Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

2010 Cibola National Wildlife Refuge
Field 51 Vegetation and Monitoring Report

Agreement No. R10AP30003

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

September 2011

Lower Colorado River Multi-Species Conservation Program
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The Nature Conservancy

Lower Colorado River
Multi-Species Conservation Program

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EXECUTIVE SUMMARY

GeoSystems *Analysis*, Inc. (GSA), in conjunction with the University of Arizona Office of Arid Lands Studies conducted a research project between 2006 and 2009 to determine the feasibility of using native seeds for revegetation along the Lower Colorado River (LCR). As a portion of Grant R10AP30003, *Groundwater and Soil Salinity Monitoring Network in Support of Long-term Irrigation and Salt Management of MSCP Restoration Areas*, GSA continued monitoring existing small-scale study plots at Cibola NWR Field 51 during 2010.

This report presents task activities and results for Task 3e during calendar year 2010, which consisted of vegetation monitoring and irrigation management of Field 51 at Cibola NWR to evaluate original study parameters (i.e. planting technique, seed treatment, and irrigation type), long-term vegetation trends, and the effects of two distinct irrigation regimes during the growing season on plant establishment, survival, and growth. The following small-scale field study plots established in 2007 through 2009 at Cibola NWR Field 51 were monitored:

- 2007 Mixed cottonwood-willow test plots—Shallow, frequent irrigation (application of 5.5 cm of water approximately once per week throughout the growing season) vs. deep, infrequent irrigation (application of 22 cm of water approximately once per month throughout the growing season).
- 2008 Goodding's willow test plots—Shallow, frequent irrigation (application of 7 cm of water approximately once per week throughout the growing season) vs. deep, infrequent irrigation (application of 21 cm of water approximately once per three weeks throughout the growing season).
- 2009 Goodding's willow test plots—Deep, infrequent irrigation (application of 21 cm of water approximately once per three weeks throughout the growing season).

KEY RESULTS SUMMARY

Key findings from 2010 study activities include the following:

2007 Small-scale Study Plots:

- Fremont cottonwood has maintained dominance of crown cover in the small-scale study plots. Crown cover of cottonwood increased from 70% in October 2008 to 76% in October 2009. Crown cover of saltcedar decreased from 12% to 9% during that time period. Crown cover of other non-seeded species combined decreased from 15% to 11%.
- Fremont cottonwood canopy cover was more than double that of saltcedar after four growing seasons. Canopy cover of cottonwood increased from 72% to 77% between October 2009 and October 2010. Canopy cover of saltcedar decreased from 37% to 30%.
- Overall saltcedar mortality was 7.6% between October 2009 and October 2010. Total

tree counts of Fremont cottonwood increased, indicating re-sprouting of previously-assumed dead trees.

- Despite very high tree densities, mortality was observed for two cottonwoods and one saltcedar greater than 100-cm tall at the onset of the growing season.
- Generally, greater growth of Fremont cottonwood than of saltcedar between fall 2009 and fall 2010 surveys.
- No effects of irrigation treatment (shallow, frequent vs. deep, infrequent) on Fremont cottonwood or saltcedar mortality or growth rates.

2008 Small-scale Study Plots:

- Saltcedar and other volunteer species (primarily arrowweed) have maintained dominance of crown cover in the 2008 small-scale study plots. Crown cover of saltcedar decreased from 44% in October 2009 to 24% in October 2010, while other volunteer shrub and forb cover increased from 38% to 58%. Crown cover of Goodding's willow decreased from 9% to 7% during that time period.
- Canopy cover of saltcedar decreased from 78% in October 2009 to 74% in October 2010. Canopy cover of Goodding's willow remained at approximately 19% during that time period. Canopy cover of grass and sedge species decreased slightly, whereas canopy cover of non-seeded shrubs and forbs (primarily arrowweed) increased.
- Goodding's willow density remains much lower than saltcedar density, at an overall average of 2.7 stems per square meter compared to 26.0 stems per square meter for saltcedar.
- Overall mortality of Goodding's willow and saltcedar was 58% and 16%, respectively, between October 2008 and October 2009. Mortality was higher for smaller individuals of both species.
- Mortality of Goodding's willow was higher under deep, infrequent irrigation, whereas mortality of saltcedar was unaffected by irrigation regime.

2009 Goodding's willow small-scale study plots:

- Higher seeding rates resulted in denser Goodding's willow establishment, with highest crown and canopy cover observed at 1,685 PLS/m2.
- Crown cover of volunteer shrubs and forbs remains dominant at 57%. Saltcedar and Goodding's willow crown cover are 19% and 15%, respectively.

- Canopy cover of Goodding's willow increased from 21% to 29% between September 2009 and October 2010. Canopy cover of saltcedar increased from 24% to 39% during that time period. Other volunteer shrub and forb canopy cover decreased from 91% to 85%.
- Goodding's willow density remains higher than that of saltcedar density, at an overall average of 8.8 stems per square meter compared to 3.6 stems per square meter for saltcedar. Saltcedar density remains much lower than that observed in 2007 and 2008 study plots.
- Overall mortality of Goodding's willow and saltcedar was 50% and 37%, respectively, between September 2009 and October 2010.
- Tree heights of Goodding's willow and saltcedar were generally similar after two growing seasons.

In addition to previous study conclusions presented by GeoSystems Analysis, monitoring of seed plots during 2010 indicates:

- Long-term survival of Goodding's willow at Cibola National Wildlife Refuge is uncertain. Herbivory may be a concern for Goodding's willow seedlings.
- Despite similar vertical growth rates and higher density of Goodding's willow than saltcedar, crown and canopy cover were generally similar after two growing seasons (2009 study plots).

1.0 INTRODUCTION

This report documents activities conducted by GeoSystems *Analysis*, Inc. (GSA) for Task 3e (*Vegetation Monitoring and Irrigation Management of Field 51 in Cibola NWR Farm Unit #1*) of Grant R10AP30003, *Groundwater and Soil Salinity Monitoring Network in Support of Long-term Irrigation and Salt Management of MSCP Restoration Areas*. This task consisted of vegetation monitoring during 2010 for seed feasibility study plots established for Contract No. 06CR308057, *Feasibility Study Using Native Seeds in Restoration*, *California-Arizona-Nevada*, between calendar year 2007 and 2009.

