicity studies conducted with technical grade imazapyr.

Species / Test	LD_{50} / LC_{50}	NOEL
Northern Bobwhite LD_{50} (mg/kg)	> 2150	2150
Mallard duck LD_{50} (mg/kg)	> 2150	2150
Northern Bobwhite LC_{50}	> 5000 ppm	5000 ppm
Mallard duck LC_{50}	> 5000 ppm	5000 ppm
Northern Bobwhite Reproduction study	--------	1890 ppm
Mallard duck Reproduction study	--------	1890 ppm
Northern Bobwhite Reproduction study	--------	1800 ppm
Mallard duck Reproduction study	--------	1800 ppm

Table 3. Summary of the avian toxicity studies conducted with ARSENAL.

Species / Test	LD_{50} / LC_{50}*	NOEL*
Northern Bobwhite LD_{50}	> 2150 mg/kg	2150 mg/kg
Mallard duck LD_{50}	> 2150 mg/kg	2150 mg/kg
Northern Bobwhite LC_{50}	> 5000 ppm	5000 ppm
Mallard duck LC_{50}	> 5000 ppm	5000 ppm

*Based on ARSENAL herbicide concentrations.

Table 4. Summary of the fish toxicity studies with technical grade imazapyr.

Species / Test	LC_{50}	NOEC
Bluegill sunfish LC_{50}	> 100 mg/L	100 mg/L
Channel catfish LC_{50}	> 100 mg/L	100 mg/L
Rainbow trout LC_{50}	> 100 mg/L	100 mg/L
Atlantic Silverside LC_{50}	**> 184 mg/L**	**184 mg/L**
Rainbow trout early life-stage	-------	92.4 mg/L
Fathead minnow Early life-stage	-------	118 mg/L
Fathead minnow Life-cycle	-------	120 mg/L

Table 5. Summary of the aquatic invertebrate toxicity studies with technical grade imazapyr.

Species / Test	LC_{50} / EC_{50}	NOEC
Daphnia magna EC_{50}	> 100 mg/L	100 mg/L
Eastern oyster shell Growth inhibition	> 132 mg/L	132 mg/L
Pink Shrimp LC_{50}	> 189 mg/L	189 mg/L
Daphnia magna life-cycle	----------	97.1 mg/L

Table 6. Summary of the algae and aquatic plant toxicity studies with technical grade imazapyr.

Species / Test	EC_{50}	EC_{25}
Green algae EC_{50} (*Selenastrum capricornutum*)	71 mg/L	48 mg/L
Freshwater diatom EC_{50} (*Navicula pelliculosa*)	> 59 mg/L	> 59 mg/L
Saltwater diatom EC_{50} (*Skeletonema costatum*)	85.5 mg/L	42.2 mg/L
Blue-green algae EC_{50} (*Anabaena flos-aquae*)	11.7 mg/L	7.3 mg/L
Duckweed EC_{50} (*Lemna gibba*)	0.024 mg/L	0.013 mg/L

Table 7. Summary of algae and aquatic plant studies with ARSENAL Railroad herbicide (The Railroad product is the same as ARSENAL herbicide, but contains a surfactant in the formulation).

Species / Test	**EC_{50}***	**EC_{25}***
***Selenastrum* EC_{50}**	**14.1 mg/L**	**8.36 mg/L**
Lemna EC_{50}	0.0216 mg/L	0.0132 mg/L

*Results expressed as mg a.e./L.

SPRAY DRIFT CONTROL MODELS

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Introduction

My first experience with saltcedar (*Tamarix spp.*) was simple and basic and I relate this example to demonstrate how complicated things have become. We had one of those bushy trees with long pink flowering spikes in our back yard when I was growing up. That tree was Pop's favorite place to cut a switch to deal with any kind of childhood misconduct! I had not thought much about saltcedar and those memorable occasions back on the farm until we were recently involved with North Star Helicopters in a cooperative research study on spray drift. They related their experience with Texas Department of Agriculture and the program to get rid of saltcedar on the Pecos River. I do not recall ever thinking as a child that it would be good to get rid of that saltcedar tree in the back yard, because it also provided shade which was a premium commodity in West Texas. But if I had been old enough for such a task, it would probably have been a simple matter. However, it is no longer a simple matter; just consider an example of how complicated things have become – concern has been expressed about getting rid of saltcedar because it has crowded out native nesting sites of the southwestern subspecies of the willow flycatcher (*Empidonax trailii extimus*), which is a federally endangered bird (Unitt, 1987); the flycatcher now nests in saltcedar, and if we get rid of the saltcedar, other native species may not reestablish, so the willow flycatcher would be without a nesting site! – And I formerly thought it was only a switch and shade tree!

Chemical control has been shown to be an effective and economical control measure for saltcedar (Duncan and McDaniel, 1992; Lym, 2002), and aerial application of herbicides is a reasonable method of choice in large areas that are inaccessible and unfavorable for ground operations. Because of the common proximity of saltcedar to waterways and the concern about water supply and water quality, off-target deposits of herbicides in water and on watersheds is a significant issue that must be dealt with appropriately. It is not only with saltcedar and water where off-target deposits and spray drift from application of pesticides is an important matter. Spray drift is noted as a major problem for the pesticide application industry (Wolf, 1998). Product manufacturers under the auspices of the Spray Drift Task Force (SDTF), U.S. Department of Agriculture (USDA), and the Environmental Protection Agency (EPA) have worked together through a Cooperative Research and Development Agreement (CRADA) over the past ten years to develop methodologies to better understand and control spray drift. The EPA is following this effort with their current work on proposed product label language for spray drift mitigation that was drafted to appear on most pesticide product labels. Efforts under the aforementioned government/industry CRADA have led to the development of a spray drift model called AgDRIFT® (Teske, et al., 2002). One of USDA's contributions to the effort was development of aerial spray nozzle atomization models (Kirk, 2000; Kirk, 2002). Both of these models can provide useful information and guidance for spray drift mitigation to applicators of pest control materials.

The objective of this paper is to briefly present 1) EPA's proposed label language for spray drift, 2) the USDA aerial spray nozzle atomization models, and 3) the AgDRIFT® spray drift and deposition model.

Proposed Label Language for Spray/Dust Drift

In August of 2001, the EPA published a notice of proposed regulation relating to product label language for mitigating spray drift (Mulkey, 2001). The EPA notice requested public comment and reaction to the proposed regulation. Numerous comments were received from most all segments of the industry. EPA is considering the comments and plans to conduct listening sessions across the country. Revised regulations will then be issued for public comment. All stakeholders should keep abreast of this process and be prepared to provide comments to EPA when the revised regulations are issued. However, the reality of current label practice by the product manufacturers and EPA is that some of the provisions of the proposed regulation are already appearing voluntarily on product labels. Consequently, it is important that operators and applicators understand that labels are being changed as existing products are relabeled under FIFRA guidelines.

EPA's proposed label guidelines on spray drift follow the Agency mandates to protect the environment and that pesticide use will not cause unreasonable adverse effects. Even though some product labels have said "do not drift," EPA is on record that they recognize that a limited amount of drift can and will occur when pesticides are applied as sprays. EPA will establish the guidelines and regulations on product label language for spray drift mitigation, but the responsibility for protecting people and the environment from adverse effects of pesticide application clearly rests with the applicator. An additional goal of the effort to revise product labels has been to make the language on labels clear, doable, and enforceable both for applicators and lead agency regulators.

There are two general segments of the proposed label instructions – general overall guidance and specific guidance for labeled methods of application. For more toxic materials, certain methods of application may not be permitted. Some of the proposed label guidelines are currently common practice in the industry, but others may require additional preparation and precautions when applying products with label guidelines that are beyond current practice. Examples of additional risk mitigation labeling are no-spray zones and specific buffer zone widths. Not all product labels are expected to specify buffer zones, and when specified, they may not apply to all methods of application. The label guidance for products, which by toxicity or other need, that will require no spray zones or buffer zones is still under development. These details will likely be in the revised label language guidance on which the industry will have further opportunity to provide input and comment. The goal is to develop label guidance language that will satisfy EPA mandates, address the major causes of spray drift, and provide workable guidance to product manufacturers and applicators.

USDA Aerial Spray Nozzle Atomization Models

The major factors that contribute to off-target movement of sprays have been reasonably documented in the technical literature. The extensive research conducted by the SDTF and others in recent years confirmed what was already known and provided a comprehensive database for development of process and predictive models that can be useful both to applicators and regulators. The major factors contributing to off-target movement of sprays can be categorized as equipment parameters, application techniques, weather effects, and properties of the spray mix. The single factor recognized as dominant in off-target movement or spray drift is spray droplet size. Depending on the application technique, there are several factors that influence spray droplet size. For example with aerial application, nozzle type, nozzle orifice size, nozzle angle, spray pressure, and aircraft speed are the dominant factors. Applicators tend to give considerable credence to the importance of spray nozzle type, orifice size, nozzle angle, and spray pressure in determining droplet size. However, for fixed wing aircraft operating in the turbine class, aircraft speed can considerably overshadow the influence of other variables in determining droplet size. Applicators need to understand that, and know how to deal with it while maintaining the efficiency of modern high speed agricultural aircraft. The importance of aircraft speed in determining droplet size can be expressed with the CP-03 nozzle -- a 10 mph change in airspeed produces (1) similar change in droplet size as switching from the 30 to the 90 degree deflector, or (2) similar change in droplet size as switching from the .061 to the .171 orifice. In other words, the range of droplet size control is generally higher with airspeed than with any of the other variables under operator control. However, there are some fundamentals that provide framework within which to deal with these factors.

The American Society of Agricultural Engineers (ASAE) is a professional engineering society that maintains a voluntary cooperative standards program for agricultural machinery and systems. For example, the standards carefully describe and specify dimensions, sizes, etc. for different categories of three-point hitches for farm equipment. With equipment manufacturers complying with that standard, a farmer can hitch a red implement to a green tractor with no particular problem. Without such standards there would be all manner of incompatibility problems. You can understand the advantage of implement manufacturers complying with such a voluntary standard. (It has been years since a two point hitch was manufactured – not because it was a bad idea, but because it was not compatible with anything else.)

ASAE also has standards for agricultural spray operations. These standards put everyone on the same page with common definitions and understanding of spray parameters. One of the standards – (ASAE S572 AUG99 – ASAE Standards, 2000) defines the spray droplet spectrum in six different size categories ranging from very fine to extremely coarse. The standard specifies a characteristic – DROPLET SPECTRA CLASSIFICATION or DSC – to describe a given spray spectrum. Applicators understand that most all hydraulic nozzles produce a range of droplet sizes, some smaller and some larger than a number or letter used in the standard to describe the various size categories. The standard for DSC categories links the data with the instrument on which the data are collected. However, similar instruments are expected to give similar DSC categories for a given nozzle. The USDA aerial spray nozzle atomization models were developed with the same instrument as the ASAE reference nozzles shown in Figure 1 so the categories expressed in the models are based on these data.

Spray nozzle manufacturers catalogs often provide DSC and droplet size data for selected nozzle and operator inputs for ground rig applications. However, those values are not relevant for aerial application because of the tremendous influence of air shear forces on atomization of sprays released from aircraft. Thus the more complicated aerial atomization process cannot be described in a single chart, graph, or table for a given nozzle. Descriptions of such multivariable processes are readily described with computerized models in relatively simple spreadsheet calculators. This was the process selected to develop models for estimating atomization parameters for aerial spray nozzles.

The USDA models are computerized calculators for estimating aerial spray nozzle atomization parameters from the applicator's spray nozzle selection and input of planned operating conditions. The spreadsheet models are available on the Internet at http://apmru.usda.gov/downloads/downloads.htm/. The models are formatted for the Microsoft Excel™ spreadsheet. Atomization models are available for nine nozzles commonly used on fixed-wing aircraft and nine nozzles commonly used on helicopters. Use of the models begins with selection of the type of aircraft (fixed-wing or rotary-wing) and the atomization model for the nozzle to be used. Model inputs are orifice size, nozzle angle (or other specified nozzle parameter), spray pressure, and airspeed. After each parameter is entered, the model computes the expected atomization parameters for the conditions specified. Spreadsheet models provide a digital computation of spray nozzle atomization parameters and provide ready opportunity for "what if" computations of droplet size and relative spray drift expectations from model inputs of different operating conditions.

The models can be used to assist aerial spray applicators in compliance with a label specification to apply a given product in a DSC of Coarse as follows: Suppose the applicator has selected disc orifice straight stream nozzles based on their propensity to produce a relatively coarse droplet spectrum with low drift potential. Orifice size 12 is selected to give the appropriate spray rate with the number of nozzles on the aircraft. The nozzles are oriented straight back, 0^o, to reduce the effect of air shear on atomization. The applicator normally operates his aircraft at 130 mph and normally uses spray pressure of 30 psi. With these factors set, the model estimates a DSC of Medium. The applicator must now adjust operational factors to achieve a DSC of Coarse and understands that airspeed and spray pressure are primary factors in controlling droplet size and DSC from the straight stream nozzles. Alternatives for the applicator to consider are decreasing airspeed and/or increasing spray pressure. Experimentation with airspeed and pressure entries into the model shows that increasing pressure to 60 psi and decreasing airspeed to 120 mph will give a DSC of Coarse with the orifice size 12. Reducing airspeed and increasing pressure changed flow rate such that an orifice size 10 was more appropriate for the desired spray rate. While maintaining pressure at 60 psi and airspeed at 120 mph, and changing orifice size to 10, the model predicted a DSC of Coarse as required on the product label. The spreadsheet with the selected alternative is shown in Figure 2. It is important to note from model estimates that the percentage of spray volume in the highly driftable portion of the droplet spectrum less than 100 µm diameter was reduced from more than 5 percent to less than 1 percent.

Use of these aerial spray nozzle models will help applicators be more precise in their applications and will facilitate compliance with regulations already on the books in some states and on some product labels and will further equip applicators to readily deal with expected new regulations.

AgDRIFT® Model

The Spray Drift Task Force spent upwards of $20 million over the past dozen years to develop a database that they and EPA could use to register and re-register crop production and protection products. This extensive effort served to reinforce the existing scientific database and to provide scientifically sound measures for assessing potential off-target risks by providing applicators with guidance to mitigate potential off-target or spray drift problems.

We can be confident at this point that SDTF research has documented spray drift and many of its causes, but very few of its real effects. But regardless of how tired applicators are of hearing about spray droplet size and spray drift, droplet size is still the most important factor that applicators can influence to control/reduce spray drift. Spray drift is also affected by several other factors that applicators can either control or affect with mitigation methods that can be assessed in the AgDRIFT® model. AgDRIFT® is a mechanistic computerized model that was developed over several years by Continuum Dynamics, Inc. with support from NASA, DOD, and USDA. The SDTF adopted and enhanced the computer code and developed the Windows interface for the current version of the model.

The AgDRIFT® computer input screen has several libraries of model input parameters that operators or applicators can select to describe their particular operation. There are 72 different aircraft that are contained in the Aircraft library. Several different spray nozzles or droplet size distributions can also be selected. The USDA aerial nozzle atomization models are incorporated in AgDRIFT® and there are several other input variables including height of flight, and weather conditions so spray drift can be more accurately predicted.

Examples of the overall capability of the AgDRIFT® model are not possible because of limited space in this paper. However, a brief example is included here to show the capability for estimating spray drift under two conditions for a single aircraft.

AgDRIFT® has standard or default input conditions for each aircraft. The default value inputs to the model predict the downwind spray deposits for the selected conditions. Figure 3 shows the portion of the aerial spray deposit pattern that is depicted in the AgDRIFT® output screen. Figure 4 shows the model output graph for an Air Tractor AT-502 with deposits for the default input values and deposits with a single drift mitigation option – coarse spray compared to medium spray as the default value. The patterns show the predicted deposits for different distances downwind. It is apparent from model outputs that changing spray droplet size from DSC medium to DSC coarse significantly reduces downwind drift deposits. Deposits at 500 feet downwind are four times higher with medium spray as compared to coarse spray.

AgDRIFT® is a comprehensive model that permits applicators to assess all of the primary factors that influence spray drift and tailor the output to their aircraft, operational, and environmental conditions. Use of the model will help applicators better understand spray drift phenomena, the factors under their control, and what can best be done in their operation to control spray drift. The AgDRIFT® model is available on the Internet through contact with SDTF personnel. A copy of the model may be obtained by sending an electronic mail request to David Esterly at envfocus@comcast.net . The message should explain the need for and intended use of the model and should also include a statement such as:

> "I attended the Saltcedar Conference at San Angelo, Texas, on July 16-17, 2003, where Buddy Kirk outlined the utility of AgDRIFT®. I certify that I have read the conditions on the SDTF web site and I will not distribute AgDRIFT® in any form without prior specific permission from the SDTF."

Applicants will be checked as legitimate users and be given instructions and a password for downloading AgDRIFT® at www.agdrift.com .

Summary

We mentioned in the beginning that the world in which we live and operate is more complicated than formerly. Consequently there are more factors to consider in doing any job right. Regulations are a fact of life for most all industries and operations. Applicators must know and understand how to comply with regulations and operations in their profession. Tools to help applicators be more proficient and professional in their operations are available. Applicators must take advantage of the tools and information available – or someone is likely to ask "Why not?"

Figures

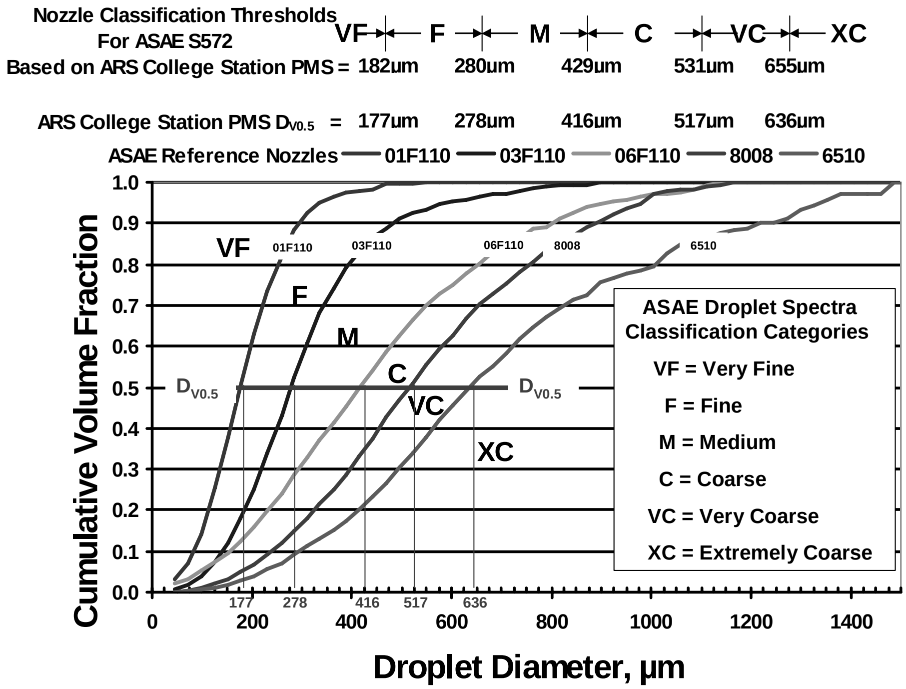
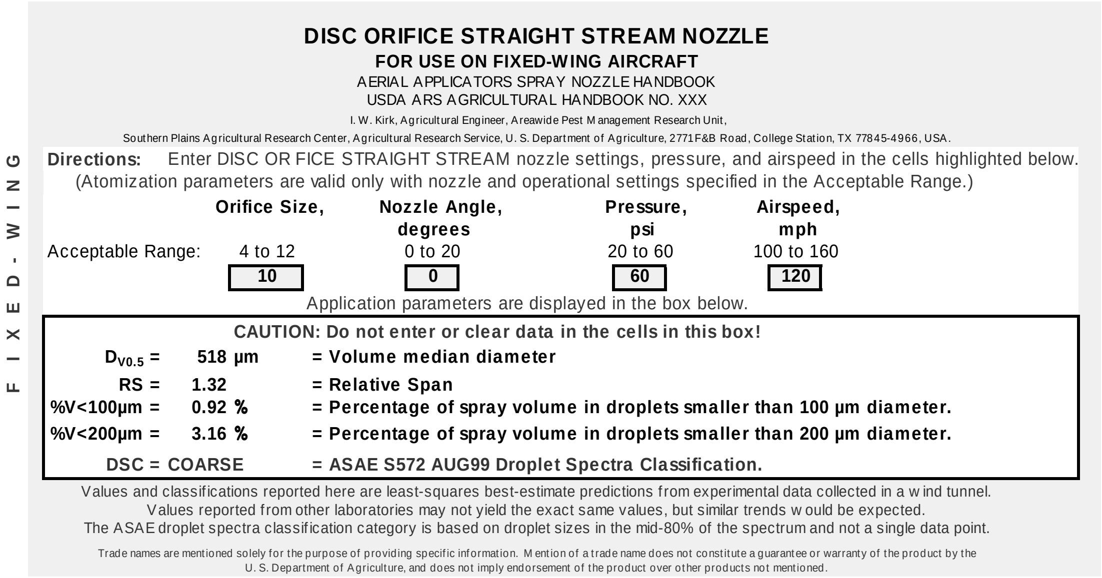


Figure 1. ASAE reference nozzle data from ARS PMS instrument at College Station, Texas.