The feasibility study consisted of a research program initiated in 2005 by the Bureau of Reclamation (Reclamation) to determine whether native seed can be used, in combination with large-scale agricultural practices, to expand cottonwood-willow and mesquite bosque plant communities on the Lower Colorado River (LCR). Development of seeding methods is desired given the long-term revegetation goals of the LCR Multi-Species Conservation Program (MSCP) to increase cottonwood-willow habitat by almost 6,000 acres and mesquite bosque by 1320 acres and the potential for reduced planting costs and increased genetic diversity compared to vegetative propagation.

A combination of greenhouse and field-scale studies were designed and conducted at the University of Arizona Southwest Center for Natural Products Research and Commercialization Center (NPC) and the Cibola National Wildlife Refuge (Cibola NWR), respectively, as described in the annual study plans (GSA 2006, 2007a, 2008a, 2009a). Specific tasks and schedules of Contract No. 06CR308057 relevant to the present memorandum were as follows.

Year 2 (2007) Greenhouse Studies and Small-scale Field Studies

- Task 5: Conducted small-scale field studies at Cibola NWR Field 51 to evaluate effects of planting technique, seed treatment, and irrigation type on germination, establishment, and growth of Fremont cottonwood, Goodding's willow, and coyote willow.

Year 3 (2008) Small-scale Studies

- Task 5U-5: Continued monitoring of small-scale field study plots at Cibola NWR Field 51 implemented in May 2007 to evaluate survival and growth of Fremont cottonwood, Goodding's willow, coyote willow, and saltcedar through the 2008 growing season. Analyzed the effects of irrigation depth and frequency.
- Task 5U-6: Conducted small-scale field studies at Cibola NWR Field 51 to evaluate planting

technique, seed treatment, and irrigation type effects on germination, establishment, and growth of Goodding's willow for one growing season.

Year 4 (2009) Small-scale Studies

- Task 8: Continued monitoring of existing Task 5 small-scale field study plots previously established at Cibola NWR Field 51.
- Task 9: Conducted additional small-scale field studies at Cibola NWR Field 51 to evaluate seeding rate effects on the establishment of hydroseeded Goodding's willow for one growing season.

During 2010, GSA continued vegetation monitoring of existing small-scale field study plots previously established in 2007, 2008, and 2009, at Cibola NWR Field 51 through Sub-task 3e of the current grant.

2.0 TECHNICAL APPROACH

During 2007 through 2009, GSA established a series of small-scale (6 m by 12 m) study plots to determine the effectiveness of direct seeding of Fremont cottonwood, Goodding's willow, and coyote willow. Various seeding and irrigation methods were implemented during the first growing season as detailed for the 2007, 2008, and 2009 study plots in GSA 2008, GSA 2009, and GSA 2010, respectively. These initial treatment variables were implemented to determine optimal seeding methods, seeding rates, and irrigation methods for direct seeding. The effects of these treatments on the first growing season are detailed in the above-referenced reports.

Primary objectives of long-term monitoring are the following:

- Determine effects of the initial treatment variables on native tree species establishment for the determination of optimal seeding methods for large-scale restoration projects.

- Monitor growth rates, survival, and competition within and between seeded and volunteer species to determine if direct seeding results in favorable vegetation communities to support the habitat requirements of native fauna.

- Determine the effect of irrigation rates and frequencies on survival, growth, and competition of native and non-native tree species.

Study plots and irrigation specifications are detailed (by year) below, followed by a description of irrigation and monitoring methods.

2.1 Study Plot Detail

2007 Small-scale Study Plots

During 2007, 36 small-scale study plots of mixed Fremont cottonwood, Goodding's willow, and coyote willow seeding were established. The objective was to determine the effectiveness of seeding method (uncleaned hydroseed, cleaned hydroseed, or cleaned broadcast seed), sprinkler irrigation for three weeks during establishment (sprinkler or no sprinkler), and on-going surface irrigation technique (border-strip or furrow irrigation) on the establishment and growth of Fremont cottonwood, Goodding's willow, and coyote willow. These 6 m by 12 m plot studies were implemented on the east end of Cibola NWR Field 51 in a split-plot design (Figure 1). Additional detail, including study approach and results from the 2007 growing season are presented in the 2007 Annual Report (GSA 2008b).

A range of riparian species and saltcedar densities were established in the 2007 Plots. Overall, high establishment was observed for Fremont cottonwood and saltcedar, with very low establishment of Goodding's and coyote willow. Therefore, cottonwood and saltcedar have been the focal species of continued vegetation monitoring efforts.

Results from the 2008 and 2009 growing seasons are detailed in the 2008 (GSA 2009b) and 2009 (GSA 2010) annual reports, respectively. Monitoring during the 2008 and 2009 growing seasons indicated higher survival and growth rates of Fremont cottonwood compared to saltcedar. Additionally, decreased watering frequency did not result in greater soil water depletion at 1 m below ground surface (bgs) or increased mortality rates of established trees.

Monitoring in 2010 had the following objectives:

- Determine growth and survival rates for seeded riparian species and volunteer saltcedar plants during a fourth growing season.
- Quantify additional establishment of native and introduced species.
- Determine the effects of two different irrigation regimes on cottonwood and saltcedar growth and survival. Water was applied at a rate of 60% of reference evapotranspiration (ET_0).

2008 Small-scale Study Plots

During 2008, additional small-scale field plots of Goodding's willow were implemented. The objective was to determine the effectiveness of seeding method (un-cleaned hydroseed or cleaned broadcast seed) and surface irrigation method (border-strip or furrow) on the establishment and growth of Goodding's willow, provided removal of potential competition with Fremont cottonwood and enhanced weed control compared to 2007 Plots. These 6 m by 12 m plot studies were implemented on the east end of Cibola NWR Field 51, adjacent to 2007 Plots in a full factorial design (Figure 2). Additional detail, including study approach and results are presented in GSA (2009b).

A range of Goodding's willow and saltcedar tree densities were established in the small-scale study plots, with approximately five times higher density of saltcedar than Goodding's willow. Continued monitoring had the following objectives:

- Determine growth and survival rates for seeded Goodding's willow and volunteer saltcedar plants for three growing seasons.
- Quantify additional establishment of native or introduced trees.
- Determine the effects of two different irrigation regimes on Goodding's willow and saltcedar growth and survival. Water was applied at a rate of 80% of ET_0, similar to the water application for 2007 Plots during the 2008 growing season (GSA 2009b).