DISC ORIFICE STRAIGHT STREAM NOZZLE

FOR USE ON FIXED-WING AIRCRAFT

AERIAL APPLICATORS SPRAY NOZZLE HANDBOOK
USDA ARS AGRICULTURAL HANDBOOK NO. XXX

I. W. Kirk, Agricultural Engineer, Areawide Pest Management Research Unit,
Southern Plains Agricultural Research Center, Agricultural Research Service, U. S. Department of Agriculture, 2771F&B Road, College Station, TX 77845-4966, USA.

Directions: Enter DISC OR FICE STRAIGHT STREAM nozzle settings, pressure, and airspeed in the cells highlighted below. (Atomization parameters are valid only with nozzle and operational settings specified in the Acceptable Range.)

	Orifice Size,	**Nozzle Angle, degrees**	**Pressure, psi**	**Airspeed, mph**
Acceptable Range:	4 to 12	0 to 20	20 to 60	100 to 160
	10	0	60	120

Application parameters are displayed in the box below.

CAUTION: Do not enter or clear data in the cells in this box!

$D_{V0.5}$ = 518 µm = Volume median diameter
RS = 1.32 = Relative Span
%V<100µm = 0.92 % = Percentage of spray volume in droplets smaller than 100 µm diameter.
%V<200µm = 3.16 % = Percentage of spray volume in droplets smaller than 200 µm diameter.
DSC = COARSE = ASAE S572 AUG99 Droplet Spectra Classification.

Values and classifications reported here are least-squares best-estimate predictions from experimental data collected in a wind tunnel.
Values reported from other laboratories may not yield the exact same values, but similar trends would be expected.
The ASAE droplet spectra classification category is based on droplet sizes in the mid-80% of the spectrum and not a single data point.

Trade names are mentioned solely for the purpose of providing specific information. Mention of a trade name does not constitute a guarantee or warranty of the product by the U. S. Department of Agriculture, and does not imply endorsement of the product over other products not mentioned.

Figure 2. Fixed-wing disc orifice straight stream nozzle model with operator inputs of Orifice Size = 10, Nozzle Angle = 0^o, Spray Pressure = 60 psi, and Airspeed = 120 mph.

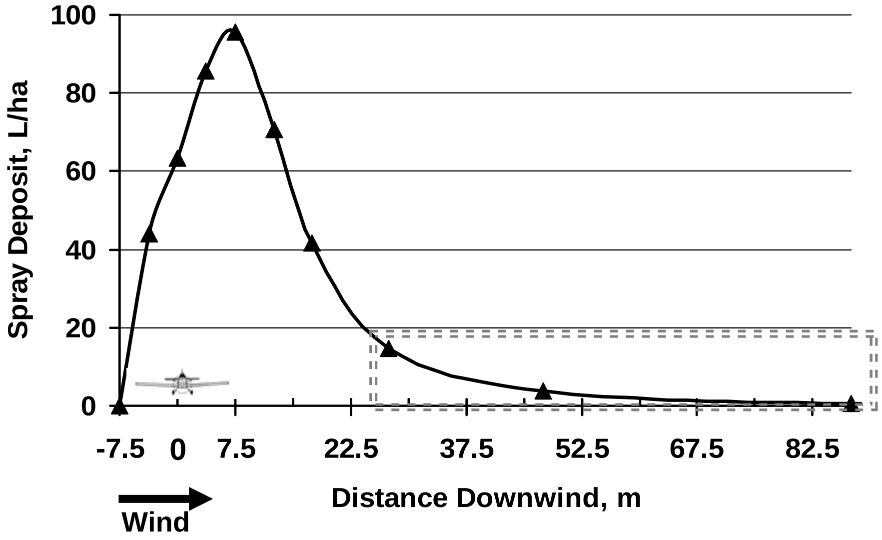
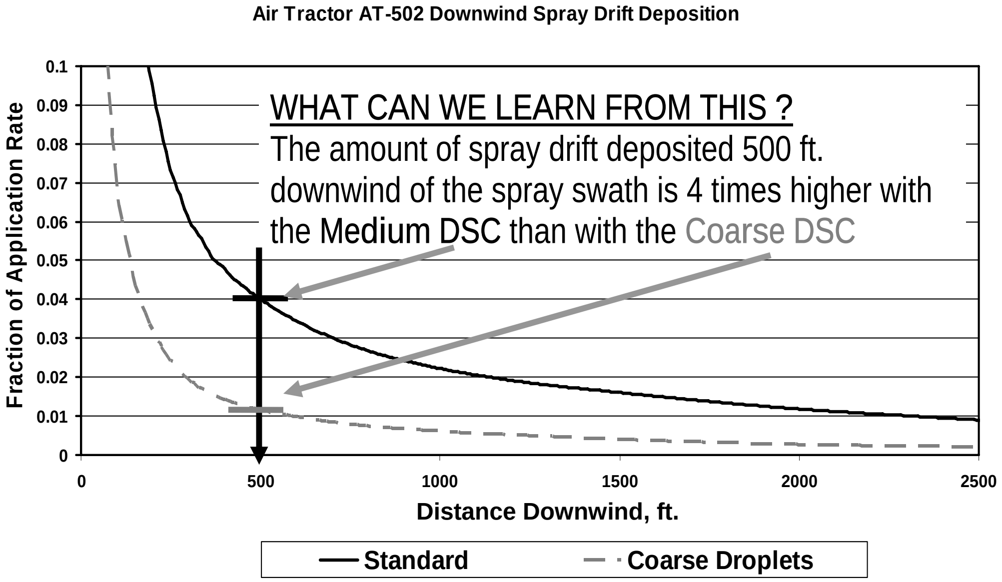


Figure 3. Typical aerial spray deposit pattern for application in a crosswind. The double-dashed segment of the deposit pattern, but on a much expanded scale, is what is typically depicted in an AgDRIFT® output screen.



WHAT CAN WE LEARN FROM THIS ?
The amount of spray drift deposited 500 ft. downwind of the spray swath is 4 times higher with the **Medium DSC** than with the Coarse DSC

Figure 4. Spray drift deposits predicted from AgDRIFT® for Standard or default conditions (Airspeed = 155 mph, Droplet DSC = Medium, Spray release height = 15 feet, Boom length = 75% of wingspan, Wind speed = 10 mph, Swath offset = ½ swath) compared to Standard for all of the default conditions except Droplet DSC = Coarse.

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FIRE IN SALTCEDAR ECOSYSTEMS

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Introduction

Saltcedar (*Tamarix* spp.) has invaded North American ecosystems since escaping from cultivation in the 1870s (Robinson 1965). Since that time, it has become extensively naturalized along riparian areas in the western United States and Mexico. This short time period makes it difficult to surmise what a natural-occurring fire regime would be for saltcedar-dominated ecosystems. However, saltcedar-dominated communities accumulate litter rapidly from dead and senesced woody material (Busch and Smith 1995) that could allow those communities to burn every 15 to 20 years. The frequency and intensity of fires in these communities is often greater than would normally occur in the native riparian communities allowing for competitive advantages for saltcedar or replacement of native vegetation by saltcedar.

Fire Ecology

Saltcedar is often referred to as a fire adapted species (Tesky 1992; Busch and Smith 1993). This description is applied to it largely because of its ability to rapidly resprout from basal buds and rhizomes following fire. Prolific flowering and seed production throughout the growing season from non-burned sites can be carried by wind or water to burned sites for establishment of new saltcedar plants following fire. Additionally, resprouting, burned plants can shift from rapid, vegetative growth (long shoots) to short shoot growth with reproductive shoot within a couple of months after being top-killed by fire (Mitchell, pers. comm.). Flowering and seed production in postburn regrowth is increased over non-burned saltcedar. This ability to return to a reproductive state and increase seed production following fire may allow saltcedar to increase its density and coverage in comparison to other riparian shrubs and tree. Seed production such as this is especially advantageous at times of the growing season when native riparian vegetation is not flowering. Saltcedar, however, is not very shade tolerant, especially in establishment periods. Overall, surviving saltcedar plants can be described as having efficient fire recovery mechanisms (Busch and Smith 1993).

Herbaceous components of saltcedar ecosystems are generally benefited by fire. This is especially true for perennial grasses. The growth patterns and resource allocation to above ground material by perennial grasses give them an advantage in frequent fire regimes over woody plants. This advantage of perennial grasses over woody plants is true even for resprouting shrubs and trees because of the large amount of resources and structure produced by woody plants in above ground leaves/shoots and the location of growing points above ground. Resprouting woody plants also must initiate growth from new below ground growing points. Perennial grasses such as saltgrass (*Distichilis spicata* L.), alkali sacaton (*Sporobolus airoides* Torr.), giant sacaton (*S. wrightii* Munro), and bermudagrass (*Cynodon dactylon* (L.) Pers.) are often associated with saltcedar ecosystems. Much of this association is due to the ability to tolerate the saline soil and water conditions in the cases of saltgrass, alkali sacaton, and bermudagrass. Diversity of grasses and forbs in saltcedar ecosystems varies greatly throughout saltcedars' range depending on factors such as saline conditions, soil type, flooding frequency, climate, precipitation patterns, and depth to/quality of groundwater.

Native woody riparian vegetation is often the desirable plant community where saltcedar-dominated ecosystems exist. Species such as cottonwood (*Populus* spp.), willow (*Salix* spp.), and screwbean mesquite (*Prosopis pubescens* Benth.) also resprout from basal buds and/or rhizomes, but the rate of regrowth is less than that of saltcedar following top-kill. In many instances, browsing of cottonwood and willow regrowth, new growth, and seedlings by wildlife and/or livestock further reduces its ability to compete with saltcedar resprouts. These factors often contribute to saltcedar dominance following fire if restoration measures are not taken.

Native riparian trees and shrubs can compete well with saltcedar during establishment in many cases (Stromberg 1997; Gladwin and Roelle 1998; Stromberg 1998; Taylor and McDaniel 1998; Taylor et al., 1999; Hughes 2000; Sher et al., 2000). When establishing on disturbed areas following flooding, native riparian woody plants can effectively compete and often shade-out saltcedar. However, disturbance such as fire do not provide the moisture conditions for seed germination and survival like many flooding events do provide. Occurrences such as regular monsoon rainfall or flooding are required after fire to provide conditions which germinate and establish seedlings of any of these species. In those instances where fire is the disturbance, though, the seedlings of native riparian trees and shrubs will often be competing with established vegetation that is resprouting, and therefore, be at a disadvantage. For fires to enhance native woody seedlings in favor of saltcedar, the fire would need to occur prior to native plant flowering and germination events; the native woody plants would need to be protected from top-kill by the fire in order to be capable of producing seed; seedlings would have to be free from shading by established resprouting woody plants; and moisture requirements must be met for germination, establishment, and survival. These types of combinations are very hard to meet without intense manipulation, and therefore, saltcedar-dominated ecosystems usually persist in the presence of fire disturbances.

Fires also cause changes in soils that can be detrimental or beneficial. Increases in soil pH, changes in nutrient quantities/availability, and rapid growth of vegetation resulting in decreased soil moisture are all effects following fire (Wright and Bailey 1982). Fire may increase salinity and elevate concentrations of phytotoxic boron in alluvium resulting in disadvantages to less tolerant plants and there recovery (Busch and Smith 1993). However, prescribed fires can be managed to benefit management objectives without harming soil productivity.

Fire Use

Fire in saltcedar ecosystems has many negative attributes. It provides for rejuvenation of decadent saltcedar stands. Fire can also increase the extent and/or density of saltcedar within riparian areas by providing seedbeds in previously occupied or shaded areas. Because saltcedar stands can develop extremely high fuel loads, wildfires in saltcedar stands are hazardous to people/property, expensive to fight, and difficult to stop.

Prescribed burning is a treatment option for saltcedar ecosystems that is not intended to eliminate all saltcedar, but offers a low-cost means to prevent saltcedar from becoming a dense, impenetrable thicket. Opinions and results are mixed concerning fire-induce mortality of saltcedar from past wildfires and prescribed fires, with some sources struggling to ignite a fire that will carry (Hoddenbach 1987; Kunzmann and Bennet 1987; Fox 2001). Preliminary results from prescribed burning research along the Pecos River watershed north of Roswell, NM showed that saltcedar mortality averaged 30% (≥1 growing season postburn) when burning saltcedar-dominated areas that had not been burned for >25 years (Racher et al. 2003).

Prescriptions for burning saltcedar have been developed to safely apply fire to saltcedar ecosystems (Racher 2003). The simple principle of using blacklines at least 213 m wide allow for saltcedar burning under a wide range of fuel and weather conditions to meet management goals. Dense, decadent saltcedar stands readily burn, often as crown fires. A frequent fire return interval (<8 years) for prescribed burning saltcedar stands requires adequate herbaceous fuel accumulations and continuity because saltcedar plants will not accumulate enough decadent material to burn by itself. Grasses such as saltgrass, bermudagrass, and giant sacaton can provide the fine fuel matrix to accomplish frequent burning that can possibly eliminate saltcedar.

Prescribed fire in saltcedar ecosystems can be used as the only treatment to reduce the sphere of influence of saltcedar canopies. Racher et al. (2003) reported average reductions of 74% and 91% in saltcedar canopy cover in dense saltcedar at 2 different sites. This prevents saltcedar from becoming a closed-canopy monoculture and allows herbaceous production for wildlife and livestock. Although the regrowth from surviving saltcedar is rapid following fire, the reduced leaf area of these plants should translate into reduced total water used for years following burning. Saltcedar also shows higher post-fire water use efficiency that cottonwoods and willows (Busch and Smith 1993).

Fire can be used to prepare sites for restoration efforts. Removal of biomass by fire allows access for personnel and equipment that perform many types of restoration methodologies. Volatilization also provides seedbed preparation for revegetation and natural regeneration. However, the removal of biomass must be recognized for its potential to open areas up to saltcedar colonization, as well as native plants. Prescribed fires can be timed and planned to benefit restoration of native plants. If fires are performed immediately before desirable vegetation produces seed with a chance for germination/establishment and desirable plants are protected from the fire so that seed source is available, the chances of restoration to native plant communities is increased.

Another role of prescribed fire in saltcedar ecosystems is to facilitate fire management. Hazardous fuel accumulations in saltcedar are well known and difficult to handle in wildfire situations. Uses for saltcedar biomass for fuelwood and as an energy source are being experimented with, but the feasibility of these uses is yet to be proven. Reduction of the fuel accumulations through properly conducted prescribed fires reduce fire fighting costs and dangers to fire personnel, the public, and personal property.

The best use of fire in saltcedar ecosystems, though, is as a part of an integrated weed management program such as that described by Masters and Sheley (2001). The use of biological, chemical, mechanical, and cultural weed control methods in various combinations will be the most effective means for managing saltcedar ecosystems. For example, where saltcedar dominates, herbicidal saltcedar control can be followed by fire to reduce the biomass and allow restoration efforts. This type of treatment kills new saltcedar plants before the bud zone becomes protected by soil. This type of treatment is a very low-cost treatment for large areas when compared to other options.

Another example is provided by Fox (2001) in which fire was the first occurrence; followed by relatively low cost mechanical treatments to provide additional saltcedar mortality, aesthetic benefits, and disturb soil surfaces to facilitate natural regeneration; lastly, low-volume herbicide treatments were performed to reduce surviving saltcedar plants. In this example, the fire provided the opportunity to use lower-cost mechanical treatments and provided access for chemical control methods which otherwise would have been nearly impossible.

A third scenario shown to be successful (Fox 2001) is following fire with individual plant treatment by herbicides to maximize control. In this scenario, the fire allows access to sometimes impenetrable stands of saltcedar; the reduction in number and stems of saltcedar reduces the amounts and costs of expensive herbicides; and the saltcedar plants that resprout should be exhibiting short shoot growth to ensure effective translocation of herbicides to roots. Saltcedar management programs that focus on a single treatment at one point in time will most likely fail. Saltcedar ecosystems must be continually managed to provide the product(s) managers desire from riparian areas. The ultimate goal of almost all parties is to reduce saltcedar in riparian ecosystems.

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AERIAL SPRAYING AND MECHANICAL SALTCEDAR CONTROL

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From the 1940s to present the literature is full of countless descriptions of attempts to control saltcedar. A lesson learned early on, but what must still be reiterated, is that there is no single effective control method. Only by use of treatment combinations logically applied over fairly long time horizons can one expect to eliminate saltcedar. On floodplains adjacent to the Rio Grande and Pecos a great deal of work has been conducted to reduce saltcedar stands. This paper emphasizes recent experiences gained from saltcedar control work along both rivers, but especially on the Bosque del Apache (BDA) National Wildlife Refuge near Socorro, NM. Much of this work has been directed towards water conservation and the restoration of riparian habitats that are of special benefit to wildlife (Taylor and McDaniel 2003).

Root Crown – The Focal Point for Control

Saltcedar's root systems are dominated by a root crown extending 12-18 inches below the soil surface from which stems resprout following aboveground trunk and stem removal (Figure 1). Control methods that damage top-growth but fail to destroy or extract the root crown are considered suppression techniques. These include fire, mowing, grazing by goats or other livestock, defoliating herbicides, foliage feeding insects, etc. Methods that target and destroy the root crown are the only techniques that truly provide plant control.

Mechanical Saltcedar Control

Large-scale mechanical broadcast treatments for control of saltcedar monocultures along the Rio Grande in New Mexico (Taylor and McDaniel 1998) utilize a two-phase approach whereby aerial trunks and stems are first cut at the soil surface and piled using a D-7 class bulldozer equipped with a front-mounted brush blade. A 3-yd capacity articulating loader equipped with a brush rake working in tandem with bulldozers facilitates piling. Piles are allowed to dry for a month or longer prior to burning. This work is usually accomplished during winter months to avoid harsh hot summer conditions that contribute to equipment over-heating and summer nesting seasons for bird species.

Root plowing and raking, the second phase of control, occur during hot and dry summer months, usually May and June when root material is subject to desiccation as it is removed from the soil. A 12-ft wide root plow, pulled by a D-7 class bulldozer, is used to sever the root crown from the remaining root mass about 12-18 inches below the soil surface depending on the maturity of the saltcedar stand. A D-8 class bulldozer equipped with a 21-ft wide hydraulic root rake containing teeth 4-ft long in length and spaced 15 inches apart is recommended to rake root material from the soil surface. The material is windrowed and later piled using the articulating loader. Piles are subsequently burned.

An experienced operator can clear a typical saltcedar stand with plant populations averaging 10-12 ft in height and 3000-4000 plants/acre at the rate of about 6 acres/day. Root plowing is accomplished at a slower rate of about 3 acres/day, while root raking can progress rapidly at a rate of about 15 acres/day. Costs for mechanical saltcedar control can vary depending on stand characteristics. Generally, shorter stature, dense stands that are not fully mature will take longer to complete control work than larger trees with fewer stems. Satisfactory control prior to site restoration must reduce plant densities to 20 plants/acre or less (~99% control). To achieve this level of control, sites must often be root plowed and raked twice in opposite directions. Follow-up individual plant control treatments (grubbing or herbicide application) are advised for a 2-year period following initial control work. Costs/acre and percent control for various projects on the BDA refuge based on contracted equipment and labor are provided in Table 1.

Herbicide Coverage – The Key to Aerial Spraying

Aerially applied spray mixtures that render the entire saltcedar canopy to glisten with liquid long after spraying has concluded is what commercial applicators should strive to achieve for optimum plant control. This can partially be accomplished by equipping the correct spray system to the aircraft and to spray under optimal environmental conditions. The goal is to maximize herbicide absorption and translocation throughout the plant, which is best achieved by wetting the entire foliage surface area with droplets that ideally remain damp for 15 minutes or longer.

Herbicide-burn (-mechanical) Saltcedar Control

The herbicide-burn saltcedar control program is relatively new and has emerged from an experimental phase to use as a practical control tool on large monotypic tracts (McDaniel and Taylor 2003). The herbicide treatment includes 2 quarts of imazapyr or a 1 quart imazapyr plus 1 quart glyphosate mixture applied in water with a 0.25% by volume nonionic surfactant and a 0.07% by volume drift control agent (Duncan and McDaniel 1998). Applications can be made with either fixed-wing or helicopter aircraft in August or September prior to fall color change when plants are actively storing carbohydrates in root systems in preparation for winter dormancy. Moderate temperatures (60-80^{o}F), high relative humidity (65-90%), and light winds (3-7 mph) are ideal to maximize herbicide activity. Applications should be made only to mature, active growing (or healthy) saltcedar stands to maximize surface area for herbicide interception and translocation to meristematic regions in the plant. Herbicide applications to recently burned or disturbed stands will result in poor control due to disproportionate aboveground to belowground biomass ratios. For maximum control, sites receiving herbicide treatment should not be disturbed for 3 years to allow complete herbicidal efficacy.

A prescribed burn follows herbicide treatment to remove aerial trunks and stems. The order of these treatments cannot be reversed. Initial stand canopy coverage should be 60-70% to carry the fire and to maximize fuel consumption. Moderate temperatures (64-85^{o}F) and relative humidity (30-40%), and light winds (3-7 mph) are important environmental conditions for burning standing dead (herbicide treated) saltcedar to assure fuel consumption (>98%) and safe burning conditions. Such conditions coincide with the summer rainy season, primarily in August in New Mexico and western Texas. With preparation of 50 ft firebreaks surrounding treated areas, prescribed burning can be conducted safely due to the high fuel moisture content of adjacent untreated saltcedar. Long-term saltcedar control using the herbicide-burn control technique has been 93% or greater. Costs/acre and percent control for various projects on the BDA refuge are provided in Table 2.

If conditions necessary for prescribed burning can not be met, follow up mechanical treatments, such as chaining, cabling, bull dozing, mulching or roller chopping can be used to down dead aerial trunks and stems. In some cases stacking the debris and burning the piles may be desired or necessary. Along the Pecos River near Artesia, NM, costs/acre for chaining averaged about $7.00/acre and roller chopping about $10.00/acre 3 years after aerially spraying saltcedar.

Airplane vs Helicopter Applications

Equipped with the correct spray system, either aircraft can be used to successfully deliver a lethal spray mixture to saltcedar. The helicopter is advantageous for spraying "tight" difficult areas that require precision application, such as edges of meandering rivers or saltcedar growing interspersed with native vegetation that must be protected. Fixed-wing aircraft are advantageous for spraying large monotypic blocks of saltcedar, such as on floodplains, where these aircraft can deliver an overlapping spray pattern at a lower flying cost than the helicopter.

Aircraft equipped with satellite guidance systems and GIS capabilities has become a must when spraying in wildland situations. This alleviates the need for on the ground flaggers and provides detailed maps showing areas sprayed. Remarkable progress has been made with onboard computer systems that allow pilots to adjust spray pressure, flow rates, and other spray operations in the air. Similarly, on-the-ground mixing equipment has become more sophisticated and procedures have been improved to increase cost efficiency and better meet increasingly stringent environmental regulations. As new technologies become available aerial applicators are often the first adopters as they strive to keep their business on the cutting edge. The aerial applicator is a vital key to insure a successful saltcedar control program. Thus, obtaining the most qualified individual to do this critical work is a must.

In recent years, fixed wing aircraft have successfully been used to spray floodplain saltcedar along the Pecos River near Artesia, NM (about 3,800 acres) and on the Bosque del Apache (about 1000 acres). In general, saltcedar control has exceeded 90% plant kill. The imazapyr + glyphosate mixture has primarily been used for saltcedar monocultures whereas straight imazapyr has been applied where cottonwood and other sensitive trees are growing. Most spraying has been conducted by Don Kubecka, owner of Ag Aero (915 758-9271, Rt 4 Box 417, Seminole, TX). This company flies Air Tractors (earlier 502 but now 602 series) that are equipped with about 66 CP straight stream adjustable nozzles (0.172 orifice size) on a boom that fits about 70% of the wing span. Spraying has been accomplished at a high volume (7 to 10 gpa) and by use of relatively large spray droplets (>500 µm). An overlapping spray swath pattern is critical for obtaining sufficient herbicide coverage on saltcedar, thus care must be taken not to allow the spray swath to exceed 50 to 60 ft.

Precision aerial application is a unique feature provided by helicopters. They have principally been used to spray saltcedar growing on the edge of the meandering Pecos from Santa Rosa, New Mexico to near Grandfalls, Texas (about 13,000 acres along 400 river miles sprayed from 1999 to the present). Bob Ewing, owner of North Star Helicopter (409 384-5315, Box 2010, Jasper, TX) has been responsible for application work and has been particularly innovative in designing both on-the-ground and on-board computer support systems (Trimble GPS guidance system, variable rate flow meter, display unit for GIS display). Spray accuracy and precision is enhanced by use of a boom that is partitioned into 1/3rd increments so that either outside edge or directly under the belly can be used to spray separately or combined when desired. The boom is fitted with Accu-flow nozzles that can be adjusted to deliver large droplets (>1000 µm) that results in a spray swath pattern that is essentially square or straight down, increasing the need for accurate GPS navigation to minimize skipped areas between the swaths. North Star Helicopter, Inc. has assembled an excellent ground support system (tanker trucks with landing decks, separate water and herbicide mixing tanks, computer driven flow meters, etc.). Combined, this advanced equipment design provides for a productive and environmentally sensitive spraying operation.

Because saltcedar grows close to water its habitat is nearly always considered environmentally sensitive. This is especially true where it occurs in close proximity to agricultural or residential land, or it occupies areas with endangered species (plant or animal) and other critical riparian habitat concerns. Precision aerial application has gained added significance in large scale saltcedar control programs because pilots must be able to identify property boundaries and locate avoidance zones. GPS and GIS systems are available today to assist operators in precision application of herbicides to within feet of where it is intended to be delivered. With today's technology it is possible to pre-map areas to be sprayed and pre-program the on-board spray system so that the herbicide is sprayed only on defined treatment areas. This has added a new dimension with respect to restoration of riparian habitats where pre-planning and mapping are critical to eventual success (Taylor and McDaniel 2003).

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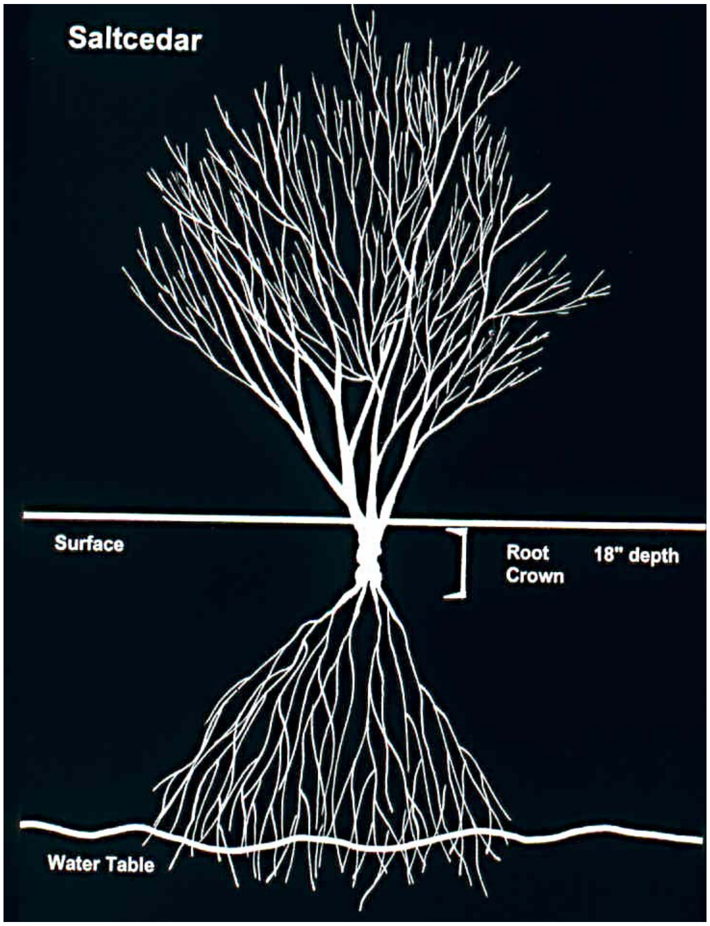

Figure 1. Diagram of the above and belowground root system of saltcedar showing the location of the root crown.

Table 1. Mechanical saltcedar control costs and plant mortality at sites on the Bosque del Apache National Wildlife Refuge, NM.

Site	Year	Cost/acre	% Control
Unit 28	1989	$419/acre	98%
Unit 29	1990	$525/acre	98%
Unit 30	1992	$302/acre	99%
Unit 33	1995	$595/acre	97%
Unit 26	1997	$690/acre	99%

Table 2. Herbicide-burn saltcedar control costs and plant mortality at sites on the Bosque del Apache National Wildlife Refuge, NM.

Site	Year	Cost/acre	% Control
Unit 33	1995	$114/acre	93%[1]
Unit 34C	2001	$182/acre	76%[2]
Unit 34B	2001	$225acre	91%[3]

[1] Control after 6 years with application made using a fixed wing aircraft applying an imazapyr/glyphosate mixture in a 7 gallon/acre total spray volume.

[2] Control after 2 years with application made using a helicopter applying an imazapyr/glyphosate mixture in a 15 gallon/acre total spray volume.

[3] Control after 2 years with application made using a helicopter applying imazapyr in a 15 gallon/acre total spray volume.

INDIVIDUAL PLANT TREATMENT OF SALTCEDAR

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Saltcedar management in New Mexico and the U.S. Southwest during the 1900's can be divided into three distinct phases. Saltcedar expansion into major river systems and flood plains went largely unchecked for the first 40 years of the 20th Century. Problems caused by saltcedar growing in main channels became recognized during the 1940s. Through the 1970s, various land clearing and water management efforts to remove saltcedar were employed by irrigation districts, U.S. Army Corps of Engineers, U.S. Bureau of Reclamation and others (Anonymous 1951; Hollingsworth 1973). The primary goals of saltcedar manipulation were: (1) to facilitate water transport, (2) to reduce flood and surface flow, (3) to reduce sedimentation, and (4) to enhance irrigation return flows (Graf 1978). In some locations, saltcedar removal was intended to improve recreational opportunities and/or wildlife habitat (Kerpez and Smith 1987).

During the 1980s, emphasis on large-scale land conversion began to diminish as public concerns and questions were raised about the expense and ecological effects of such attempts. Also, the resource value of riparian areas became a major concern. Therefore, the optimization of a single-return project, such as increasing water yield, could no longer be the sole justification for vegetation manipulation. A comprehensive approach that attempts to suppress saltcedar in order to restore the perceived natural riparian vegetation is now the goal of efforts to manage saltcedar-infested floodplains and channels in the Southwest.

Since its introduction to the U.S., saltcedar has proven to be a very resilient and difficult-to-control species. Saltcedar is considered to be both a flammable fuel and a fire tolerant plant. Fires burn quickly through green or dormant saltcedar and will usually result in total top kill of the burned stand. However, seldom is mature saltcedar killed with fire. The saltcedar root crown is well protected and resprouting typically begins soon after the fire. Resprouts may reach 6 to 10 ft. in the first growing season after a fire. Repeated yearly prescribed burning has been shown to suppress saltcedar and cause some mortality after three or four yearly burns.

Historically, mechanical control practices have shown only slightly more success in saltcedar mortality. Mowing or shredding saltcedar shows results similar to burning. Bulldozing and root plowing have provided the most mortality of any mechanical control operation. However, resprouting is a major concern as saltcedar will sprout vigorously and form new plants if stem or root segments are buried or partially buried in warm moist soil (Gary and Horton 1965).

The historical response of saltcedar to herbicides has also been varied, with little satisfactory control except under specific conditions or following several years of repeated treatment. Most of the herbicides historically used for saltcedar control are no longer manufactured or are not currently approved by the EPA for use on saltcedar. Of the herbicides used by Hollingsworth (1973), only triclopyr is currently in use.

The most successful saltcedar control efforts of the past utilized a combination of techniques and tools. Herbicide applications following root plowing, mowing or prescribed burns were shown to result in some saltcedar mortality (Howard et al. 1983).

Ground-Based Foliar Treatments

The introduction of imazapyr in the mid-1980's initiated a new effort to use herbicides for saltcedar management. Researchers in New Mexico began field trials in 1987 using imazapyr and other herbicides to develop recommendations for saltcedar control. Ground-based foliar spray trials of individual plants were applied with either a backpack or a trailer-mounted power sprayer. Plot size was determined by the number of trees sprayed with one tank of solution. Tree size was, therefore, the determinate factor in the number of trees sprayed per plot, but usually 25 or more trees were treated.

The liquid herbicides were mixed in water with a 0.25% v/v nonionic surfactant. An indicator spray dye was added at the recommended rate to each spray mix. Plants were sprayed to wet foliage, but not drip. Particular attention was paid to spray terminal ends of all branches, including blooms. The interiors of plants were then laced with the spray solution to complete treatments. Efforts were made to spray all sides of the treated plants.

Imazapyr was applied alone in the first trials, but beginning in 1990, mixtures with glyphosate were compared. The advantage of an imazapyr-glyphosate combination is a reduction in treatment costs. Saltcedar mortality was determined at 3 yr. post treatment by counting the number of dead plants in each plot and dividing by the total number of plants. Mortality rates are combined by herbicide rate across all sites and trials for purposes of reporting.

Saltcedar mortality data from 23 NMSU individual plant trials indicated imazapyr at 1% v/v or imazapyr plus glyphosate applied at 0.5 plus 0.5% v/v usually provided more than 90% mortality when sprayed between June and September (Table 1). In eight of nine trials when saltcedar was sprayed in August and September, mortality was at least 99% when sprayed with the 1% v/v imazapyr rate (Figure 1).

Table 1. Average percent apparent mortality to saltcedar by month of treatment with foliar applications of various herbicides applied to individual trees for trials in New Mexico, 1987-1994.

	Month applied					
Herbicide rate	May	Jun	Jul	Aug	Sep	Oct
Imazapyr (%)	------------------------------% mortality------------------------------------					
0.5	33	63	77	-	72	-
0.75	-	55	87	91	-	-
1.0	54	90	88	99	96	-
1.25	-	95	80	-	-	-
Imazapyr (%)+ Glyphosate (%)						
0.25 + 0.25	-	-	-	-	99	63
0.25 + 0.5	-	-	-	-	99	68
0.5 + 0.5	-	-	-	98	99	74
0.75 + 0.75	-	-	-	97	-	-

Dashes indicate the treatment was not applied during the month.

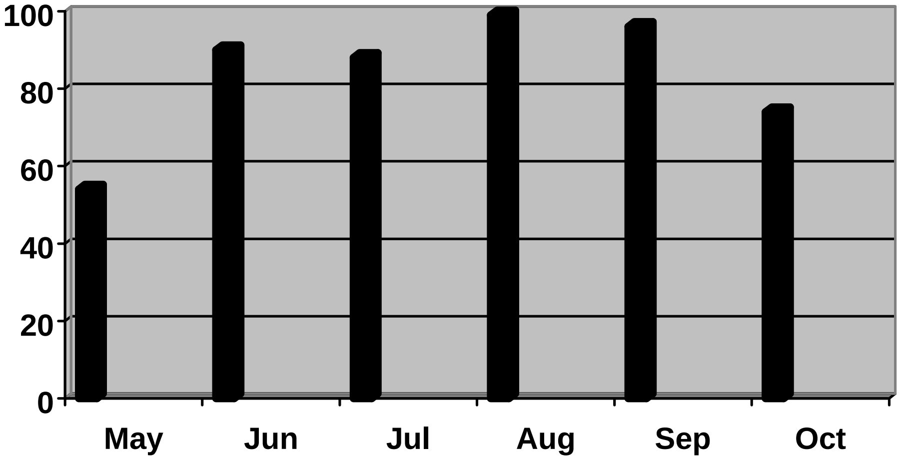

Figure 1. Mean saltcedar mortality by month of treatment across all sites and years for a 1.0% solution of imazapyr foliar applied to individual plants for trials in New Mexico, 1987-1994.

Mortality was generally less when saltcedar was sprayed early (April) or late (October) in the growing season. Herbicide efficacy was rarely greater when higher concentrations of the herbicides were used in the spray solution. Glyphosate applied alone at 2% v/v provided only 32% mortality, indicating the necessity of adding imazapyr to the glyphosate solutions.