2009 Small-scale Study Plots

During 2009, 12 additional small-scale field plots of Goodding's willow were implemented. The objective was to determine the effectiveness of variable seeding rates (design rates of 50, 100, or 150 Pure Live Seed (PLS)/ft^2) on the establishment and growth of Goodding's willow given furrow irrigation and hydroseeding of un-cleaned seed. As for 2008 Plots, extensive weed control (spraying of grasses) was implemented. These 6 m by 12 m plot studies were located on the east end of Cibola NWR Field 51, on the southern end of 2008 Plots (Figure 3). Plot placement was randomized. Additional detail, including study approach and results are presented in GSA (2010).

Continued monitoring has pursued the following objectives:

- Determine survival rates for seeded Goodding's willow and volunteer saltcedar plants for two growing seasons.
- Quantify additional establishment of native or introduced trees.

Because plots were established on the southern end of 2008 Plots and irrigation lines, these plots were subject to the deep, infrequent irrigation regime during 2010.

2.2 Irrigation Application

Irrigation treatments in 2010 were used to look at two different irrigation regimes for each set (i.e. either 2007 mixed riparian Plots or 2008 Goodding's willow Plots) of Plots. For a given set of Plots, the objective was to apply similar volume of irrigation water over the year under the two irrigation regimes: shallow, frequent irrigation (A blocks) and deep, infrequent irrigation (B blocks), but to allow two soil water depletion levels in the rooting zone between irrigation events. Irrigation block layout is depicted in Figure 4. Because of the placement of the 2009 Plots, these plots were included in the B block irrigation treatment for 2008 Plots.

For 2007 study plots, the target irrigation rate was 60% of reference evapotranspiration (ET_0) (i.e. a crop coefficient (K_c), of 0.6 was assumed). Thus, the evapotranspiration (ET) rate for the 2007 Plots was estimated by Equation 2.1:

$$ET = K_c \times ET_0 \tag{2.1}$$

Half of the 2007 Plots (shallow irrigation Blocks A1 and A2) were irrigated when 5.5 cm of ET, as estimated by Equation 2.1, had accumulated since the previous irrigation event. The other half of the plots (deep irrigation Blocks B1 and B2), were irrigated when 22 cm of ET, as estimated by Equation 2.1, had accumulated since the previous irrigation event. During the summer, the irrigation frequencies required based on these guidelines were approximately once per ten days (A blocks) or once per five weeks (B blocks).

For the 2008 Plots, the target irrigation rate was approximately 80% of ET_0 (K_c of 0.8). Half of the 2008 Plots (shallow irrigation Block A3) were irrigated when 7 cm of ET, as estimated by Equation 2.1, had accumulated since the previous irrigation event. The other half of the 2008 Plots and all the 2009 Plots (deep irrigation Block B3) were irrigated when 21 cm of ET, as estimated by Equation 2.1, had accumulated since the previous irrigation event. During the summer, the irrigation frequencies required based on these guidelines were approximately once per week (A Blocks) or once per three weeks (B Blocks).

Irrigation management by GSA followed this schedule between March 1 and October 31, 2010. One irrigation block was watered at a time (i.e. A1, A2, A3, B1, B2, B3E, or B3W). As described in the 2007 Annual Report (GSA 2008b), a totalizing flow meter was installed adjacent to the irrigation pump and was used to guide irrigation application. When the flow meter malfunctioned, prescribed irrigation volumes were applied based on flow rates and irrigation duration required for previous irrigation events.

Prior to each irrigation event, the cumulative flow volume was recorded from the flow meter display, and the flow volume was monitored until the required volume of water was applied. The irrigation protocol in 2009 was implemented as described in the 2007 Annual Report (GSA 2008b). The prescribed irrigation depth for B blocks was sometimes greater than the combined daily infiltration and surface storage capacity of the plot area. Therefore, irrigation water application to the B blocks sometimes occurred over a period of two days for each irrigation event.

2.3 Vegetation Surveys

2010 vegetation monitoring of the Plots consisted of point transect monitoring and quadrat monitoring late in the growing season (i.e. October 2010). A stratified random design of monitoring was used, whereby one sample type was located randomly within each third of the plot (with plot divisions into thirds based on distance from the gated irrigation pipe). Three previously-established vegetation point transects were monitored per plot. In the 2007 and 2008 Plots, three 0.5 m by 1.0 m quadrats and three transects along one edge of each quadrat, traversing the plot from north to south, were monitored. For the 2009 Plots, two quadrats were monitored along each transect to increase the spatial coverage of surveys and allow more effective monitoring of lower tree densities. An example survey schematic (for the 2007 Plots in this case) is shown in Figure 5.

Because root surveys were previously conducted in ten of the 2007 Plot quadrats, repeat measurements were not made in these quadrats. For these Plots, only un-disturbed quadrats and transects were used for vegetation monitoring. No root surveys were conducted in the 2008 or 2009 Plots. Therefore, previously-monitored quadrats and transects in these plots were used for vegetation monitoring. The number of quadrats per 2008 Plot was reduced to three from nine during 2008 in order to mimic the study design of the 2007 Plots, whereas monitoring was continued in all six quadrats for 2009 Plots.

To determine growth rates for individual trees and mortality of Fremont cottonwood, Goodding's willow, and saltcedar, GSA monitored individual trees within 2007 and 2008 Plot quadrats. This procedure allowed follow-up measurements of individual trees at the end of each growing season. Individual tree tagging in 2007 Plots was completed in May 2008. Individual tree tagging for 2008 Plots was implemented in May 2009. Tree tagging has not been implemented for 2009 Plots. Therefore, growth rates and size-specific mortality have not been monitored for those quadrats.

As for previous surveys, species-specific data were analyzed for seeded riparian species (Fremont cottonwood, Goodding's willow, and coyote willow) and saltcedar. Grasses and sedges were lumped (denoted "G/S") and other species (including arrowweed) were classified as shrubs and forbs (denoted "S/F"). Survey methods are briefly reviewed below.