These results led to the development of recommendations for saltcedar control on an individual plant treatment (IPT) basis in New Mexico (Duncan and McDaniel 1999). These recommendations include: (1) treat young or regrowth saltcedar because plants under 12 ft. in height are more easily sprayed and controlled than larger trees, (2) treat areas previously root plowed, mowed or cleared once the resprouts have reached at least 4 ft. in height, or treat areas where saltcedar appears to be newly invading, (3) treat areas with plant densities of fewer than 200 plants/ac, (4) treat with imazapyr at 1% v/v with water, a 0.25% v/v nonionic surfactant and an indicator spray dye, or treat with a combination of imazapyr plus glyphosate applied at 0.5 plus 0.5% v/v with water, nonionic surfactant and spray dye, (5) spray foliage to wet, concentrating on terminal ends of all branches. Allow two full growing seasons before follow-up management.

Carpet Roller Treatments

Vallentine (1989) suggested carpet roller treatments as a means to reduce the amount of herbicide introduced into the environment, which also reduces application costs. The carpet roller wipes the herbicide solution directly onto contacted plants without affecting understory vegetation.

Trials utilizing a carpet roller (Mayeux and Crane 1983) were established by New Mexico researchers to investigate the practicality of using the equipment to control saltcedar. Herbicide solutions were sprayed onto the surface of the revolving carpet, which then wiped the solution onto low growing (<10 ft tall) saltcedar plants.

Results indicate that imazapyr applied at 0.125% v/v or imazapyr plus glyphosate applied at 0.125 plus 0.125% v/v provided 92 and 85% mortality, respectively. Glyphosate applied alone at 0.5% resulted in only 5% mortality, whereas imazapyr applied alone at 0.25% provided 94% mortality 2 yrs after application.

A problem noted in the carpet roller trials was the presence of obviously untreated plants. This was attributed to operator inexperience as more untreated plants were encountered in earlier plots as opposed to those established later. As the tractor operator became more experienced, the incidence of untreated plants declined. Therefore, a recommendation was developed to apply imazapyr at 0.125 or 0.25% v/v in August-September using a carpet roller.

Cut-Stump Treatments

Often, saltcedar occurs within remnant stands of desirable native trees, shrubs or herbaceous cover. The use of mechanical treatments or foliar applied herbicides is limited because of the need to preserve native vegetation. Cut-stump treatments of saltcedar are being used in several areas in New Mexico. Current strategies are to remove the top growth during the winter using chainsaws and to immediately (within 10-15 minutes) apply a solution of 33% triclopyr plus 67% crop oil or diesel oil. Applications may be made by either low volume backpack sprayers or by brushing the solution onto the cut stump. With either application method, it is imperative that the cut stump be thoroughly treated in order to obtain root kill. Mortality rates following cut-stump treatments should be expected to be approximately 60-80%. Therefore, follow up treatments using ground-based foliar application techniques are recommended.

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RESTORATION WITH NATIVE SPECIES FOLLOWING SALTCEDAR REMOVAL

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Introduction

Historically, riparian communities of the Rio Grande and Rio Pecos were dominated by mosaics of cottonwood (*Populus* spp) and willow (*Salix* spp) forests, mesquite (*Prosopis pubescens*) and wolfberry (*Lycium andersonii*) brushlands, saltgrass (*Distichlis spicata*) and alkali sacaton (*Sporobolus airoides*) meadows and grasslands, and annual and emergent marshes (Crawford et al. 1993). These vegetative communities were established and maintained by spring flooding events that scoured the floodplain and provided soil disturbance and moist areas for germination of aerially dispersed or waterborne seed (Szaro 1989). Today, less water is available to maintain lower elevation riparian areas due to agricultural and urban water demands across the western landscape. Catastrophic flooding is now less frequent and historic river flow patterns have been altered which have impacted native vegetation recruitment and maintenance (Taylor et al. 1999). In this void, exotic species such as saltcedar and Russian olive have spread rapidly further degrading these once rich riparian habitat mosaics.

High wildlife diversity, particularly for bird species, characterizes native dominated habitat mosaics (Hink and Ohmart 1984). This diversity has been compromised with the expansion of exotic species and is the motivating force behind extensive efforts to control saltcedar and restore native riparian vegetation at the Bosque del Apache National Wildlife Refuge (refuge) near Socorro, New Mexico. Limited water resources present serious challenges to these restoration efforts. Sites have been restored under a variety of circumstances ranging from flood management mimicking natural river hydrographs for the recruitment of native species, to artificial revegetation on sites where flood management is not possible. Several key factors including depth to water table, flood frequency, soil texture, and soil salinity characterize riparian vegetative communities and dictate restoration potential (Anderson and Ohmart 1982).

Restoration Using Controlled Flooding

Controlled flooding coinciding with the natural seed rain of native species closely emulates natural regeneration processes. This technique is particularly effective when used in combination with mechanical saltcedar control which removes competing vegetation and provides light, soil minerals and nutrients for developing seedlings (Taylor et al. 1999). Native seed germination and plant growth is stimulated by soil disturbance and is influenced by key soil characteristics and hydrologic conditions inherent to the site. Flooding is also the natural process whereby soil salinity is reduced through leaching (Shafroth et al. 1995). Wetter sites with high groundwater and more frequent surface flow naturally develop vegetation suited for these conditions such as willow. Soil salinity is generally well leached at such locations. Drier sites with higher groundwater and limited surface flow are more characteristic of saltgrass meadows or mesquite brushlands (Bosque del Apache NWR, unpublished data).

On the Rio Grande and Rio Pecos, peak flood periods historically occurred in late May and early June as snow melted at higher elevations (Auble et al. 1994). Flood peaks were followed by precipitous drops in river flow as runoff moved through the river system. Native vegetation evolved to cope with these drying river conditions by quickly developing root systems to maintain contact with declining water tables. Although both native plants and saltcedar are established using controlled flooding, native plants are better able to survive dry conditions following flooding. For example, cottonwood mortality can be 70% after one year while saltcedar mortality can be over 90% (Dellorusso 1999, Taylor et al. 1999, Sprenger et al. 2002). These mortality rates result in a balanced mixture of native vs. exotic plants by the second year of growth. Cottonwoods are better able to compete for available soil nutrients and water and growth rates can be twice those of saltcedar (Dellorusso 1999). The resulting plant community is characterized by robust native species growth and saltcedar suppression in the understory.

Often, saltcedar can be easily controlled while preserving native seedlings through light discing in September following spring establishment (Smith et al. 2002). Native seedlings, particularly cottonwood, have deeper roots and heavier root structure than saltcedar seedlings allowing for high native seedling survival following light discing to control saltcedar. On more saline sites such as developing saltgrass meadows, light discing in July following spring seedling establishment can also control saltcedar while enhancing saltgrass growth by cutting and spreading remnant saltgrass rhizomes in moister soil substrates (Bosque del Apache NWR, unpublished data).

River flooding still occurs on some major southwestern river systems although less frequently than what once occurred historically. Overbank flooding events are now managed by river regulatory entities through a network of flood control dams and levees to protect agricultural irrigation infrastructure and urban communities. During cyclical periods of abundant snowfall in mountain watersheds water may be available in excess of agricultural and urban needs. Riparian restoration can occur concurrent to water delivery from upper storage reservoirs to those further downstream by matching historic river flow patterns within existing levee systems. In a more controlled setting, flooding for riparian purposes is possible on areas such as state and federal wildlife refuges or tribal lands outside river levees utilizing appropriated irrigation water.

Restoration Using Artificial Plantings and Seeding

Many sites along the Rio Grande and Rio Pecos have no natural or controlled flooding potential and must be revegetated artificially. Weed competition can often limit the survival and growth of planted materials (Anderson 1988). Managers should therefore consider treating saltcedar monocultures using herbicide-burn control practices which result in limited growth of competing weeds. Factors influencing revegetation potential have been documented for more common plant species. For example, some species can survive through contact with the water table, therefore it is important to know water table depth and its annual fluctuation (Swenson and Mullins 1985). Plant species also have thresholds for survival and growth based on soil and salinity parameters (Taylor and McDaniel 1998a). Many sites have not benefited from the leaching effects of flooding for many years and salinity levels are quite high. Some sites have such high salinities that revegetation is not possible. Clay soils should be avoided as planting substrates.

Considering the high costs associated with saltcedar control and revegetation, some preliminary information on these parameters should be gained prior to the selection of areas for saltcedar control. Preliminary site reconnaissance should evaluate water table depths through the establishment and monitoring of water table wells at key locations. Basic knowledge of soil salinity can be obtained using the electromagnetic induction method that measures apparent electrical conductivity across the soil profile non-invasively (Sheets et al. 1994). Although accuracy is limited beyond very low electrical conductivity readings, the instrument can help determine site suitability for some plant species that require low salinity levels for establishment and growth.

Following saltcedar control, detailed information is required to develop accurate planting prescriptions in the field to assure restoration success. The most practical method involves development of a grid system across the area with each grid cell consisting of one-half acre (Taylor and McDaniel 1998b). Soil samples are taken at the center of each grid, 15 inches below the soil surface and 18 inches above the water table and sent to a soil laboratory specializing in riparian revegetation for analysis to determine soil texture and electrical conductivity. From this information, a series of contour maps are generated outlining water table depth, soil texture and salinity. Field planting crews are provided with grid sheets outlining plantings based on species survival and growth tolerances to water table depth, soil texture, and soil salinity (Table 2).

Cottonwood and willow trees and shrubs are planted using dormant poles augered to the water table to establish forested areas (Swenson and Mullins 1985). This technique requires cutting saplings of sufficient length and small butt diameter during winter months. All lateral branches are trimmed leaving only 2-3 apical branches prior to soaking butt ends in water for a 10 day period prior to planting. On average, a 3-person crew is able to auger and plant 150-180 poles per day using a large production auger drilling machine (Taylor and McDaniel 1998b). Understory plantings can be made using 30 inch container nursery stock augered into water tables of generally 5 ft or less and at locations where electroconductivity reading are less than 8.0 (Fenchel et al. 1996). This technique relies on root development to the water table. Plantings are usually made in August and require supplemental water for a 1-2 month period. Planting density is about 100 trees or shrubs/acre, a density shown to benefit wildlife (Anderson and Ohmart 1982). Plant survival for both techniques is about 90% after 4 years with about a 24% annual growth rate (Taylor and McDaniel 1998).

Where water tables are deep and/or electroconductivity readings are high, other establishment techniques must be used. Rainfall harvest is one such method for establishing seedling shrubs where electrical conductivity levels are below 8.0 (Oaks et al. 1993). A road grader is used to construct a long shallow V-shaped water catchment. Seedlings are planted at 5 foot intervals at the bottom of the catchment and the banks are lined with plastic. Seedlings obtain supplemental water from surface rainfall or undersurface condensation funneled from the plastic to seedling root zones. Survival and growth rates are comparable to poles and containerized stock.

In areas of higher electroconductivity (8-14), seeding mixtures of 4-wing saltbush and salt tolerant grasses such as alkali sacaton are prepared and seeded following the onset of summer rains (Bosque del Apache NWR, unpublished report). Sites where electroconductivity levels are above 14.0 cannot be revegetated successfully (Anderson and Ohmart 1982). Seed can often take up to 4 years to germinate and growth can be slow depending on the timing and amount of late summer and winter precipitation.

Overall revegetation costs can range between $1,100 and $1,500 per acre (Taylor and McDaniel 1998b). These costs include site suitability potential analysis, plant materials, and labor. Over 80% of costs associated with revegetation are plant materials. Costs for plant materials can often be reduced for cottonwood and willows through harvest at natural nursery sites along rivers and ditches. Only 5% of total costs are associated with site suitability determination, quite low when the importance of this activity is considered.

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Table 1. Cottonwood and saltcedar plant recruitment using controlled flooding and percent survival after one year on the Bosque del Apache National Wildlife Refuge, New Mexico.

	Cottonwood			Saltcedar		
Site	1st Year	2nd Year	% Survival	1st Year	2nd Year	% Survival
Rio Grande[1]	5	1	20%	112	5	4%
Unit 30[2]	30	16	47%	69	6	9%
Unit 26[1]	26	9	22%	22	3	14%

[1] median values
[2] mean values

Table 2. Water table depth, soil texture, and soil electroconductivity requirements for revegetation on the Bosque del Apache National Wildlife Refuge, New Mexico

Species	**Water table depth**	**Soil texture**	**Soil Electroconductivity (dS/m)**
Cottonwood	5-13 feet	Sandy-Loamy	<1.0-2.0
Black Willow	3-6 feet	Sandy-Loamy	<1.0-2.5
New Mexico Olive	< 5 feet	Sandy-Loamy	<1.0-2.5
Screwbean	< 5 feet	Sandy-Loamy	2.5-8.0
Wolfberry	< 5 feet	Sandy-Loamy	2.5-8.0
4-Wing Saltbush	< 15 feet	Sandy-Loamy	8.0-14.0

INITIAL RESULTS OF BIOLOGICAL CONTROL OF SALTCEDAR (TAMARIX SPP.) IN THE UNITED STATES

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Introduction

Saltcedars (*Tamarix* spp., family Tamaricaceae) are deciduous shrubs or small trees of riparian areas in deserts and steppes, ranging from Japan to western Europe and down to South Africa. They are commonly used as ornamentals, for windbreaks and shade, and to stabilize soil. Following the intentional introduction of around 10 species of saltcedar into the United States and Mexico beginning in the early 1800s, a few species (primarily *T. ramosissima, T. chinensis,* and their hybrids) have become highly invasive in riparian areas, especially in the southwestern United States (Baum 1967, Crins 1989, Gaskin and Schaal 2002, Robinson 1965). Several characteristics of saltcedar have contributed to its invasion of such areas. They produce large amounts of small seed throughout the season, which are windblown or waterborne, and they reproduce vegetatively. Saltcedars are facultative phreatophytes, utilizing either ground water or soil moisture, and possess deep taproots up to 30 m long. Saltcedars can utilize saline groundwater and excrete the excess salts through leaf glands. They are tolerant of a wide range of growing conditions, drought, flooding, fire and the destruction of aboveground parts, such as by animal browsing and mechanical and some chemical control methods (Crins 1989, DeLoach 1991). Both anthropogenic changes in western riparian ecosystems which created ideal conditions for saltcedar invasion, as well as the ability of saltcedar to move into and modify undisturbed environments, has created what is considered to be an ecological disaster for watersheds of the West (DeLoach et al. 2000).

Prospects for Biological Control

Biological control involves the use of natural enemies to suppress a pest population, decreasing the damage that it causes (Van Driesche and Bellows 1996). A few *Tamarix*-feeding insects and mites were accidentally introduced along with saltcedar into the United States, but the damage inflicted by these particular species does not seriously harm the plants. Little feeding by native insects on saltcedar has been reported, although many insects visit the flowers (DeLoach et al. 2003). However, over 300 host-specific insects exist throughout the range of saltcedars in the Old World (Kovalev 1995). Several are considered to be pests of saltcedar, some of which can be quite damaging (DeLoach et al. 2003, Kovalev 1995). Therefore, ample opportunities exist to select candidate insect agents that potentially can control saltcedar. However, an effective agent must also be safe to introduce into a new area, i.e., damaging only to the plant targeted for control. The saltcedar family Tamaricaceae is restricted to the Old World and only one other closely related plant genus (*Frankenia*, family Frankeniaceae) exists in both the Eastern and Western Hemispheres. Only two insects have been reported feeding on both saltcedars and *Frankenia* (Kovalev 1995). Hence, the likelihood that a particular insect agent will attack non-saltcedar plants in North America should be very low to non-existent. The standard procedure required of all weed biological control programs is to confirm this experimentally. In the case of saltcedar, *Tamarix aphylla* (athel) and species of *Frankenia* are considered to be "critical test plants", in which serious damage to these plants by candidate biological control agents is unacceptable. Athel is an evergreen, tree-sized species that is used as an ornamental and shade tree in some areas, especially Mexico. Six species of *Frankenia* are found in areas of the U.S. and Mexico where saltcedar has invaded, one of which, *F. johnstonii*, is federally listed as endangered although it may soon be delisted (Lewis et al. 2003a).

Biological Control Program

Cooperative surveys to identify potential biological control agents of saltcedar were initiated by the United States Department of Agriculture, Agricultural Research Service (ARS) in the late 1960s. Surveys were conducted in Israel, India, Iran, and Turkey (Gerling and Kugler 1973), in Pakistan (Habib and Hassan 1982), and in Turkey (Pemberton and Hoover 1980). Saltcedar research at the ARS Grassland, Soil and Water Research Laboratory at Temple, TX began in 1986 and is ongoing (DeLoach 1991). Similar research has been conducted at the ARS Exotic and Invasive Weed Research Unit at Albany, CA since 1998, and overseas testing of control agents is taking place at cooperating laboratories in France, Israel, China, Turkmenistan, and Kazakhstan. To date, three insects have been tested in quarantine at the Temple laboratory and petitions for release submitted to the Technical Advisory Group for Biological Control Agents of Weeds (TAG), an advising body to the USDA Animal Plant Health and Inspection Service, Plant Protection and Quarantine (APHIS). These include a leaf-feeding beetle, *Diorhabda elongata deserticola* (Coleoptera: Chrysomelidae), a mealybug, *Trabutina mannipara* (Homoptera: Pseudococcidae), and a leaf-feeding weevil, *Coniatus tamarisci* (Coleoptera: Curculionidae). All three insects have been recommended for release by TAG; however, only the leaf beetle, *D. elongata deserticola*, has been approved by APHIS for release.

The petition submitted to TAG in March 1994 asked for their recommendation (provided in October 1994) for open field releases of *D. elongata deserticola* imported from China and Kazakhstan. However, in February 1995 the southwestern subspecies of the willow flycatcher (*Empidonax traillii extimus*) was listed as federally endangered. This bird was found nesting in saltcedar, especially in some areas of Arizona (Finch and Stoleson 2000). Therefore, consultation was required with the U.S. Department of the Interior, Fish and Wildlife Service (FWS) under the Federal Endangered Species Act of 1973 and the National Environmental Policy Act. A Biological Assessment had to be prepared (DeLoach and Tracy 1997) and an additional

Research Proposal was required and submitted to the FWS in August 1998 (DeLoach and Gould 1998). The FWS agreed to allow releases of the leaf beetle into field cages in June 1999. An Environmental Assessment was prepared by APHIS in March 1999, and a Finding of No Significant Impact was issued by APHIS on 7 July 1999. Release permits for *D. elongata deserticola* were therefore issued during July and August 1999.

These initial permits were limited to a research phase in which the beetles were to be released into secure field cages at 10 specified sites in Texas, Colorado, Wyoming, Utah, Nevada and California. The beetles were to be monitored in the cages for 1 year to determine their overwintering ability, other mortality factors, rate of increase, and damage to saltcedar and non-target plants in the cages. The beetles then could be released into the open field for a 2-year period, during which the degree of control, dispersal and effects on native plants and insects would be monitored. At the end of this 3-year research period, FWS, ARS, and APHIS would review the research results and decide how the Implementation Phase (wider distribution of the insect) would proceed.

Biology of *Diorhabda elongata deserticola*

The biology of the leaf beetle originating from Fukang, China and Chilik, Kazakhstan was studied in the U.S. and is reported below (Lewis et al. 2003b). It is generally similar to reports of the beetle's biology from China and Kazakhstan (Li and Ming 2001, 2002; Mityaev and Jashenko 1999-2002). Both adults and larvae feed on the foliage of saltcedar. The 3rd instar (final stage) larvae do most of the damage, which consists of both consuming the foliage and feeding on the bark of small twigs, causing the terminal foliage to die. The beetles overwinter as adults under litter beneath the trees. Overwintered adults in Colorado and Wyoming (see Field Cage Releases below) emerge during late-April and early-May and egg laying occurs during May. Larvae develop during May and June, and pupate in the leaf litter. The 1st generation of adults is produced in late-June to mid-July. In areas where daylength is sufficient, reproduction occurs and a 2nd generation of adults is produced from mid-August through September. These adults overwinter without reproducing.

Based on a literature review and overseas surveys, *D. elongata deserticola* was expected to be highly host-specific, being recorded only from *Tamarix* spp. and occasionally from *Myricaria* spp. (an Old World plant in the same plant family) (DeLoach et al. 2003, Lewis et al. 2003a). Host range tests were conducted in quarantine from 1992 to 2000 at Temple, TX and Albany, CA utilizing various *Tamarix* spp. and hybrids and 58 other species of plants. As mentioned previously, special attention was paid to larval development and adult egg laying on *T. aphylla* (athel) and *Frankenia* spp. In greenhouse and laboratory tests, the percentage survival of neonate larvae to adulthood ranged from 55-67% on *Tamarix* spp. (55% on athel), 12% on the related *Myricaria* sp. (found only in the Old World), 2% on *Frankenia* spp., and 0% on all other plants (DeLoach et al. 2003). Additional tests focusing on *Frankenia* spp. as potential hosts showed higher larval survival, in one test up to 60% on *F. palmeri* (Lewis et al. 2003a). However, adult beetles exposed simultaneously to *Tamarix* and *Frankenia* spp. in large, outdoor field cages at Temple readily laid eggs on *Tamarix* spp. (including athel) but rarely on *Frankenia* spp. One-half as many eggs were laid on athel as compared to saltcedar. If no saltcedar was present in the cages, only a couple adult beetles and no eggs were found on the *Frankenia* plants. Rather, most adults and all the eggs were found on the cage walls (Lewis et al. 2003a). Additional field cage observations, in which potted *Frankenia* plants (*F. jamesii* or *F. salina*) were placed inside cages containing field-grown saltcedar and several hundred adults and larvae of *D. elongata deserticola*, revealed only limited feeding and a couple eggs on the *Frankenia* plants, in contrast to the severe defoliation of the saltcedar (Lewis et al. 2003a). Hence, it is expected that there will be some feeding and reproduction on athel, although to a lesser extent than for saltcedar, but little attraction to or egg-laying on *Frankenia* in the field. Therefore, *D. elongata deserticola* from Fukang, China and Chilik, Kazakhstan are considered safe to release in the field.

Field Cage Releases: July 1999 to May 2001

The leaf beetle was released into field cages at 10 sites in six western states – at eight sites during summer 1999 and at the remaining two sites the following year. The cages were located on public or private lands near Seymour, TX; Lockwood, Bishop and Woodland, CA; Pueblo, CO; Delta, UT; Schurz, Fallon and Lovelock, NV; and Lovell, WY. Beetles originating from Fukang, China were used at all sites except one (Delta, UT) where beetles from Chilik, Kazakhstan were used instead. The beetles overwintered very well in the field cages at 6 of the northern sites (Lovell, WY; Schurz and Lovelock, NV; Delta, UT; Pueblo, CO; and Bishop, CA) and less well at Fallon, NV and Woodland, CA. They failed to overwinter at the two most southern sites (Seymour, TX and Lockwood, CA). Two generations of larvae were produced, the life stage most damaging to saltcedar. At some sites the beetles increased in numbers such that the enclosed saltcedar plants were completely defoliated in both 1999 and 2000.

At the Seymour site, adult beetles were replaced in the cages in April and May of 2000 and 2001. In both years, good reproduction occurred and larvae defoliated plants during June. However, the 1st generation adults that emerged in late June did not reproduce but instead entered diapause (a state of dormancy) and subsequently failed to overwinter. Similar results were observed at Temple, TX. Based on additional observations and experiments with cooperators, the most likely explanation for the lack of overwintering success at Seymour is that the adult beetles require long summer daylengths to remain reproductive. Beetles originating from Fukang, China, that were released at most of the field sites, require daylengths greater than 14 hr 45 min to avoid entering diapause. The maximum summer daylength at Fukang (44º17′ N) is 15 hr 30 min. Maximum daylength at Seymour (33º35′ N) is 14 hr 21 min while at Temple (31º10′ N) it is only 14 hr 10 min. Therefore, the beetles in Texas enter diapause in early July and presumably use up their fat reserves, starving before new saltcedar foliage becomes available the following March (Lewis et al. 2003b).

Open Field Releases: May 2001 to Early Spring 2003

Open field releases were made at the six northern sites where good overwintering occurred and also at Seymour, TX where beetles were replaced in the cages after failing to overwinter. Field releases were not made at the other three locations. Beetles were liberated from the field cages during May or June 2001 except for small colonies that were maintained in the field cages.

During the summer of 2001, a few to moderate numbers of beetles (eggs, larvae and adults) were found during weekly surveys at all locations except Seymour until late-August/early-September. At this time the beetles were assumed to have entered overwintering diapause. No egg laying was observed at Seymour following the initial release and no adults were recovered. Feeding damage to saltcedar was minor this first summer. The most damage occurred at Pueblo, CO where approximately two-thirds of a large tree was defoliated. This saltcedar plant was 10 m away from the initial release point.

Beetle densities and feeding damage were similar during the spring and early summer of 2002. Beetles had dispersed some 50 to 100 m in radius from the release point. Extensive feeding damage and defoliation of entire trees was observed at Lovelock, NV and Pueblo, CO in August 2002 when larvae of the 2nd generation reached the 3rd instar, the final and largest larval stage. By late August at Lovelock, NV the beetles had nearly defoliated all the saltcedar trees in an area 100 m in diameter. This was due to both consumption of the foliage and girdling of small twigs. Additional heavy feeding had occurred in a concentric ring 50 m wide outside the defoliated area.

Substantial feeding damage also occurred at Lovell, WY. However, many beetles were killed by ants at the release site, which may have prevented the population build-up of the beetles. No feeding damage was observed at the three remaining release sites, and establishment in the open field appears to be limited or has not occurred, probably due to predation by birds or ants or premature overwintering of the adults. The increase and dispersal of beetle populations and damage to saltcedar continue to be monitored at the release sites, as well as changes in the plant, bird, and butterfly communities.

Future Prospects

The leaf beetle from Fukang, China and Chilik, Kazakhstan appears promising in northern areas, where it has established and spread. The amount of defoliation necessary to kill saltcedar, especially large trees, and thus provide satisfactory control remains to be seen. Nevertheless, preliminary results two years after initial releases are encouraging. New release sites throughout the range of saltcedar are being requested of the FWS and APHIS.

At release sites south of the 38th parallel, where daylengths do not exceed 14 hr 45 min during the summer, the beetles have not established. Research is therefore underway with leaf beetles from other locations in the Old World that have daylength requirements of less than 14 hr 45 min. We are currently assessing how much, if any, damage they cause to non-saltcedar plants and whether they can successfully overwinter. For example, leaf beetles from Crete, Greece have a similar host range to those from Fukang. They also survived the 2002-2003 winter with apparently little mortality in field cages at Temple and reproduced very well starting in April. If approved for release, such beetles could establish in Texas and other areas in the southern range of saltcedar.

Diorhabda beetles may fail to establish at some locations for various reasons, such as continued issues with premature diapause induction or predation. Furthermore, adequate control of saltcedar at certain locations may require the use of additional species of biological control agents. Testing in France, Israel, Kazakhstan, and China has begun or is completed on ca. 20 insect species that attack saltcedar in a variety of ways (leaf feeders, sap suckers, flower gallers, stem gallers, root gallers). We plan to include tests addressing their safety from predators such as fire ants.

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Saltcedar Project Updates

COLORADO RIVER SALTCEDAR CONTROL PROJECT

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Introduction

The Colorado River, measured in length and drainage area, is the largest river wholly in the State of Texas. The headwaters are located in northeastern Dawson County (32° 41'N, 101° 44'W), from which the Colorado then flows generally southeastward for 600 miles until it drains into Matagorda Bay (28° 36'N, 95° 59'W). Its drainage area is 39,900 square miles, and its runoff reaches a volume of more than 2 million acre-feet near the Gulf. Major impoundment's as water flows down the river include Lake J.B. Thomas (Borden and Scurry Counties), E.V. Spence Reservoir (Coke County), O.H. Ivie Reservoir (Coleman, Concho, and Runnels Counties), Lake Buchanan (Burnet and Llano Counties) and Lake Travis (Travis County).

Extent of Saltcedar Infestation

At present, saltcedar has invaded the upper Colorado River and its tributaries from the headwaters above Lake J.B. Thomas to the dam at O.H. Ivie Reservoir, a distance of more than 170 river miles, including the basins of Spence and Ivie Reservoirs. Decreasing water levels at Spence Reservoir and Ivie Reservoir have exacerbated the saltcedar problem, exposing new shoreline to invasion. At present Lake Spence is at 6% capacity with approximately 7000 acres of saltcedar. Ivie Reservoir is at 37% of capacity with approximately 9,000 acres of saltcedar. Saltcedar extends on both of these reservoirs from current water lines to conservation pool level. It is important to note there were no known populations of saltcedar within the Ivie Reservoir basin prior to 1995.

The total acreage of saltcedar within the upper Colorado River Watershed (Ivie Reservoir and above), as determined by satellite imagery, is estimated to be 22,518 acres (Table 1). It is unknown the degree of infestation or acreage of saltcedar on the 190 miles of Colorado River between Ivie Reservoir and Lake Buchanan. Saltcedar was found for the first time on the upper end of Lake Buchanan, 3 years ago under low water conditions. That population was submerged shortly thereafter following heavy rains within the watershed above. Acreage of saltcedar above Lake Thomas, near the headwaters of the Colorado River has also not been determined. In this area, saltcedar populations are scattered and intermixed with other native species and difficult to classify using satellite imagery.

Table 1. Estimated saltcedar acreage within the Colorado River watershed as determined by satellite imagery (Data supplied by Texas Department of Agriculture and the UT Center for Space Research).

River/Tributary	Miles	Acres
Colorado River	169	3228
Bull Creek	12	144
Bluff Creek	17	204
Willow Creek	25	300
Deep Creek	22	264
Champion Creek	10	120
Beals Creek	64	768
Oak Creek	5	30
Valley Creek	10	60
Quarry Creek	14	84
Coyote Creek	2	12
Elm Creek	9	54
Champion Creek Reservoir		500
Lake Colorado City		750
Lake Spence		7000
Lake Ivie		9000
Total		22518

Colorado River Saltcedar Task Force

To address the issue of saltcedar control along the upper Colorado River, the Texas Cooperative Extension (TCE) organized a task force to begin development of a management plan. The first meeting was held in San Angelo, Texas on February 15, 2001. Represented on the task force were representatives from Texas Parks & Wildlife Department (TPWD), Colorado River Municipal Water District (CRMWD), Natural Resources Conservation Services (NRCS), Texas

State Soil & Water Conservation Board (TSSWCB), North Star Helicopters, BASF Chemical Co., Texas Department of Agriculture (TDA), Texas Agricultural Experiment Station (TAES) and the Upper Colorado River Authority (UCRA). Later task force meetings grew to include the Lower Colorado River Authority (LCRA), Texas Farm Bureau, U.S. Army Corps of Engineers (USACE), USDA-ARS, U.S. Fish & Wildlife Service (USFWS) and Dow AgroSciences.

One of the first actions taken by the task force was to identify issues that needed to be addressed to allow development of a saltcedar control plan. The two primary issues identified were current spraying restrictions to protect the Texas poppy-mallow and the need to accurately map saltcedar populations within the watershed.

Endangered/Threatened Species

The highest priority issue identified by the Colorado River Saltcedar Task Force was the current restriction under the Arsenal 24(c) label that prohibited spraying within 2 miles of the Colorado River in Coke, Mitchell and Runnels counties for protection of the endangered Texas poppy-mallow *(Callirhoe scabriuscula)*. These three counties lie within the middle of the Colorado River saltcedar infestation. The 2 mile spray buffer from the Colorado River prohibited development of any effective saltcedar control program.

To address this issue, task force members from TCE, CRMWD, and TDA began informal consultation with the USFWS to investigate control options that would allow treatment of saltcedar without risk to the Texas poppy-mallow. For two years these task force members worked on this issue culminating in an amended Arsenal 24(c) label that satisfied the USFWS, TDA and the U.S. Environmental Protection Agency (EPA).

Fortunately, the Texas poppy-mallow is restricted to specific soil types (Tivoli and Brownfield Sands). It was agreed that saltcedar could be successfully sprayed on the Colorado River without risk to the Texas poppy-mallow for the following reasons:1) these soils are located on uplands, usually on the north side of the river, and are not found associated with saltcedar along the river or within the lake basins, 2) current herbicide application technology (rotary-wing aircraft, large droplet sizes, and GPS guidance systems) allows spraying of saltcedar with minimal drift, 3) Arsenal has only a 25 to 142 day half-life in generic soils, 4) the optimal spray window for saltcedar control is the dormant season for Texas poppy-mallow, and 5) Arsenal has no known activity on seed germination. Specifically the amended Arsenal 24(c) (1/17/03) reads

> "*To prevent impacts to the federally endangered Texas poppy-mallow, all aerial applications within 1/4 mile of Tivoli or Brownfield sands in Coke, Runnels and Mitchell counties must be made by rotary-wing aircraft using controlled droplet nozzles and boom configurations and air speeds below 60 mph to achieve an average spray droplet size of 1000 microns or greater. In addition, a 60 ft aerial spray buffer in topography or lateral distance from the Tivoli and Brownfield sands must be maintained at all times*" The amended label places no restrictions on the effective control of saltcedar along the Colorado River.

During the consultation process with the USFWS concerns were raised about the impact of saltcedar control efforts on the threatened Concho water snake *(Nerodia harteri paucimaculata)*. This concern was successfully addressed because, 1) Arsenal is virtually non-toxic to mammals, birds, fish and aquatic invertebrates, 2) Arsenal does not accumulate in fish tissues, which is important to the snake because of its piscivorus diet, 3) the Concho water snake is rarely found more than 3 ft from the water or exposed on open land, thus spray exposure will be minimal and 4) most importantly, saltcedar seriously degrades instream flows, which in turn degrades Concho water snake habitat.

Mapping Saltcedar Populations

The Colorado River Saltcedar Control Task Force identified mapping of existing saltcedar populations along the Colorado River as the second priority before development of a management plan could begin. The TDA provided leadership for this task. Because there was no budget to support the mapping, and the mapping would cover an area many counties in size, low cost Landsat ETM+ imagery was used. The low resolution of this imagery did not allow accurate differentiation of desirable woody plants growing within saltcedar areas, but did provide general estimates of saltcedar acreage's along the river and its many tributaries (Table 1). The University of Texas Center for Space Research provided assistance in GIS analysis of this imagery.

Saltcedar Control Plan for Upper Colorado River

Once the endangered species constraints on spraying were eliminated and basic mapping data was available, the Colorado River Saltcedar Task Force began development of an integrated control plan, from the headwaters above Lake Thomas to the dam at Lake Buchannan. The upper Colorado River was divided into 6 segments, with treatments sequenced over a 7-year period. The objective of the plan is to begin treatment at the headwaters above Lake Thomas, moving in an orderly fashion downstream treating all major tributaries and lake basins. The plan integrates biological (leaf beetle, *Diorhabda elongata*) with chemical control techniques to extend treatment life. A basic outline of the control plan follows:

Year 1

Segment 1 (Headwaters to Lake J.B. Thomas Dam) Because of the scattered populations of saltcedar above Lake Thomas, this segment will be treated using biological control options only (*Diorhabda elongata*). The Lake Thomas dam provides a barrier to seed dispersal down river. The goal of implementing biological control within this segment will be to further reduce seed production.

Segment 2 (Lake J.B. Thomas dam to top of E.V. Spence Reservoir basin). This river segment is estimated to be 100 miles long with an average band of saltcedar 200 feet wide along each side of the river. There are also several major tributaries within this segment. Total acreage to be treated is estimated at 4,200 acres. The river and tributaries will be treated with a ½ gal/ac rate of Arsenal using rotary-wing aircraft.

Segment 6 (O.H. Ivie Reservoir dam to Lake Buchanan dam). This segment is not thought to support a significant stand of saltcedar, although seedlings were found in the Lake Buchanan basin three years ago. Higher water levels have inundated those seedlings. The river portion of this segment will be surveyed on a bi-annual basis. Individual plant treatment methods or restricted ground broad cast methods will be used to control seedlings and isolated stands as they are found.

Year 2

Segment 3 (E.V. Spence Reservoir basin). An estimated 7,000 acres of saltcedar is now present in the E.V. Spence Reservoir Basin. The area will be treated with a ½ gal/ac rate of Arsenal using a combination of fixed-wing and rotary-wing aircraft. Rotary-wing aircraft will be used to treat any saltcedar occurring within 400 yards of Texas poppy-mallow habitat. Fixed-wing aircraft will be an option for the remainder of the basin.

Year 3

Segment 4 (E.V. Spence Reservoir dam to head of O.H. Ivie Reservoir basin). This segment includes 69 miles of river and several tributaries with an estimated 1068 acres of saltcedar. Treatment will be by rotary-wing aircraft using a ½ gal/ac rate of Arsenal.

Segment 6 (O.H. Ivie Reservoir dam to Lake Buchanan dam). The river portion of this segment will be surveyed on a bi-annual basis. Individual plant treatment methods or restricted ground broad cast methods will be used to control seedlings and isolated stands of saltcedar as they appear.

Year 4

Segment 5 (O.H. Ivie Reservoir Basin). Approximately 9,000 acres of saltcedar are present in the O.H. Ivie Reservoir basin. Because of the irregular shoreline, this segment will be treated using primarily rotary-wing aircraft and a ½ gal/ac rate of Arsenal.

Segment 2 (Lake J.B. Thomas Dam to beginning of E.V. Spence Reservoir Basin). Biological control (*Diorhabda elongata*) will be introduced 3 years post spraying to extend overall treatment life.

Year 5

Segment 3 (E.V. Spence Reservoir basin). Biological control (*Diorhabda elongata*) will be introduced 3 years post spraying to extend overall treatment life.

Segment 6 (O.H. Ivie Reservoir dam to Lake Buchanan dam). The river portion of this segment will be surveyed on an annual basis. Individual plant treatment methods or restricted ground broad cast methods will be used to control seedlings as they appear.

Year 6

Segment 4 (E.V. Spence Reservoir dam to top of O.H. Ivie Reservoir Basin). Biological control (*Diorhabda elongata*) will be introduced 3 years post spraying to extend overall treatment life.