<u>Point Transects</u>

Species-specific crown and canopy cover was estimated via point transects. Two wood stakes were placed on either side of the plot (north or south), and a tape measure was attached to each stake. A dowel was held vertically at each transect point at one-foot (approximately 30 cm) intervals and each cover type below the dowel at each point was recorded on datasheets. Each cover type was recorded a maximum of once per point. The cover percentage of each component was obtained by dividing the number of "hits" by the number of sample points, as described by Equation 2.2:

$$Cover = (x / n) \times 100\% \qquad 2.2$$

where x is the number of hits for a given cover type, and n is the number of observation points per plot (i.e. n = 63 at 20-feet of plot width with 1 observation per foot times three transects per plot).

The first cover type below the dowel represented crown cover, whereas canopy cover included both crown cover and understory cover. Crown cover indicates the dominant (tallest) species in the observation area, whereas canopy cover indicates total abundance of a given cover. Therefore, canopy cover is greater than or equal to crown cover. By definition, the combined crown cover of all cover types, including bare ground and litter, must equal 100%, whereas the total vegetated canopy cover per species must be less than or equal to 100%.

Quadrat Analyses

Quadrats consisted of 1 by 0.5 m rectangles (0.5 m^2) constructed from ¾-inch diameter PVC pipe. Three random numbers were selected to determine the location of each quadrat. The combination of random numbers determined the location of the reference corner for quadrats within each third of a given plot (e.g. Figure 5). For plots on the west side of the irrigation pipes, the random numbers determined the location for the northeast corner of the quadrat. For plots on the east side of the irrigation pipes, the random numbers determined the location for the northwest corner on the quadrat. Once this corner was located, the adjacent north-south edge was aligned with the cover transects.

Within quadrats, the cover of all species was visually estimated using sociologic classification; crown and canopy cover for each observed species was estimated to cover classes. In the 2007 and 2008 Plots, an aluminum tag with a unique identification number was affixed to each Fremont cottonwood, Goodding's willow, coyote willow, and woody saltcedar within a given quadrat. Due to the abundance of saltcedar plants in the 2008 Plots, saltcedar plants were only tagged and counted for half of each quadrat.

Tree heights were measured to the nearest 0.5 cm, and the number of height measurements was used to tabulate stem density (stems per square meter). All other species were monitored by assigning a relevé index and estimating the average plant height. Data for the three quadrats per plot were combined to provide an overall estimate for the plot. The combined quadrat area represented approximately two percent of the total plot area for 2007 and 2008 Plots and four percent of the 2009 Plot area for. Repeat measurements of tagged trees allow for determination of growth between fall 2009 and fall 2010 surveys.

Statistical Analyses

Statistics were analyzed via Student's t-tests for treatment variable effects. Additionally, linear analysis of variance (ANOVA) modeling was conducted using JMP 6™ (SAS Institute, Cary, N.C.).

In order to determine if treatment effects observed in the initial survey were sustained over more than one growing season, the effects of seed application method, surface irrigation method, and seeding rates in 2007 and 2008 Plots were determined for:

- Crown cover of seeded and non-seeded species.
- Canopy cover of seeded and non-seeded species.
- Stem density of seeded species and saltcedar.
- Height of seeded species and saltcedar.

Least-squared means were compared via Student's t-tests to determine significant differences between treatments. Because seeding rate was not a major variable for 2007 and 2008 Plots, it could not be included as part of the factorial design, but was included as a continuous variable in the ANOVA models. As a result least-squared means for different seeding rates were not available in the results. Direct (increasing) or inverse (decreasing) relationships were calculated and the P-values associated with those relationships are presented.

ANOVAs were also constructed to assess the effects of initial tree height (during May 2009 survey), irrigation treatment (A, shallow or B, deep, as described previously), surface irrigation method (furrow or border-strip irrigation), cottonwood and saltcedar crown cover, and cottonwood and saltcedar stem density on cottonwood and saltcedar growth rates. The overall crown cover from each plot and the average stem density for the three quadrats were used as independent variables. In the ANOVA results tables, the P-values for effects and interactions are based on F-tests. Significant differences for least-squared means were based on Student's t-tests on means and α of 0.05.

Because the design for 2009 Plots was randomized with only one treatment variable, means were compared via Student's t-tests on means or proportions, as appropriate.

All graphical results are presented with 95% confidence intervals on the mean. For selected comparisons, Student's t-tests were conducted to determine significant differences with an α of 0.05.

2.4 Results: Continued Monitoring of 2007 Small-scale Study Plots

2.2.1 2007 Small-scale Plots: Rainfall and Irrigation Water Application

Rainfall data for 2010 are provided in Table 1. Irrigation event application depths are shown in Table 2 and Table 3 for the A and B irrigation blocks, respectively. The total depth of applied water for the 2010 growing season (March through October) averaged 132 cm for the A blocks. Based on ET0 (calculated via the Penman-Monteith equation (FAO 1998)) and rainfall at the nearby Cibola weather station, the applied water to the A Blocks correlates to approximately 63% of ET0. The total depth of applied water averaged 130 cm for the deep irrigation B blocks correlated to approximately 63% of ET0.

2.2.2 Vegetation Monitoring: 2007 Small-scale Plots: Treatment Variables

2009 ANOVA results for the 2007 Plot treatments are provided in Table 4 and Table 5 for seeded and non-seeded species, respectively. These results evaluate the effects of initial seeding and irrigation methods on plant establishment and cover after four growing seasons (i.e. May 2007 through October 2010). Treatment effects are discussed in detail below.

Crown and canopy cover of Fremont cottonwood in plots irrigated with sprinklers during establishment were lower compared to no sprinkler irrigation, similar to previous surveys, despite no difference in establishment rates between the irrigation treatments (Table 4). Average cottonwood tree height was no longer significantly lower in sprinkler-irrigated plots (Table 4) indicating that the slower tree stem growth rates observed in sprinkler-irrigated plots during 2007 and 2008 recovered after three growing seasons. Crown cover of saltcedar was also lower in sprinkler-irrigated plots; however, canopy cover of this species did not differ between these treatments (Table 5). Crown and canopy cover of grasses continue to be greater in sprinkler-irrigated plots (Table 5), likely due to reduced cottonwood and saltcedar cover.