Year 7

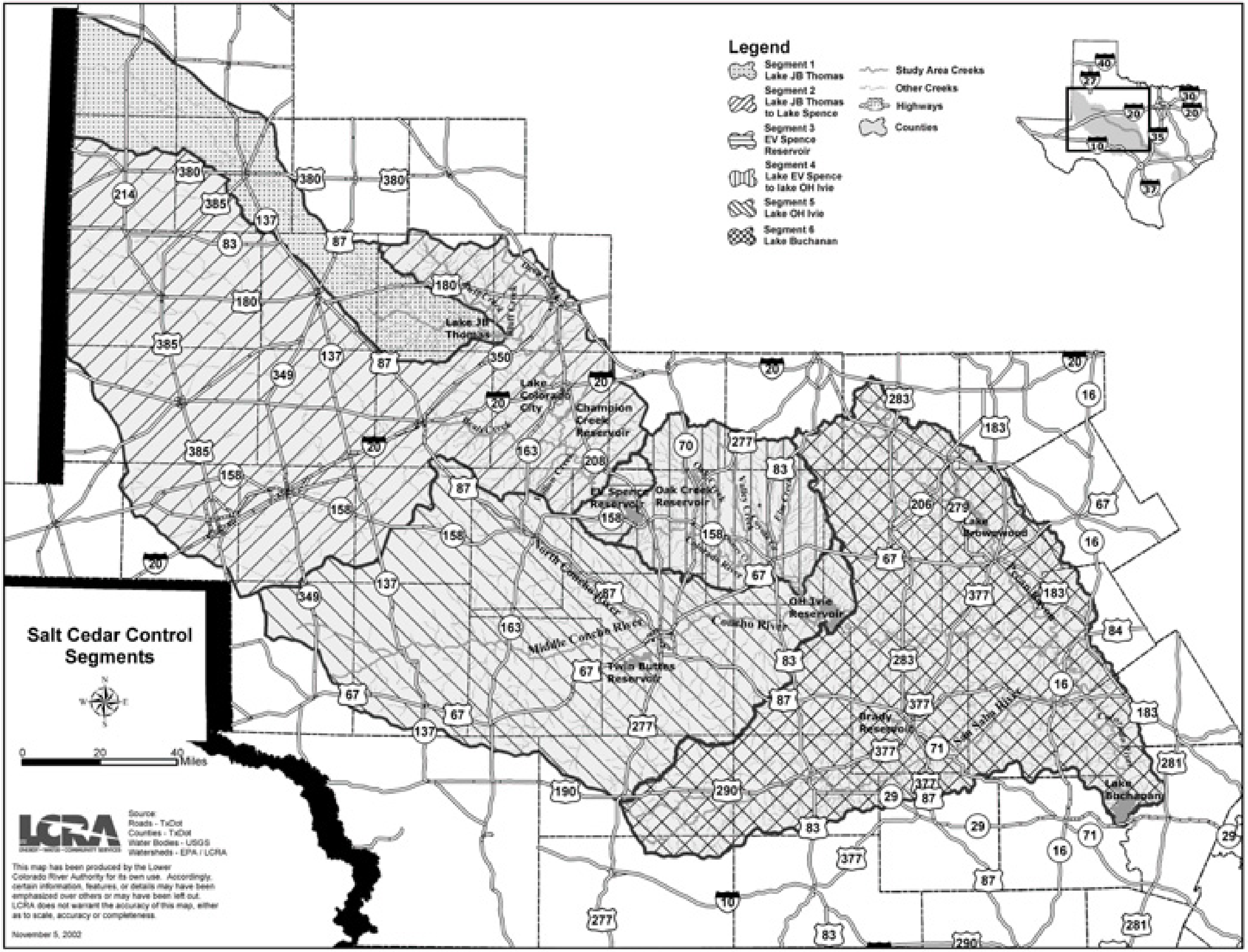
Segment 5 (O.H. Ivie Reservoir Basin). Biological control (*Diorhabda elongata*) will be introduced 3 years post spraying to extend overall treatment life.

The estimated cost of this 7-yr program is $5 million. The program is designed to be flexible to meet funding constraints, while ensuring treatments occur in an orderly fashion from the headwaters downstream.

To document any increased river flow following treatment, USGS gauging stations within the treatment segments will be used. Monthly water quality samples collected by CRMWD personnel for Clean Rivers Program (CRP) monitoring will be evaluated in an effort to measure river salinity changes that may result from saltcedar control. Discharge measurements are also made at the CRP monitoring sites. These measurements will supplement river flow data acquired from the USGS gauges.

Recent Developments

As of spring 2003, a proposal has been submitted to obtain Clean Water Act Section 319(h) funding to initiate spray treatments in late summer 2003. State funded watershed brush control efforts by the TSSWCB in the Champion Creek watershed are being used as cost-share to obtain this funding. If funding is granted, the local Soil & Water Conservation Districts in the upper Colorado River basin will administer the program under technical guidance by the TCE, NRCS and the CRMWD.



Salt Cedar Control Segments

Source:
Roads - TxDot
Counties - TxDot
Water Bodies - USGS
Watersheds - EPA / LCRA

This map has been produced by the Lower Colorado River Authority for its own use. Accordingly, certain information, features, or details may have been emphasized over others or may have been left out. LCRA does not warrant the accuracy of this map, either as to scale, accuracy or completeness.

November 5, 2002

THE PECOS RIVER ECOSYSTEM PROJECT

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Background of Situation

Historically, the mighty Pecos River was a barrier not easily traversed by the likes of John Chisolm during early day cattle drives in the 1800s. Its flow varied from a torrential current to a shallow, wide meandering river. From Ft. Sumner, NM to Langtry, TX, the Pecos River could be crossed in about 7 locations, each with its own name. Contrast that with the current description of the Pecos River as a narrow, deeply incised channel with very little base flow resulting in the appearance of a stream rather than a river. Cattle can cross the river, just about anywhere they choose… if they can get through the saltcedar to the river.

The river was and continues to be the life blood of agricultural interests along its stretch through New Mexico and Texas. Today, in the northern portion of the river in Texas, it is not a naturally flowing river, but primarily an irrigation delivery system. Water is released from Red Bluff Lake to seven lower irrigation districts, generally during the months of March through September supporting mainly cotton, melons, and alfalfa production.

It is not known exactly when and where saltcedar was first introduced to the Pecos River, but the plant has spread down river and has created an ecological disaster along its entire length in New Mexico and Texas. Saltcedar and mans activities to harness the river for agricultural uses have led to an ecological transformation of the river. Saltcedar has been recognized by both states as a serious problem since meetings in the 1940s to establish the Pecos River Compact Commission. Control efforts, primarily mechanical, have been initiated in the past, but with little lasting effect. The negative effects of high water use by saltcedar resulting in lowered water tables and decreased river flows have been compounded with a serious drought in the region for the past 7-10 years.

Project History

Saltcedar forms a near continuous buffer along both banks of the Pecos River from Red Bluff Dam southward for the entire area (approx. 180 river miles) of the Red Bluff Irrigation District. Within this stretch of river, it averages about 30 to 40 acres per river mile or 150 feet on each river bank. Additionally, the Pecos River in Texas is a meandering stream with a ratio of river miles to air miles of about 3 to 1. A primary concern of efforts to control saltcedar was to minimize effects on native vegetation to facilitate re-stabilization of stream banks. This situation created a real challenge for any saltcedar control program.

The Pecos River Ecosystem Project was proposed by the Red Bluff Water and Power Control District in 1997 to address saltcedar issues along the Pecos River. The initial objectives of the project were to increase efficiency of water delivery in the river to irrigation districts within the Red Bluff District, restore the native ecosystem, and improve the quality of the water. After four years of herbicide application on the saltcedar, the project has emerged as the first step to what could be important to the overall statewide plan for water conservation along Texas' rivers by managing saltcedar infestations. Success of the Pecos River Ecosystem Project can be attributed mainly to its cooperative effort and organization. Numerous agencies, organizations, and companies were involved in the organizational efforts early in the project development, listed below.

- Upper Pecos Soil and Water Conservation District
- Texas Cooperative Extension
- Texas Department of Agriculture
- USDA Natural Resources Conservation Service
- Red Bluff Water and Power Control District
- Irrigation Districts in Loving, Reeves, Ward and Pecos Counties
- US Environmental Protection Agency
- Pecos River Compact Commission
- International Boundary and Water Commission
- BASF
- Local landowners

The first step undertaken by the group was to develop a section 24(C) special use label to use Arsenal™ herbicide on saltcedar within rangeland and aquatic areas in Texas. The label was prepared by the Pesticide Division of the Texas Department of Agriculture and approved for use in 1999. The project was setup with two major phases, saltcedar treatment phase and debris removal phase. Also of major concern to the project group was the revegetation of the river banks with native plants to complete the ecosystem restoration. Once the label and initial funding were secured, the project was ready to begin the first phase of herbicide treatments. The Upper Pecos Soil and Water Conservation District Board of Directors were selected to administer the project.

Phase one of the project began in October 1999. During the initial meetings to begin planning the process of saltcedar removal, several major concerns emerged. First, the treatment method selected should provide a high rate of saltcedar mortality while minimizing the detrimental effects on existing native vegetation. Second, this should be accomplished in the most economical way possible. And finally, soil loss from stream banks should be minimized as much as possible. Another daunting task was to obtain permission from private landowners to treat saltcedar along the river as most of the land was under private ownership. A "spray easement" was developed and used as a contract between the Project and private landowners, allowing access for treatment and follow-up management for a 10 year period. To date, over 800 easements have been signed by private landowners, with a rejection rate of less than 1%. Bids were solicited from aerial applicators in late summer 1999 with the project ultimately being awarded to North Star Helicopters from Jasper, Texas. With funding, landowner permission, and applicator contract in hand by August 1999, initial treatments began in September.

Project Accomplishments

Applications of 4 pints a.i./acre of Arsenal™ were made with helicopter applying the herbicide with large droplets and high total spray volume. The helicopter had the advantage of being able to fly at slower air speeds compared to fixed-wing aircraft, which made the sharp turns of the river much easier to navigate. The helicopter application also provided for much higher precision of application by utilizing specialized nozzle and boom technology. The herbicide was applied in a total spray volume of 15 gallons per acre with a 1500µ droplet. Less than 1% of the droplets were driftable fines (<200µ). The boom was also sectioned into 3 – 15 ft. sections for an overall width of 45 ft. Combinations of the boom could be turned on to allow for a 15, 30 or 45 ft. swath width. This further reduced the amount of herbicide that came in contact with off-target vegetation. Another advantage of the helicopter over fixed-wing aircraft was its ability to land on loader trucks that were positioned near the river and eliminated the need of ferrying to and from a landing strip.

Helicopters were also equipped with GPS navigational equipment to aid in application. The use of on-board GPS allowed for near elimination of skips between spray swaths and allowed the pilot to easily return to the point where they finished spraying the previous batch load. The system was also tied into the sprayers flow control system so that rate of flow through the boom was varied to precisely match ground speed, eliminating the need to maintain a constant ground speed. After completion of treatments, GPS log files were downloaded to a computer to produce maps of the treated area and make calculations about the area treated.

An extensive monitoring program was initiated prior to the beginning of the project in 1999. The specific objectives of the monitoring project are to determine the effects of saltcedar removal on water quality and quantity in the Pecos River. Water quality is monitored through annual and real-time measurements of electrical conductivity. Water quantity is being evaluated through evaluation of historical and current release and delivery data from Red Bluff Water and Power Control District. A study is also being conducted to estimate water use by saltcedar along the river using shallow groundwater monitoring wells. More information on this study can be found in these proceedings in the paper by White et al. This research currently estimates that saltcedar evapotranspiration along the Pecos River is 5-8 ft. per year. Further research is attempting to characterize water salvage following control of saltcedar. Current estimates of salvage below are calculated using an estimated salvage of 7.7 acre-feet for every acre of saltcedar treated (see White et al.). This value is derived from subtracting estimated native plant evapotranspiration from estimated saltcedar evapotranspiration for net salvage. While the estimate should be considered preliminary, the research will continue to refine salvage estimates by characterizing evaporation, channel loss, base flow, and saltcedar evapotranspiration.

The project was privately funded in 1999 and 2000 by money obtained from irrigation districts along the Pecos River. Approximately 66 river miles (Table 1.) or about 1344 acres of saltcedar were treated with an actual spray cost of $253,555. Estimated annual water salvage from applications in 1999 and 2000 are 10,284 acre-feet of water per year. Additionally, native grasses are coming back vigorously on the bare ground that now receives sunlight.

During the 2001 legislative session, $1 million was allocated to the Pecos River Ecosystem Project by the State of Texas. Eight percent of these funds were used for project administration and monitoring with the remaining 92% used for saltcedar treatments in 2001 and 2002. Third year (2001) applications treated approximately 57 river miles or 1440 acres of saltcedar at a cost of $263,000. Estimates indicate 11,102 acre-feet of water salvage per year from the 2001 applications. From 1999 through 2001, 2774 acres of saltcedar were treated at a total cost of $515,635. This acreage treated will potentially release an estimated 21, 386 acre-ft. of water per year at a cost of $7.90 - $8.22 /acre-ft., assuming a mere 3 year treatment life (Tables 2 and 3).

Fourth year applications were completed in September 2002. Approximately 3567 acres were treated including segments of the river between Red Bluff and Grandfalls, TX that were not sprayed during the previous years, from the New Mexico/Texas state line to Red Bluff Lake (including areas around the lake) and 5 miles of Salt Creek from the convergence with the Pecos to the bridge over highway 285. Estimated annual water salvage from this treated acreage is 27,501 acre-ft.

Project Summary

To summarize, from 1999 through 2002, 128 miles of saltcedar along the Pecos River and its tributaries in Texas (6341 acres of saltcedar) have been treated resulting in an estimated 36,743 acre-ft. of water salvaged through 2002. An additional 48,887 acre-ft of water salvage is estimated for 2003 for a total cumulative water salvage estimate of 85,630 acre-ft through five years of the project. Projected water salvage and costs are presented in Tables 2 and 3. Average percent mortality of saltcedar from aerial applications is 90 to 95%. Debris removal and follow-up management continues to be a priority to complete the project. The project directors are currently trying to secure funding to begin this second phase of the project.

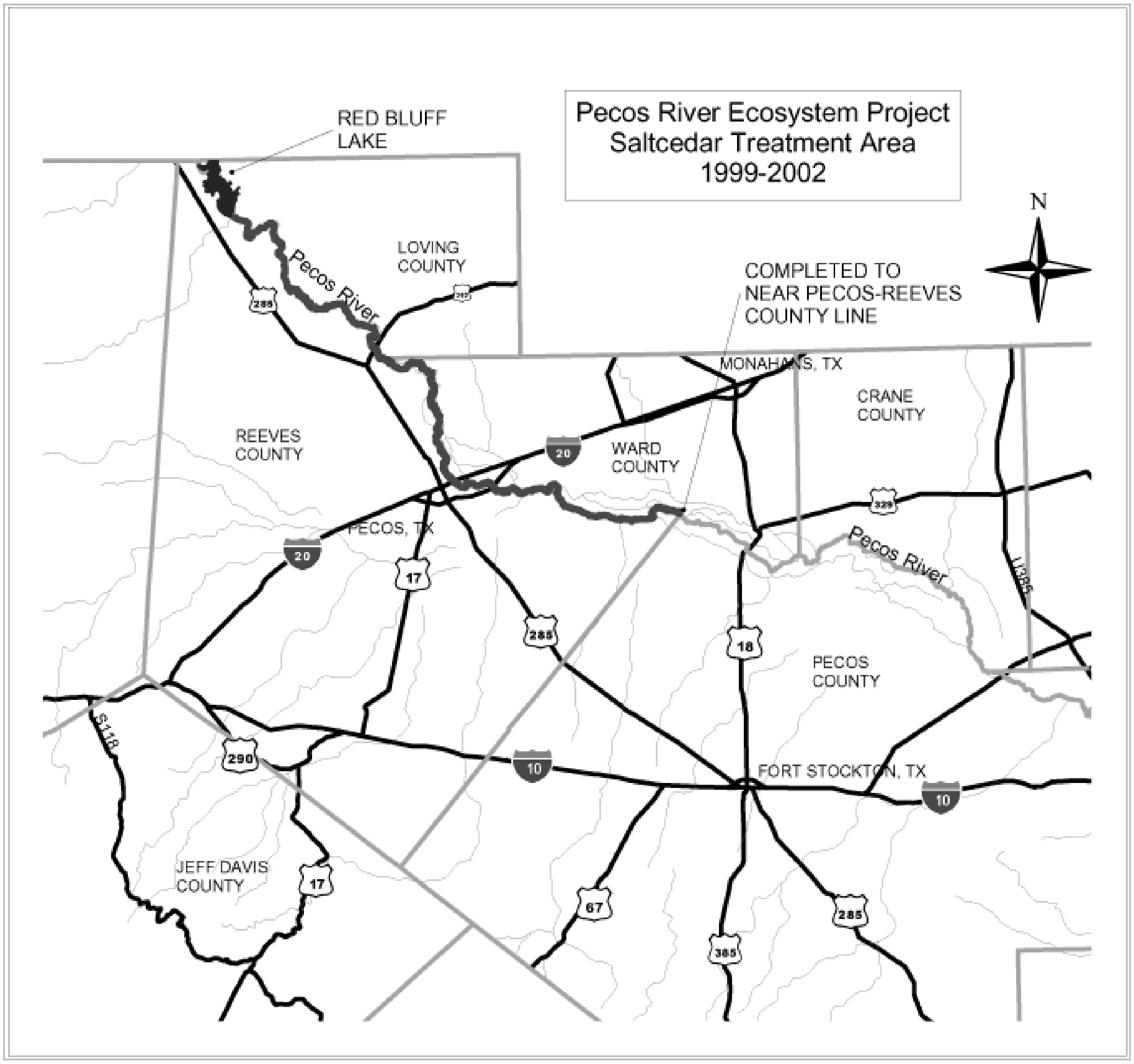
Additional information on the project can be obtained from the Internet at the following web site:

http://farwest.tamu.edu/rangemgt/prep.html

Research and monitoring efforts on the Pecos River Ecosystem Project were funded by a grant from the Texas Department of Agriculture and by the Rio Grande Basin Initiative administered by the Texas Water Resources Institute of the Texas A&M University System Agriculture Program with funds provided through a grant from Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, under Agreement No. 2001-45049-01149.

Table 1. Saltcedar acreage treated on the Pecos River Ecosystem Project as measured with GPS log files from helicopter.

Area Treated	**Year Treated**	**Acres Treated**	**Total Acres**	**River Miles**	**Acres/Mile**
Red Bluff Lake	2001	22			
	2002	1137			
	Total		**1159**		
Salt Creek	2002	151			
	Total		**151**	**5**	**30.3**
Red Bluff to Mentone	1999	658			
	2000	47			
	2001	240			
	2002	1031			
	Total		**1975**	**40**	**49.4**
Mentone to Barstow	2000	527			
	2002	432			
	Total		**959**	**26**	**36.9**
Barstow to I-20	2000	102			
	2001	301			
	2002	224			
	Total		**628**	**20**	**31.4**
I-20 to Grandfalls	2001	876			
	2002	592			
	Total		**1468**	**37**	**39.7**
Grand Total	1999	658			
	2000	676			
	2001	1440			
	2002	3567			
	Total		**6341**	**128**	**49.5**



Map showing general area of saltcedar treatments along the Pecos River in Texas from 1999-2002. Treatments were completed from the state line north of Red Bluff Lake to the Pecos-Reeves County line.

Table 2. Estimated potential water salvage (acre-feet) from control of saltcedar along the Pecos River in Texas from treatments applied in 1999 through 2002.

Year Treated	**Acres Treated**	**2000 Water Salvage**	**2001 Water Salvage**	**2002 Water Salvage**	**2003† Water Salvage**
1999	658	5073	5073	5073	5073
2000	676		5211	5211	5211
2001	1440			11,102	11,102
2002	3567				27,501
Total Annual	**6341**	**5073**	**10,284**	**21,386**	**48,887**
Cumulative		**5073**	**15,357**	**36,743**	**85,630**

**** Estimated water salvage (ac-ft) based on a preliminary estimate of 7.71 ac-ft/acre of saltcedar treated; data from 2001 water monitoring wells along the river. †Projected**

Table 3. Estimated cost of water salvage** from the Pecos River Ecosystem Project, 1999-2002 Treatments.

Year Treated	**Acres Treated**	**Total Treatment Cost**	**Estimated Annual Water Salvage**	**Cost/ac-ft. salvaged - 1 year return**	**Cost/ac-ft. salvaged - 2 year return**	**Cost/ac-ft. salvaged - 3 year return**	**Cost/ac-ft. salvaged - 4 year return**
1999	658	$125,020	5,073 ac-ft.	24.64	12.32	8.21	6.16
2000	676	$128,535	5,211 ac-ft.	24.66	12.33	8.22	6.16
2001	1440	$263,000	11,102 ac-ft.	23.69	11.84	7.90	5.92
2002	3567	$660,000	27,501 ac-ft.	24.00	12.00	8.00	6.00
Totals	**6341**	**$1,176,555**					
Avg.				**24.25**	**12.12**	**8.08**	**6.06**

** Estimated water salvage based on a current estimate of 7.71 ac-ft/acre of saltcedar treated; data from 2001 water monitoring wells along the river.

* Cost/acre-ft. illustrated based on a 1 to 4 year return.

NEW MEXICO SALT CEDAR CONTROL PROJECT
REPORT FOR JULY 1, 2002 TO JUNE 30, 2003

Debbie Hughes
Executive Director
New Mexico Association of Conservation Districts

Stan Bulsterbaum, Project Coordinator- Lower & Northern Rio Grande
Howard Shanks, Project Coordinator –Northern Rio Grande & Pecos
Bill See, Project Manager & Fiscal Agent- Pecos
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Mary Lou Ballard, Fiscal Agent-Northern Rio Grande
Dr. Keith Duncan & Dr. Kirk McDaniel – Technical Advisors

The following is a comprehensive report for the New Mexico Salt Cedar Control Project. This project encompasses the Pecos and Rio Grande Rivers and eighteen (18) Soil and Water Conservation Districts (SWCD's). The Rio Grande region extends from above Espanola, New Mexico to the US/Mexican Border and the Pecos region extends from Guadalupe County to the Texas state line in Eddy County.

This is a progress report on the expenditures of the funds appropriated through New Mexico State Legislature to the local SWCD's within the project area. The budget is 2.5 million for non-native phreatophytes control on each river. The following report refers to language and requirements included in the legislation.

Development and Management of Native Restoration Plans

Northern Rio Grande

All of the districts in the northern region of the Rio Grande have applied for assistance under the Corps 1135 program. This program entitled " Bosque Restoration" provides an avenue for restoration of bosque environment. Preliminary restoration plans (PRP's) will be developed. If the Corps Division office approves the plan, then a feasibility study begins and an Environmental Assessment is developed. Matching funding including in-kind services will be committed by the districts, if and when a project cooperation agreement is signed.

The Santa Domingo Pueblo staff informed the Coronado SWCD they are willing to prepare their own restoration plan on the area proposed for aerial spraying within Pueblo property.

Southern Rio Grande

Bureau of Reclamation (BOR) is developing an Environmental Analysis for their lands on the Rio Grande River.
A restoration plan is currently being developed for the lower Rio Grande.

Pecos River

The Carlsbad SWCD is developing the restoration plans for the Pecos River and they are also participating with the Corps 1135 program.

Flight maps for the Pecos River from North Star Helicopters, Inc. have been down loaded into Arc View files. These files have been used by the NM State Engineers office to create maps of the treatment areas within the project.

Bureau of Land Management (BLM)is developing a Programmatic Environmental Analysis for the Bureau lands on the Pecos River.

Public Hearings- planned and conducted

Public hearings were conducted by the soil and water conservation districts to receive public comment as follows:

Tierra Y Montes	Aug. 5 2002
Guadalupe	Aug. 5, 2002
DeBaca	Aug. 6, 2002
Hagerman-Dexter	Aug. 13, 2002
Chaves	Aug. 13, 2002
Central Valley	Aug. 19, 2002
Carlsbad	Aug. 15, 2002
Coronado	Nov 14, 2002
Ciudad	Nov 14, 2002
Santa Fe Pojoaque	Nov 13, 2002
Valencia	Nov 13, 2002
East Rio Arriba	Dec. 2002
Socorro	Nov 13, 2002
Socorro	Nov 14, 2002
Socorro	Dec 6, 2002
Sierra	Nov 25, 2002
Caballo	Nov 26, 2002
La Union	Jan. 16, 2002
La Union	Jan 17, 2002
Carlsbad	Dec. 5, 2002

May 19	Anthony	6pm
May 20	Radium Springs	6pm
May 21	Hatch	noon
May 21	T or C Civic Center	6:30pm
May 22	Las Nutrias Senior Center	6-8 pm
May 23	Sarracino Middle School	6-8 pm

Additional public meetings for the Pecos are planned for summer 2003.

Northern Rio Grande

The Santa Fe- Pojoaque SWCD conducted an acequia restoration workshop on March 12th for mayordomos and ditch board members, with approximately 15 people attending. The workshop included a field activity to demonstrate the proper use of chemical application and treatment alternatives. The district is planning on providing the herbicides for the landowners.

The La Cienaga watershed group is especially interesting because they have two members who will provide a in- kind assistance especially in the education aspects. These members include a Las Colondrinas Museum, which is a living history museum that provided an outdoor learning experiences for the public, including children. The other is a local botanical site that is also interested in educating the public about riparian restoration. Education is an important issue to the Santa Fe Pojoaque district as well as local people taking responsibility for their lands.

East Rio Arriba SWCD will conduct three local meetings to make presentations about the salt cedar program and look at potential sites.
These locations are Velarde, Abique and San Juan Pueblo. The local board has taken an active role in setting up meetings and talking to local landowners. It is anticipated that we can let RFP'S in April and work begin in May or June.

Coronado SWCD has conducted a meeting with the Santa Domingo Pueblo and significant interest is present to treat the area of Galisteo Creek between Albuquerque and Santa Fe. The Santa Domingo Pueblo officials at meeting on 4/9/2003 indicated they would send Coronado SWCD a letter of interest for this project until the Pueblo staff can get an approved resolution from the Pueblo council to confirm actual commitment.

Aerial Spraying and Ground Applications

Northern Rio Grande

The Coronado district has the opportunity to treat about 700 acres of land on the Santa Domingo Pueblo with aerial application. An additional treatment adjacent to the Pueblo is being planned by the Corps of Engineers, which will bring the total acreage on Galisteo Creek to around 1200 acres.

Coronado SWCD has two sites identified for stump treatment work. There is an additional area involving three private landowners that are interested in the treatment.

Valencia SWCD has awarded one contract for stump treatment within its district. This is the first site that is on Middle Rio Grande Conservancy District (MRGCD) lands. The final proposal price was $ 2,672.00 per acre. They have recently completed 10 acres on the Rio Grande in Valencia County.

The northern region now has a request for proposals form and joint powers agreement form for operating within the Middle Rio Grande Conservancy District. Valencia, Ciudad, and Coronado SWCDs will use all these documents.

Valencia SWCD has contacted Isleta Pueblo and Laguna Pueblo and both have indicated interest in aerial spray operations. All of the Rio Puerco and portions of the Salado drainages are involved. This will amount to extensive acreage. Some computer mapping of the area has been done to date.

Ciudad has advertised four sites for treatment by commercial contractors, and has three sites proposed to be done using prison inmate work crews. The inmate program appears to have considerable promise where stump treatment is the only option since it much cheaper. The inmate supervisor for the program has a person who has a certified chemical applicator's license and works with the crew as fuels are cut. One of the Ciudad sites is with the City of Rio Rancho and extensive help has been received on the project from the city. One city councilor for the city is highly involved with the project. The other sites include the Rio Grande Nature Center and the National Hispanic Cultural Center.

Santa Fe-Pojoaque SWCD issued RFPs in February and a contract was awarded to the Deveg Group in March. The bid ranged from $ 1,894 peracrefor cut and pile to $ 2,294 for cut & chip. Only one qualifications-based bid was received. They have five sites.

Lower Rio Grande

7,145 acres are planned for aerial treatment on the Lower Rio Grande in September. 4,000 of those acres are located in Socorro County. To date 3,145 acres are signed up in Sierra & Caballo districts. Of the amount committed for aerial application, 1,000 acres is located on Bureau of Reclamation lands and 1,000 acres belongs to Ted Turner.

The Sierra SWCD has negotiated an MOU to conduct ground and aerial work on Bureau of Reclamation (BOR) lands of the Rio Grande.

The LaUnion SWCD completed 35 acres of cut stump treatment on the Leasburg State Park and private land in Dona Ana County.

The Sierra SWCD has completed 29.9 acres of cut stump treatment in T or C, NM on private land at a cost of $1,900 per acre.

On the groundwork is being planned on a pilot project with the International Boundary and Water Commission on the Lower Rio Grande.

Pecos River in New Mexico- Aerial Application

- **9,100 acres**
- **184.57 Miles of River**
- **43.67 miles Eddy County**
- **53.8 miles Chaves County**
- **55.4 miles DeBaca County**
- **31.7 miles Guadalupe County**

Cut stump treatment was completed on 37 acres of the Hondo and Bonito tributaries involving 8 landowners at a cost of $59,000. The Guadalupe SWCD has a contract to do 30-35 acres of cut stump treatment. 20 Acres of cut-stump has also been done in Guadalupe County along the Pecos River on lands belonging to organic farmers.

20.17 Acres of cut-stump have been completed in Carlsbad along the Pecos River.

The Dexter Fish Hatchery is interested in having their lands treated if funds are available.

Priority will be given for aerial application on the Pecos River south of Avalon Lake, this will primarily be Bureau of Land Management and State Lands managed areas.

The BLM has also completed 1,900 acres of salt cedar removal on the Pecos River utilizing a machine that extracts the trees. Their cost ranges from $160 to $400 per acre. They have applied for an additional $300,000 to do more mechanical work.

Monitoring Actions for Water, Wildlife, Vegetation and Soil

Northern Rio Grande

In each of the MRGCD controlled sites a plant identification session, chemical management session, and fire control session is completed before the contractor is allowed to start work. This insures the positive native vegetation damage will be kept to a minimum, and chemical management is observed.

Ciudad SWCD will have access to monitoring data obtained from observation wells installed by the City of Albuquerque at the Rio Grande Nature Center Park. This will provide the northern region with baseline water level data within the bosque before treatment and additional data to be obtained after treatment.

Within the Valencia SWCD the MRGCD has fuel reduction plots where phreatophte vegetation is being removed. The northern region will have access to the data from this project based upon working agreement with staff from the MRGCD.

Southern Rio Grande

A soil salinity meter has been purchased by the Socorro SWCD to map salinity on treatment sites on the Lower Rio Grande.

Water Quality will be monitored using the ISC/ACE groundwater-monitoring project within the Socorro SWCD. They have installed a series of shallow ground water monitoring wells. Two graduate students from the NM Institute of Mining and Technology are collecting the data at these sites. USGS monitoring wells will also be utilized, throughout the Rio Grande valley.

Pecos River

The Carlsbad Environmental Monitoring and Research Center has started collecting base data for the soils for changes in alkalinity and stability. The salinity testing of the soils has shown the

worst areas are near bitter lakes and Malaga bend. They are doing water quality monitoring and collecting and evaluating water quantity changes using the existing gauging stations on the Pecos River. To date, the sediment rate is low, but they have not tested during a major river release event in which they do expect to see a big increase. Channel stability and areas of erosion are also being monitored.
They have started work on a model to look at 50 years of flow data on the Pecos.

Three biology Teachers and their classes, two in Carlsbad and one in Fort Sumner are planning to do an inventorying plan and animal communities along the river.
The BLM has contracted for a 2- year Breeding bird survey, which begins in May and will be conducted by Rivers and Birds, Inc. out of Taos, NM. (Primarily in Chaves County.

The BLM also has rangeland monitoring data dating back to 1982 that can be utilized to compare changes in vegetation and monitor changes. The BLM is working with the NM G&F to monitor the snails and the fish in the springs and wetland areas utilizing UNM for the fish surveys. They are also coordinating with the USF&W on these studies.
NM Natural Heritage Program at UNM is conducting geo-science mapping and infrared photos for the BLM in the Pecos River area. The BLM is installing a new gauging station west of bottomless lake state park.

Threatened or Endangered Species

The Ecological Services Division of the US Fish and Wildlife Service has been cooperating with us to determine management techniques for the project. We have four threatened and endangered species involved on the Rio Grande. The Southwestern Willow Fly Catcher, the Rio Grande Silvery Minnow, the Bald Eagle, and the Least Tern. Also present is the candidate species of concern the Yellow-billed cuckoo. The New Mexico Department of Agriculture is also working with us to submit a request for a 24-C label for Arsenal on the Rio Grande.

We have received data from the USF&W for the nesting sites of the Willow Flycatcher and have agreed to not start work until September while leaving a ¼ mile radius around the nesting clusters.

Surveys for Bald Eagles will be conducted each morning prior to the helicopter going into the air.

The districts are scheduling work within the Bosque area that are outside the breeding period dates for birds listed by the USF&W.

The Pecos Sunflower is a listed species occurring along the Pecos River, but is found only on Fish & Wildlife Refuge lands. No treatment of those lands are planned.

Additional Funding For New Mexico Projects

1.2 million dollars for management of non-native phreatophytes was appropriated during the 2003 legislative session. The legislative intent is once again for the Pecos and possibly the Rio Grande. Funding will be prioritized for aerial treatment in areas that have all agreements and requirements met. (This funding is non-reoccurring)

Approximately 2 million dollars worth of watershed projects for 8 soil and water conservation districts were authorized by the legislature from the water trust board.
About half of these projects include salt cedar management.

$180,000 for technical assistance to match the federal funds from NRCS through contribution agreements was appropriated by the legislature. (This funding is re-occurring).
Legislators approved a bill to appropriate $972,000 from the “Reserve Fund” contingent on an agreement with USDA-NRCS for technical assistance. This agreement will be between the soil and water conservation commission and NRCS to help administer the farm bill programs. We expect approximately 20 million dollars for the EQIP program to be available in NM for fiscal year 2003. The WHIP and CRP programs will also be utilized for restoration work on lands that have been treated.

The legislature appropriated $100,000 for a pilot project on the Rio Grande utilizing goats for salt cedar control. This is to be conducted in the Albuquerque area in coordination with the Middle Rio Grande Conservancy District. (This is also re-occurring funding)

The ARS/Jornada is doing research and collecting baseline data in Northern Socorro County. We will be coordinating this project as well as with NMDA to conduct workshops for local goat growers.

Funding that directs 10% of the bonding capacity of Severance Tax Funds to be invested and earmarked specifically for the water project fund was passed by the legislature. Approximately 10 million dollars should be available in this fund, but districts will have to compete with other entities for funding.

Legislation that allows for a corporate income tax credit for companies utilizing biomass including salt cedar passed and became law.

A new law instructs the Energy Minerals and Natural Resourses Department (EMNRD) to develop a “comprehensive watershed strategy that sets guidelines for state and federal management agencies and political subdivisions, including soil and water conservation districts. The strategy shall focus on removing the woody vegetation, particularly non-native species of phreatophytes, that consumes excessive amounts of water and reestablishing the natural ecology of NM.”

Other Opportunities

The USDA Forest Service has recently awarded a grant through the Collaborative Forest Restoration Program to the Sierra Soil & Water Conservation District in the amount of $310,000. This grant is to be utilized on public land to remove the high fuel hazards (salt cedar) along the Rio Grande River through the communities of Truth or Consequences and the Village of Williamsburg.

SCI/ZERI and Los Alamos Labs are entering into an MOU wit the Latvian Institute for Wood Chemistry. They will be doing an analysis on the potential value added raw materials from trees in NM including salt cedar and preparing an inventory.

Grant applied for from EPA for restoration on the Pecos River.

Working with Senator Pete Domenici drafting language for salt cedar legislation S. 1051. Working with Senator Jeff Bingaman for restoration funding through USDA-NRCS for the Pecos and Rio Grande Rivers.

$50,000 will also be spent through the Socorro SWCD for aerial treatment on BLM lands within the Cuba District on the Rio Puerco.

ARIZONA SALTCEDAR PROJECTS

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Mesa, Arizona

Introduction

Saltcedar, (Tamarix ramosissima) in the family Tamaricaceae now exists as a naturalized exotic plant in Arizona, found primarily in riparian habitats and sites with at least seasonal wetland conditions (Brock 1994). The thickest stands of saltcedar are along desert rivers and streams, especially those managed by dams, and includes streams in both the Sonoran desert and the Colorado Plateau desert grassland of northeastern Arizona. The pattern of saltcedar invasion being prevalent on managed streams has been observed by many, while the few free flowing rivers in Arizona, like the San Pedro support fewer saltcedar stands (Bowser 1957, Brock 1994). This situation is also documented through recent research findings (Paradzick 2003 personal communication). Saltcedar is not common along high elevation streams where Ponderosa pine (Pinus pondersoa) forests dominate the landscape or where the forest is classified as mixed conifers. Saltcedar invasion transformed the function of habitats by changing hydrologic conditions such as water use and alteration of stormflows in the stream channels, adding salts to the soil surface, and providing monotypic structure that affords fewer niches for wildlife.

The current situation with saltcedar in Arizona is that it is often at zenith where humans have altered the hydrologic cycle by construction of reservoirs or flood defense devices. Saltcedar invasion is prevalent around lakes and downstream from major reservoirs, with the Gila River system providing an excellent example. With the ongoing drought, saltcedar has established along retreating shorelines on reservoirs. Of particular interest is that an endangered neotropical bird, the southwest willow flycatcher (*Empidonax trailli extimus*) utilizes saltcedar as cover for nesting while it summers in Arizona. Hence we have an alien invasive plant, which some consider a noxious weed, growing where it might not be, if not for human intervention, serving as habitat for an endangered species.

As with many alien invasive species, restoration of saltcedar infested sites is best approached using integrated pest management techniques. A combination of treatments (i.e. mechanical, fire, cultural, chemical or biological) are needed to control this species and to prevent re-infestation. Large-scale (such as hundreds of acres of aerial spray treatments) vegetation management projects with saltcedar in Arizona are not currently underway, primarily because of the environmental planning process when an endangered species is involved. This paper describes research, demonstration projects, or pilot projects for proposed large-scale vegetation management and restoration of saltcedar infested areas. Projects included in this report are either recently completed, currently underway, or proposed for initiation in the very near future and includes some that are sited near Arizona in California or Utah.

Research or Demonstration Projects with Saltcedar

Arizona Strip – Saltcedar Removal

The Arizona strip is that portion of land located in the northwest above the Grand Canyon (Figure 1). Work in this area includes removal of saltcedar from sites to reduce the negative environmental effects and promote habitat improvement. These projects are coordinated by the Bureau of Land Management office in St. George, UT. In addition to the common techniques, projects here may also include mechanical removal of the canopy of saltcedar using a hydro-ax and spraying the cut stump with triclopyr (Garlon or Remedy). Crews also use chain saws to cut the stems and treat with herbicide. Volunteers from environmental organizations also assist at times doing cut stump treatments in a wilderness. Some saltcedar on the Arizona strip is also being treated with a foliar spray in imazapyr (Arsenal). Larger projects are anticipated for treatments of saltcedar on dry sites and riparian areas with imazapyr. Contributed by L. D. Walker.