Cottonwood canopy cover and tree density were highest for hydroseeded, un-cleaned seed compared to broadcast or hydroseeded, cleaned seed. However, ANOVA least-squared means of canopy cover were not significantly different at P=0.05 (Table 4). Hydroseeding of cleaned seed was intermediate, but not significantly different from the other seeding methods. Seed treatment did not result in significant differences within volunteer saltcedar or shrubs and forbs (Table 5).

Furrow irrigation continued to result in significantly greater crown and canopy cover of Fremont cottonwood compared to border-strip irrigation (Table 4). Cottonwood stem density was not significantly different between surface irrigation treatments (Table 4). These results indicate that furrow irrigation did not increase the establishment of cottonwood, but it provided more even distribution of trees. Although average cottonwood height was greater under furrow irrigation than border-strip irrigation after one and two growing seasons, significant differences were not observed after the 2009 or 2010 growing seasons (GSA 2010 and Table 4, respectively). Surface irrigation methods did not significantly affect saltcedar establishment or growth (Table 5), whereas grass and sedge cover was greater in border-strip irrigated plots compared to furrow-irrigated plots (Table 5).

Lower cottonwood crown and canopy cover were observed in plot position 1 (northern portion of Field 51, Figure 1) compared to plot position 2 or 3 (central and southern portions of the field, respectively, Figure 1, Table 4). Conversely, saltcedar crown cover and growth were greatest for plot position 1 (Table 5). These results may be due to higher subsurface salinity observed on the northern side of the field (GSA 2008c).

2.2.3 Vegetation Monitoring: 2007 Small-Scale Plots: Long-term Trends

ANOVA results for Fremont cottonwood and saltcedar growth between the fall 2009 and fall 2010 surveys are provided in Table 6; summary charts for long-term vegetation trends between 2007 and 2009 are provided in Figure 6 through Figure 8 and discussed in detail below. Due to minimal establishment of willow species in 2007 and high mortality of willow in 2008, results are only presented for cottonwood and saltcedar. Growth rate data are available only for tagged plants (Section 2.3). Therefore, many saltcedar plants were not included in the growth analysis because their stems were not sturdy enough to support identification tags. By monitoring the total number of trees in each quadrat, non-tagged trees within quadrats were included in plant density and overall species mortality analyses.

Average Fremont cottonwood crown cover across all plots increased from 70.3% in fall 2009 to 75.9% in fall 2010 (Figure 6), and canopy cover increased from 71.5% to 77.2% during that time period (Figure 7). Saltcedar crown cover decreased from 12.3% in fall 2009 to 9.1% in fall 2010

(Figure 6), and canopy cover decreased from 37.0% to 29.6% (Figure 7). Despite initially-greater canopy cover of saltcedar after the first (2007) growing season, both crown and canopy cover of cottonwood have exceeded saltcedar since May 2008, indicating superior growth rates and survival for Fremont cottonwood compared to saltcedar.

The overall average Fremont cottonwood tree density slightly increased from fall 2009 to fall 2010 (11.9 stems per m^2 to 12.1 stems per m^2) due to re-sprouting of previously-believed dead individuals, and the density of saltcedar decreased from 12.8 stems per m^2 to 11.9 stems per m^2 (Figure 8), although differences are not statistically significant. Overall mortality decreased from the 2008 to 2009 monitoring period for both species (Figure 9).

Combined grass and sedge crown cover remained near 10% from fall 2009 to fall 2010 (Figure 6). Grass and sedge canopy cover remained high (Figure 7), indicating abundance of these species in the understory. Crown cover and canopy cover of shrubs and forbs (S/F) remained near 0% and 5%, respectively in fall 2010 (Figure 6 and Figure 7), likely due to larger trees inhibiting recruitment.

2.2.4 Vegetation Monitoring: 2007 Small-scale Plots: Irrigation Treatment Effects

Overall Fremont cottonwood mortality was not affected by irrigation treatment between fall 2009 and fall 2010 surveys (Figure 9). For saltcedar, higher mortality of saltcedar was observed for the A irrigation treatment than B, which is the opposite effect as observed between fall 2008 and fall 2009 surveys (Figure 9). Mortality differences due to irrigation treatment were not observed for different size classes of tagged trees between fall 2009 and fall 2010 (Table 7). The higher mortality for saltcedar under the A irrigation treatment was therefore likely accounted for by small, untagged individuals.

Neither Fremont cottonwood nor saltcedar growth rates were affected by irrigation treatment for any tree size classes (Figure 10 and Figure 11, respectively) or other ANOVA-modeled effects (Table 6). Likewise, ANOVA analysis indicated no effects of surface irrigation method on growth of either species (Table 6).

2.2.5 Vegetation Monitoring: 2007 Small-scale Plots: Competition Effects

Greater Fremont cottonwood crown cover resulted in decreased cottonwood growth rates. However, greater Fremont cottonwood stem density did not adversely affect growth between fall 2009 and fall 2010—growth was highest at the highest tree density (Table 6). Neither saltcedar crown cover nor density consistently affected Fremont cottonwood growth (Table 6). Greater initial cottonwood tree height also resulted in higher cottonwood growth rates (Table 6).

Saltcedar growth rates were not affected by Fremont cottonwood crown cover. However, saltcedar growth rates were increased with high Fremont cottonwood density (Table 6). Higher saltcedar growth rates were observed with high saltcedar crown cover, but were not consistently affected by saltcedar density (Table 6). Greater initial height of saltcedar resulted in lower growth rates.

Mortality of both cottonwood and saltcedar was greatest for plants less than 50 cm (Table 7). Mortality for tagged saltcedar less than 50 cm tall at the beginning of the growing season was approximately 13% and mortality for cottonwood less than 50 cm tall was 36%. No mortality was observed for saltcedar plants taller than 200 cm during the 2010 growing season and only one Fremont cottonwood greater than 200 cm tall died during the 2010 growing season (n = 28 and 287, for saltcedar and cottonwood, respectively). Cottonwood mortality was greater than that of saltcedar for trees less than 50 cm in B irrigation blocks; significant differences in mortality were not observed in other height classes.