California - Experimental Saltcedar Biocontrol Program

Biocontrol of saltcedar is being carried out on a regional basis (California, Nevada, Wyoming, Utah, Colorado, and Texas) with planned sites in southern California near Barstow and the Salton Sea (Figure 1). This research is being developed in cooperation with the Agricultural Research Service, US Fish and Wildlife Service, and the US Geological Survey. Eventually this activity will move to Arizona, pending biological opinions and identification of saltcedar sites not serving as habitat to the southwest willow flycatcher (author's opinion). Saltcedar provides excellent cover but reduced forage value. Current work focuses on measuring the effects of biocontrol with the Chinese or the Eurasian saltcedar leaf beetle (*Diorhabda elongata*) on saltcedar itself, the effects on non-target organisms and the effects of reduced stand density of saltcedar will have on wildlife. Initially there has been establishment of the leaf beetle at the more northern sites, with some photoperiod problems with this beetle at more southern sites. Researchers on this project(s) report some very encouraging results in Nevada and are optimistic that with 1 or 2 more years of continued defoliation of saltcedar that a useful tool for controlling this invasive plant will be demonstrated. Contributed by Ray Carruthers and Tom Dudley.

Cave Creek – Tamarix Control Activity on the Spur Cross Ranch

Saltcedar is found in disjunct groups along Cave Creek on the Spur Cross Ranch, which is located just north of the town of Cave Creek. This unique desert riparian area was recently moved to a protected status by designating the Spur Cross Ranch Conservation Area under the Maricopa County, Parks and Recreation Department in cooperation with the communities of Cave Creek and Carefree, AZ. Control of saltcedar on this land was initiated to prevent formation of a monoculture that would inhibit colonization and establishment of native riparian trees, and realizing other undesirable effects to concentrate salts to the surface and to facilitate wildfires.

After researching appropriate methods and safety measures, saltcedar control was initiated in February 2002. Treatments included cutting the saltcedar with saws or lopping shears and painting the stump with triclopyr herbicide. On a sample of 10 trees, 0.5 in diameter X 4 in deep holes were bored into the wood and the holes filled with a solution of the herbicide. Seventy-five individual plants of saltcedar, many with multiple trunks were treated. No herbicide was used on trees adjacent to water. Literature indicates a 60 – 80% mortality success rate for this treatment. In April 2003 the mortality of the cut stump/herbicide treatments was 87 % (Figure 2, left). The stumps that were drilled had a mortality of about 93 %. Surviving foliage had a stunted appearance. Several live plants that were missed on the original treatment (Figure 2, right) will be retreated at a later date. Plant debris from the cutting was left on dry soils at the site to provide wildlife cover and as micro-sites for native plant establishment. Also shade from the debris is expected to inhibit saltcedar seedling establishment. Contributed by John Gunn.

Fig. 1. Location of some saltcedar research and demonstration projects in Arizona and neighboring states having somewhat similar climatic conditions.

Fig. 2. Left. Excellent control of a saltcedar crown using the cut stump and triclopyr herbicide treatment at the Spur Cross Conservation Area. Right. Saltcedar regrowth from missed crown. Photo April 2003 by John Gunn.

Cibola - Revegetation Strategies and Technology Development for Restoration of Xeric *Tamarix* Infestation Sites Following Fire.

The Bureau of Reclamation proposed and is initiating a study on the impacts of fire and revegetation potential on stands of saltcedar after a wildfire (Figure 3). A monotypic 67 acre stand of upland (xeric) saltcedar was burned on April 17, 2001. This afforded the opportunity to study restoration of a site that was not a candidate for revegetation with cottonwood or willow species. Several restoration techniques will be utilized in the study. These include: 1. Basal herbicide application to saltcedar sprouts and herbicide applications to secondary invasive species using labeled herbicides. 2. Mechanical treatments such as roller chopping, land imprinting and disking. These treatments will further manipulate the saltcedar, revegetate seedbeds and incorporate microbial and nutrient amendments to the soil. 3. Growth amendments will include mycorrhizal inoculum as granules, soil organic amendments in liquid formulations, and addition of nitrogen (N) from a commercial slow release fertilizer. 4. Planting techniques will include (a) broadcast, (b) disk drill with no leading and with leading openers, (c) seedling transplants placed either manually or mechanically. Site adapted revegetation species are being selected to reflect experience by agencies and private landowners, and will evaluate competition between species with in the seed mixtures. Single species trials will also be conducted using both seed and seedling transplants.

Assessment of the study plots will include pre-treatment baseline soils and vegetation inventories. Data collected will include age class, height, stem numbers and size for the saltcedar. Species frequency and stand establishment measures on the revegetation plots,

Fig. 3. A dense stand of saltcedar after burning. Note high degree of resprouting from the crowns. Lair and Wynn (2002), powerpoint document.

a vigor index (plant height, seedheads, biomass), canopy cover and bare soil or litter. Species diversity will be calculated and biomass from seeded and volunteer species measured. Wildlife habitat suitability evaluations, observations of wildlife will be documented. Contributed by Kenneth Lair and Sarah Wynn, Principal Investigators.

Cibola Project Team: This project has a group of collaborators including: Jennifer Green, Karen Reichhardt, Benjamin Lardiere, Fred Wong, Jeffery Young, and Roger Oyler of the BLM Office in Yuma, AZ, and from the Cibola National Wildlife Refuge (USFWS) Tom Alexander, John Earle, and Jim Holmes, and Roberta McDermott of the Natural Resources Conservation Service.

Grand Canyon – Tamarisk Management and Tributary Restoration

The National Park Service has been actively controlling saltcedar in side canyons, tributaries, developed areas, and springs located above the pre-dam level of the Colorado River in the Grand Canyon National Park. The saltcedar is controlled through a combination of mechanical, chemical and cultural practices (seeding). Methods include manual removal, Garlon herbicide lance injection, hack and squirt, cut stump, basal bark application and native plant restoration. Each site has methods selected that are specific to the saltcedar invasion. Over 50 separate streams, springs and other locations have received some form of treatment. Several of the sites have had saltcedar management treatments in 2 different seasons of the year. Records show that over 35,000 saltcedar plants have been treated, with 21,000 manually removed, 662 girdled, 11,725 having the cut stump treatment, 1150 basal bark application, 67 injected and 210 receiving a combination of treatments. The total area involved is 1.7 ha. While many of the plants were saplings, many large plants were controlled, eliminating a large seed source from the invasion process. Monitoring includes vegetation transects and photopoints. Contributed by Lori J. Makarick.

Imperial – Restoration and Maintenance of Restored Sites

The Imperial National Wildlife Refuge has over 250 acres of riparian areas and floodplains restored to vegetation that approximates native plant communities. This work was done to diversify the existing vegetation and to encourage the presence of wading birds and by providing water fowl impoundments. The plant communities include deciduous woody trees and marshes. Maintenance of 250 acres of land is an ongoing activity to retard the reinvasion of saltcedar. Twenty acres were recently bulldozed, saltcedar debris piles burned, root-raked and resprouts of saltcedar sprayed with herbicide. The site was restored by planting mesquite, both western honey mesquite (*P. glandulosa var. torreyana*) and screwbean mesquite (*P. pubescens*). Understory vegetation establishes through secondary succession with the most common shrub being quailbush (*A. lentiformis*). Contributed by Jackie Ferrier.

Lee's Ferry – Cold Desert Saltcedar Management

The Colorado Plateau is best described as a cold desert because of cold winters in contrast to the hot Sonoran and Mojave deserts. Projects in the vicinity of northern AZ and the extreme southern part of Utah include Lee's Ferry, Rainbow Bridge and Escalante National Monuments. The projects on the monuments have the objective to control all of the saltcedar. Treatments include hand pulling, or cut stump and herbicide applications. Saltcedar mortality from the cut stump and herbicide work has been about 90 percent. Seedlings continue to invade hence minor control efforts are needed every 2 to 3 years. About 30 acres of saltcedar has been controlled at the Rainbow Bridge and over 30 miles of stream corridors along the Escalante River and Coyote Gulch have been treated. At Lee's Ferry, a dense monotypic stand of saltcedar was bulldozed in 2001 and replaced with native riparian species. Regrowth and reinvasion by saltcedar will be managed as in the monuments. Contributed by John Spence.

Lower Colorado River – Habitat Restoration on the Lower Colorado River

Many projects have been carried out on the Lower Colorado River by the Bureau of Reclamation, often in cooperation with other federal and state agencies, non-governmental organizations (NGO) and private landholders. Projects at Cibola, Mittry Lake and Imperial are described elsewhere in this paper.

Ducks Unlimited (Imperial), Nature Trail site (Cibola), Planet Ranch and Pratt site (Yuma)

Each of these sites involves saltcedar control as maintenance and involved saltcedar removal in project initiation. However, these projects were more commonly restoration of old fields to a desert riparian type of vegetation. Common methods included soil sampling as a key to success, especially to know salinity levels and depth to groundwater. Plant reestablishment was carried out by pole plantings of Fremont cottonwood (*Populus fremontii*) and Goodding willow (*Salix gooddingii*), planting rooted stock and seeding. Irrigation was a common practice to establish plants, or pole plantings were done at a depth to place the poles in contact with shallow ground water. Some of the sites are maintained as wetlands or have open water features. Site locations are shown in Figure 1. Contributed by Barbara Raulston.

Perkinsville – Verde River SaltCedar Projects

Two projects for saltcedar control are underway on the Verde River near the community of Perkinsville. In both cases the primary goal is to increase riparian plant biodiversity and to reduce the potential of further spread of saltcedar. A secondary goal is to maintain the visual quality of the land, and improve wildlife and fish habitats. A third component is to demonstrate that sparse infestations of saltcedar can be controlled with minimal cost. In November 2002, scattered saltcedar trees were removed from a cottonwood – willow overstory to reduce competition to the understory grasses and forbs and maintain the natural riparian plant community. This project area encompassed approximately 50 acres. The treatment of choice was cut stump using imazapyr (Arsenal) as the chemical component. Cut limbs were left in place, and when dense they were scattered as later plans call for a small prescribed burn to remove the downed debris. The second project also involves the cut stump method. In these projects grazing management is also being monitored in the pastures to assure a healthy and vigorous plant community and to help prevent invasion, establishment and spread of saltcedar. Contributed by Robert Adams.

Many Farms – Saltcedar Herbicide Screening Test on Chinle Creek.
Herbicides were applied on August 1999 to a mixed stand of saltcedar and Russian olive (*Elaeagnus angustifolia*) along Chinle Creek, near Many Farms in northeastern Arizona. This herbicide screening trial included treatments of Escort, Amber, Exceed 57, CGA 362622 (sulfonyurea herbicides), Vanquish (dicamba), Roundup (glyphosate) and Arsenal (imazapyr) alone or in combinations. The chemicals were applied with a backpack sprayer, in water with a non-ionic surfactant at a total spray solution of 4 gpa to simulate aerial application. The objective was to determine the potential of these herbicides for control of these invasive species. Treatments providing the best control of saltcedar included: Exceed 57 + Roundup + Vanquish; Vanquish + Roundup, Roundup, Exceed 57 and Roundup and Vanquish + Exceed 57. Two years after treatment mortality ranged from 54 to 36 % for these treatments (Brock 2003). Less effective control was realized with Escort + Vanquish, Vanquish, Exceed 57 + Vanquish + Arsenal, Arsenal, and Escort. However, after 2 years, stems of saltcedar treated by Arsenal still retained the “green bottle brush” appearance, and more mortality was observed after this data collection. It is believed that higher mortality levels would have been achieved if the total spray volume had been increased to provide better spray droplet coverage. Future foliage applications of herbicide to saltcedar will have higher spray volumes recommended. Contributed by John Brock.

Mittry – Mittry Lake Hazard Fuels Reduction and Riparian Restoration.
Mittry South Revegetation
Restoration of a riparian habitat will follow a stand reduction of saltcedar on approximately 80 acres. The project has two main goals, reduction of volatile hazardous fuels from saltcedar and restoration with native species to create greater species diversity and complexity in plants and animals. The site treatments include: 1. Clearing and piling saltcedar using bulldozers and root-knifing (root-raking) to pull roots from the soil, native trees would be avoided if possible. The saltcedar debris will be either burned or chipped to remove it from the site. 2. Soils will be characterized for physical and chemical properties, especially salinity. The area will then be engineered to promote irrigation and leaching of salts that have accumulated under the population of saltcedar. A cover crop will be planted to reduce soil erosion. 3. A planting design will be developed and native trees, shrubs and grasses will be planted. This could include native tree species, such as cottonwood palo verde (*Cercidium floridium*), mesquite (*Prosopis), and* shrubs such as saltbush (*Atriplex*), inkweed (*Suaeda torreyana*), wolfberry (*Lycium*) and seep willow (*Salix exigua*). 4. The site will be irrigated and fertilized to promote development of the native vegetation. 5. When needed, regrowth of saltcedar will be treated with labeled herbicides. Contributed by Jennifer Green and Karen Reichhardt.

Mittry Fire Rehabilitation

A recent accidental fire consumed approximately 1300 acres of saltcedar near Mittry. Approximately 700 acres of this site will be treated to aid regeneration of a native plant community. Initial plans call for locating remnant mesquite from the mesquite woodland vegetation common to the area prior to invasion by saltcedar. An area of about 75 feet around the mesquite will be bulldozed to remove saltcedar, to reduce vegetative competition and promote better growth and development of the mesquite plants. This area would then be revegetated under less intensive treatments. Contributed by Jennifer Green and Karen Reichhardt.

The Mittry projects has a group of collaborators including: James McCray, Jennifer Green, Karen Reichhardt, Benjamin Lardiere, Fred Wong, Jericho Lewis of the BLM, Roberta McDermott of the Natural Resources Conservation Service, Julian DeSantigo, Barbara Raulston and Theresa Olson of the Bureau of Reclamation, and Russ Engle of the Arizona Game and Fish Department.

Safford - Saltcedar Eradication on the Gila River.

The Safford District of the BLM (Bureau of Land Management) and San Carlos/Safford/Duncan Watershed group partnered with volunteers on a saltcedar eradication study project on the Gila River. The hypothesis of the test was that saltcedar saplings would be out-competed by the native riparian vegetation if the saltcedar was stressed. The saltcedar plants were inhibited in root growth and allowed to be shaded by native plants. Volunteers lopped off sapling saltcedar growing in stands mixed with cottonwood and willows. Debris from the cut saltcedar plants was placed to provide cover for animals and to provide sites for sediment trapping to reduce non-point source pollutants from moving downstream. The study was successful, as the following year 98% of the saltcedar stubs had not resprouted. A conclusion was that larger saltcedar trees will need to be treated with herbicide. The results were considered promising for areas with mixtures of sapling riparian vegetation. The group plans treatments at other areas along the Gila River. Contributed by Bill Brandau and Steve Eady.

San Pedro River –

Ground and Surface Water Thresholds for Maintaining Populus-Salix Forests

This research project examines the alteration of riparian ecostystems through studies of ground and surface water thresholds for *Populus-Salix* forests. Detailed information related to this research is contained in the proceedings of this symposium (see Lite and Stromberg). In many places, water resources have been depleted for riparian communities, and saltcedar invaded such sites. *Populus-Salix* are dominant where groundwater was above 3 m of the soil surface for about 75 % of the time as measured over the two year study period. Areas with deeper water supported more saltcedar, woody shrubs and had fewer woodlands in general. Contributed by Sharon J. Lite and Juliet C. Stromberg.

Habitat for Southwest Willow Flycatcher: Vegetation and Hydrogeomorphic Considerations

This research forms the basis of a MS thesis. Floodplain cross sections were examined through riparian vegetation patches along the San Pedro and Gila Rivers in southcentral Arizona (Figure 1). Also measured were groundwater depths and local hydrology related to formation of habitat characteristics critical to southwest willow flycatcher selection of habitat. The San Pedro River has a natural flow regime whereas the Gila River has altered flow conditions below the San Carlos Dam. Gila River sites contained predominately stands of large saltcedar, whereas on the San Pedro cotton and willow were much more prevalent. The research documents that elimination of natural flow regimes is one of the factors that promotes saltcedar invasion resulting in the transformation of riparian habitats in the southwestern USA. Contributed by Charles Paradzick.

Yuma – Saltcedar Treatments for Habitat Development

The City of Yuma and various cooperators have carried out habitat development projects on sites that had been invaded by saltcedar. These restoration projects included a West and an East site. Saltcedar was mechanically removed and after drying, the debris was buried. Cottonwood, willow and mesquite bosque type habitats were created, depending on presence of soil-water. The understory was planted with saltbush (*A. canescens***)**, and wolfberry. The East site is a backwater slough that was filled by 1993 flood events. This area came to support marsh vegetation including cattail (*Typha*) and bulrush (*Scirpus*). As the marsh like character of the site developed it was frequented by large numbers of white-faced ibis and also became a nesting site for several Yuma clapper rail birds. As the water has receded, saltcedar invaded the shorelines and now very few of the ibis and no clapper rail have been are observed. In the very near future, Yuma is planning to enter a saltcedar and giant reed (*Arundo* donax) control and restoration project at this site. Contributed by Matthew Spriggs.

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TAMARISK CONTROL ACTIVITIES IN COLORADO AND UTAH

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Abstract

Tamarisk control activities in Colorado and Utah are closely aligned with proposed legislation at both the state and federal levels. This paper will discuss the implications of these legislative acts on existing and potential tamarisk control projects in the two states.

In January 2003, Colorado Governor Bill Owens issued Executive Order D-002-03 directing the Department of Natural Resources (DNR) to develop a strategic plan to control tamarisk on public lands within the next ten years. The executive order requires DNR to coordinate activities of numerous state and federal agencies, private landowners, local governments and others to identify potential funding sources, and plan activities to control tamarisk within the state by 2013.

At the federal level, Colorado Congressman Scott McInnis has introduced the "Tamarisk Research and Control Act of 2003" (H.R. 695). This legislation would provide $1,000,000 to take existing research and use it to develop long-term management and funding strategies for the Colorado River watershed in western Colorado and eastern Utah. Research activities would include: 1) an inventory of infestation by tamarisk and other non-native phreatophytes (principally Russian-olive); 2) identification of the difference in water consumption between non-native phreatophytes and typical riparian, floodplain, and adjacent upland plant communities on an acre-foot/year per acre and per river mile basis as a function of thicket maturity, floodplain morphology, climatic conditions, geology, and geographic location; and 3) document the impacts of the costs and benefits of long-term control and revegetation as well as the alternative of ***not*** implementing an effective long-term program. Principal participants will include Mesa State College (as the lead), Colorado State University, Utah State University, Tamarisk Coalition, The Nature Conservancy, and the Bureau of Reclamation.

A larger federal bill is being developed by New Mexico Senator Pete Domenici in 2003 and will likely include large-scale demonstrations and associated research. The principal objectives of the demonstrations will be to: 1) conduct demonstrations at sufficient scale to demonstrate different control and revegetation techniques; and their costs, impacts, and success rates; 2) provide sites to perform new research on the changes in water availability, water quality, habitat improvement, and biodiversity; and 3) provide public education on the problem and solutions, including information materials on the success of the demonstrations, costs, and impacts. Authorization will be for a minimum of $10 million per year over a five year period and will be directed to states with significant tamarisk problems.