In general, Fremont cottonwood growth rates were greater than those of saltcedar across tree heights and irrigation treatments (Figure 12 and Figure 13). The exception was the 300.5-400 cm height class in the A blocks, where growth rates were not significantly different between species. Growth for cottonwood increased with higher initial tree height (Table 6), likely due to greater sunlight and soil water availability. Conversely, growth for saltcedar decreased with higher initial tree height. However, growth rates were highly-variable for larger individuals (Figure 11).

2008 monitoring results indicated that beyond an intermediate Fremont cottonwood tree density of approximately ten to fifteen per m^2 (approximately one per square foot), the average cottonwood crown cover was above 60%, with less than 20% saltcedar crown cover after two growing seasons (GSA 2009b). As shown in Figure 14, saltcedar crown cover was less than 40% in all plots after four growing seasons, whereas Fremont cottonwood crown cover is greater than 50% in 31 of 36 plots. At Fremont cottonwood stem densities of over 20 per m^2, cottonwood crown cover always exceeded than that of saltcedar, and saltcedar crown cover was always less than 10%.

2.5 Results: Continued Monitoring of 2008 Small-scale Study Plots

2.3.1 2008 Small-scale Plots: Rainfall and Irrigation Water Application

Irrigation event application depths are shown in Table 8 and Table 9 for irrigation block A3 (shallow irrigation) and B3 (deep irrigation), respectively. The total depth of applied water for the 2009 growing season (March through October) was 153 cm for Block A3. Based on estimated ET_0, the applied water to block A3 was approximately 74% of ET_0. The total depth of applied water averaged 197 cm for Block B3, correlating to approximately 92% of ET_0. The discrepancy in irrigation depths was due to an irrigation event missed for block A3 and irrigation overruns on block B3.

2.3.2 Vegetation Monitoring: 2008 Small-scale Plots: Treatment Variables

2009 ANOVA results for the 2008 Plot treatments are provided in Table 10 for seeded and non-target species. These results evaluate the relationship between initial seeding and irrigation treatments on plant establishment and cover after two growing seasons (i.e. May 2008 through October 2009). Treatment effects are discussed in detail below.

Although Goodding's willow cover did not vary with seeding methods, tree density was significantly higher for hydroseeded, un-cleaned seed compared to broadcasted cleaned seed (Table 10). Variations in seed treatment did not accompany significant differences for any volunteer species (Table 10). Surface irrigation method did not have a significant effect on Goodding's willow or any volunteer species (Table 10).

Interaction results show that hydroseeding onto furrows resulted in greater Goodding's willow density and canopy cover than broadcasting onto leveled (border) (Table 10). Other interactions were not significant for Goodding's willow or saltcedar at P=0.05.

No results were significantly-correlated with seeding rates (Table 10). The actual seeding rates varied only between 1,500 and 1,850 pure live seeds (PLS) per m^2, so effects of large variation in seeding rates cannot be effectively analyzed based on the 2008 plot results.

2.3.3 Vegetation Monitoring: 2008 Small-scale Plots: Long-term Trends

ANOVA results for Goodding's willow and saltcedar growth rates between the spring and fall 2009 monitoring events are provided in Table 11; summary charts for long-term vegetation trends between 2007 and 2009 are provided in Figure 15 through Figure 17 and discussed in detail below. As for 2007 study plots, the growth rate data are available only for tagged plants. Therefore, many saltcedar plants were not included in the growth analysis because their stems were not sturdy enough to support identification tags. Non-tagged trees are included in plant density and overall species mortality analyses.

Average Goodding's willow crown cover across all plots decreased from 8.6% in fall 2009 to 7.0% in fall 2010 (Figure 15), whereas canopy cover remained near 19% over that time period

(Figure 16). Saltcedar crown cover decreased from 44.0% in fall 2009 to 24.5% in fall 2010 (Figure 15) and canopy cover decreased from 77.7% to 74.1% (Figure 16). Shrub and forb crown cover increased from 38.5% to 58.0% (Figure 15) and canopy cover increased from 61.7% to 88.1% (Figure 16). Grass and sedge crown cover declined from 4.3% to 1.5% (Figure 15) and canopy cover decreased from 40.0% to 12.2% (Figure 16).

The overall average Goodding's willow tree density decreased from fall 2009 to fall 2010 (6.4 stems per m^2 to 2.7 stems per m^2), whereas the density of saltcedar decreased from 30.8 stems per m^2 to 26.0 stems per m^2 (Figure 17). These changes correspond to overall mortality of approximately 58% and 16% for Goodding's willow and saltcedar, respectively (Figure 18).

Mortality was greater for smaller Goodding's willow and saltcedar (Table 12). No mortality was observed for Goodding's willow or saltcedar taller than 200 cm during the 2009 growing season (*n* of 9 and 38 for Goodding's willow and saltcedar, respectively). Goodding's willow mortality was greater than that of saltcedar for trees between 0 and 200 cm tall in B blocks (without considering non-tagged saltcedar, Table 12).

For trees between 100.5 and 200 cm in both A and B irrigation treatments, Goodding's willow growth rates were greater than those of saltcedar (Figure 19 and Figure 20). Significant differences were not observed for taller plants. As observed in the 2007 plots, growth rates for Goodding's willow increased with greater initial tree height, whereas the growth of saltcedar was not significantly correlated with plant height (Table 11).

2.3.4 Vegetation Monitoring: 2008 Small-scale Plots: Irrigation Treatment Effects

Goodding's willow mortality was greater for the deep, infrequent irrigation treatment (Block B3) than for shallow, frequent irrigation (Block A3, Table 12, Figure 18). Saltcedar mortality was not affected by irrigation treatment (Table 12, Figure 18). Goodding's willow and saltcedar growth between fall 2009 and fall 2010 was not significantly affected by irrigation treatment (Table 11). Likewise, no significant differences were observed between border-strip and furrow irrigation (Table 10, Table 11).

2.3.5 Vegetation Monitoring: 2008 Small-scale Plots: Competition Effects

No significant effects of Goodding's willow density or crown cover on Goodding's willow or saltcedar growth were observed (results not presented). Therefore, this effect was removed from ANOVA modeling of growth rates. Due to the prevalence of arrowweed and the expansion of grouped shrub and forb cover, this was included as a treatment effect.

Goodding's willow growth was not significantly affected by saltcedar crown cover or stem density, but growth was greater for shrub and forb crown cover greater than 60% (Table 11). Taller initial tree height resulted in higher growth rates (Table 11).

Saltcedar growth rates were not significantly affected by Goodding's willow cover or density (results not presented). Saltcedar growth was not consistently affected by saltcedar crown cover. However, growth was generally higher for greater crown cover (Table 11). Saltcedar growth was not significantly affected by shrub and forb crown cover nor initial tree height (Table 11).

2010 results indicate that Goodding's willow growth rates are no longer consistently greater than those of saltcedar (Figure 19 and Figure 20). Additionally, mortality of Goodding's willow was greater than that of saltcedar between October 2009 and October 2010 (Figure 18). These results, combined with higher initial densities of saltcedar than Goodding's willow (Figure 17), have promoted dominance of saltcedar over Goodding's willow in crown and canopy cover (Figure 15 and Figure 16, respectively). Volunteer shrubs and forbs (primarily arrowweed) have expanded in 2008 Plots and these species now compose the majority of crown cover (Figure 15) and the highest canopy cover (Figure 16) of monitored vegetation cohorts.

2.6 Results: Continued Monitoring of 2009 Small-scale Study Plots

2.4.1 2009 Small-scale Plots: Rainfall and Irrigation Water Application

Because 2009 Plots were included in irrigation of Block B3, irrigation water application is as detailed in Table 9. The total depth of applied water averaged 197 cm for 2009 Goodding's willow plots, correlating to approximately 92% of ET_0.

2.4.2 Vegetation Monitoring: 2009 Small-scale Plots: Treatment Variables

Treatment results and significant differences are presented in Table 13. After two growing seasons in the 2009 small-scale plots, crown cover of Goodding's willow was higher at the 1685 PLS/m^2 seeding rate compared to the two lower seeding rates (Table 13, Figure 21) and canopy cover increased with each increase in seeding rate (Table 13, Figure 22). However, despite an approximate 3-fold increase in seeding rate from the low to high seeding rate, significant differences were not observed for Goodding's willow tree density (Table 13, Figure 23). This is likely due to variability in tree establishment for the three replications at the highest seeding rate.

Increases in Goodding's willow seeding rates resulted in significant decreases in crown cover of shrubs and forbs (Table 13, Figure 21). This decrease is likely due to the increased cover of Goodding's willow.

Goodding's willow height after two growing seasons was not consistently affected by seeding rate. Tree heights were greatest for the intermediate seeding rate (1,150 PLS/m^2) with smaller tree heights observed for low (579 PLS/m^2) and high (1,685 PLS/m^2) seeding rates (Figure 24).

No other consistent trends were observed due to the seeding rate treatment at P=0.05.

2.4.3 Vegetation Monitoring: 2009 Small-scale Plots: Vegetation Trends for Two Growing Seasons

Crown cover for Goodding's willow increased from approximately 13% to 15% (Figure 25) between the fall of 2009 and the fall of 2010. Saltcedar crown cover also increased from 13% to 19%. Grass and sedge cover decreased from 17% to 2%, and shrub and forb crown cover remained near 57% (Figure 25).

Canopy cover for Goodding's willow increased from approximately 21% to 29% (Figure 26) between the fall of 2009 and the fall of 2010. Saltcedar canopy cover also increased from 24% to 39%. Grass and sedge canopy cover decreased from 29% to 8%, and shrub and forb canopy cover decreased slightly from 91% to 85% (Figure 26)

Between the fall of 2009 and fall of 2010, the overall density of Goodding's willow decreased from 17.5 to 8.8 stems per m^2, and the overall density of saltcedar decreased from 5.6 to 3.6 stems per m^2 (Figure 28). This corresponds to a mortality of approximately 50% and 37% for Goodding's willow and saltcedar, respectively. Although the reasons for mortality cannot be determined with certainty, the majority of mortality appeared to be due to herbivores.

2.3.5 Vegetation Monitoring: 2009 Small-scale Plots: Competition Effects

As discussed extensively in GSA (2009), saltcedar establishment was greatly-reduced in the 2009 study plots compared to the 2007 and 2008 study plots, such that native, seeded species outnumbered saltcedar after the first growing season (fall 2009 survey data) for the first time. Removal of saltcedar along the main Cibola NWR Farm Unit irrigation canal and from the fields west of Field 51 cleared for LCR MSCP riparian vegetation likely resulted in reduced air- and water-borne seed sources.

After two growing seasons, saltcedar crown cover was observed to be greater than that of Goodding's willow in seven of eleven plots (Figure 29) and overall saltcedar crown cover is greater than that of Goodding's willow (Figure 25). Crown cover of Goodding's willow was greater than that of saltcedar at the 1,685 PLS/m^2 seeding rate, but less than that of saltcedar at both lower seeding rates (Figure 21). Height of Goodding's willow and saltcedar was not significantly different at a given seeding rate (Figure 24). Because crown cover of saltcedar is similar to that of Goodding's willow despite a lower density and similar heights, saltcedar is likely growing with a wider canopy than Goodding's willow. Crown cover of volunteer shrubs and forbs (primarily arrowweed) remains greater than that of Goodding's willow at all seeding rates (Figure 21).

After two growing seasons, canopy cover of Goodding's willow was greater than that of saltcedar in only two of eleven plots (Figure 30). Overall canopy cover of saltcedar was still greater than that of Goodding's willow (Figure 30), but canopy cover of Goodding's willow was greater than that of saltcedar at the highest seeding rate (1,685 PLS/m^2, Figure 22).

After two growing seasons, Goodding's willow density was observed to be greater than that of saltcedar in eight of eleven plots (Figure 27) and overall density of Goodding's willow is still greater than (more than double) that of saltcedar (Figure 28). Mortality of Goodding's willow was 50%, and mortality of saltcedar was 37%.

5.0 CONCLUSIONS

Four years of monitoring dynamics of densely-established Fremont cottonwood and volunteer saltcedar since 2007 indicate that hydroseeding of un-cleaned seeds and furrow irrigation of cottonwood is the most effective seeding method. Even with high initial establishment of saltcedar, the plant community within seeded plots is dominated by Fremont cottonwood.

Monitoring of densely seeded Goodding's willow plots indicate that hydroseeding of Goodding's willow onto furrows is likely the most effective seeding method. When intermixed with high-density volunteer saltcedar and arrowweed in 2008 study plots, saltcedar and arrowweed are the dominant species, and mortality of Goodding's willow was greater than 50% for the third growing season. Therefore, limiting saltcedar and arrowweed establishment during the first growing season is desirable to promote re-vegetated Goodding's willow communities.

Two years of monitoring for 2009 study plots seeded at variable Goodding's willow seeding rates indicates that saltcedar and grass volunteer establishment can be limited during the initial establishment of native species. Furthermore, establishment rates were not affected by seeding rate (GSA 2010), which indicates willow density (and costs of large-scale revegetation) on the lower Colorado River can be optimized. High mortality of Goodding's willow in the 2009 study plots between October 2009 and October 2010 indicates that 1) site conditions at Cibola NWR are likely unfavorable for Goodding's willow, and/or 2) herbivory is a concern for Goodding's willow seedlings.

Specific conclusions for each of the small-scale plot experiments are provided below:

2007 Mixed Riparian Seed Small-scale Study Plots

In the 2007 Plots, Fremont cottonwood established and dominated the crown cover of many plots after the first growing season. Goodding's and coyote willow establishment was poor. Non-target species (primarily grass and sedges) dominated biomass in the small-scale plots and saltcedar stems were a significant proportion of total stem counts after the first growing season (GSA 2008b).

During the 2008 through 2010 growing seasons, cottonwood growth expanded in the small-scale study plots, increasing in crown cover from 15.9% in September 2007 to 76% by October 2010. In general, growth rates of Fremont cottonwood were greater than those of saltcedar between the fall 2009 and fall 2010 surveys. Fremont cottonwood crown and canopy cover dominated saltcedar after two growing seasons; canopy cover of Fremont cottonwood was more than twice that of saltcedar at the end of the 2010 growing season. Deep and less frequent irrigation (i.e. frequency of once per month or less) did not affect growth or survival of cottonwood or saltcedar during the second growing season (2008), appeared to favor cottonwood growth and survival over saltcedar during the third growing season (2009), and did not affect growth or survival in the fourth growing season (2010).

2007 study plot results to dates indicate that cottonwood is likely to maintain dominance in the study area. 2010 vegetation survey results indicate that an intermediate cottonwood establishment (e.g. ten to fifteen stems per square meter) may be sufficient to maintain high growth rates and reduce saltcedar growth.

2008 Goodding's Willow Small-scale Study Plots

During the 2010 growing season, Goodding's willow abundance and crown cover decreased slightly in the 2008 Plots from 6% to 3% and 9% to 7%, respectively, from October 2009 to October 2010. Saltcedar crown cover also decreased, from 44% to 24% during that same period. Volunteer shrubs and forbs (primarily arrowweed) expanded in crown cover from 38% to 58%, indicating that these species are becoming dominant. Results to date suggest that undesirable species are likely to maintain dominance in the study area.

2009 Goodding's Willow Small-scale Study Plots

Establishment rates of Goodding's willow increased from 0.1% in the 2007 study plots to 0.95% and 1.67% in the 2008 and 2009 small-scale study plots, respectively. The increased establishment was likely due to better grass management and use of hydroseeding un-cleaned seed as an optimum seed treatment.

Three-fold increases in seeding rate for the 2009 study plots did not result in significant increases in Goodding's willow crown or canopy cover after one growing season—however, increasing seeding rates resulted in greater crown and canopy cover, with no reduction in establishment percentage with high seeding rates. The average height of Goodding's willow was similar to that of saltcedar after one and two growing seasons. However, mortality of Goodding's willow was greater than that of saltcedar. Continued monitoring of these plots is needed to determine the long-term vegetation communities that will result from variable seeding rates.

In the 2008 and 2009 Goodding's willow study plots, enhanced management of undesired grass species through repeated application of herbicide reduced the abundance of grass in plots.

Growth of shrubs (primarily arrowweed, goosefoot, and (in 2008 plots) saltcedar) increased, perhaps due to reduced competition with grass. Additionally, the abundance of saltcedar was greatly-reduced in the 2009 study plots compared to the 2007 and 2008 experiments, most likely due to removal of saltcedar sources along the main Cibola NWR Farm Unit irrigation canal and from the fields west of the study site. These results indicate the need for an integrated weed management plan, whereby herbaceous and shrubby weed growth are reduced via effective pre-seeding weed management within in the field (e.g. irrigation, herbicide, and tillage cycles), volunteer establishment of saltcedar is reduced by removal of adjacent undesired seed sources, and grass growth is reduced after seeding through application of grass-specific herbicide.

6.0 RECOMMENDATIONS

Extensive recommendations for seeding demonstrations and determination of soil moisture and salinity budgets were provided in GSA (2010) and are outside the scope of the current grant. Continued monitoring of existing small-scale study plots is recommended with decreased frequency (e.g. biannually) to monitor long-term vegetation success. Specifically, because relatively low mortality has been observed for dense Fremont cottonwood in 2007 study plots, the effects of long-term, passive thinning of trees is unknown. Additionally, if Reclamation requires additional information on the effects of irrigation management on elevated soil salinity levels, the small-scale plots at Cibola NWR would provide an opportunity to test, for example, the effectiveness of prolonged leaching on reducing soil salinity.

7.0 ACKNOWLEDGMENTS

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TABLES

Table 1. 2010 rainfall data for Cibola NWR.

Date	Rainfall (mm)[1]
1/18/2010	2.3
1/19/2010	9.7
1/20/2010	3.0
1/21/2010	43.2
2/6/2010	5.6
2/10/2010	13.5
2/20/2010	3.6
2/22/2010	2.0
2/27/2010	0.3
3/7/2010	18.0
3/8/2010	0.3
4/22/2010	0.3
8/25/2010	3.6
9/10/2010	5.6
10/20/2010	6.6
12/16/2010	1.0
12/21/2010	0.8
12/22/2010	25.7
12/25/2010	0.3
12/29/2010	0.8
Total:	**31.75**

1 Data available: http://www.wrcc.dri.edu/cgi-bin/rawMAIN.pl?azACBL.

Table 2. Applied water summary for 2009 growing season, 2007 Plots, A Blocks (shallow, frequent irrigation).

Block A1			Block A2		
Date	Irrigation Depth (cm)	Elapsed Time (days)[1]	Date	Irrigation Depth (cm)	Elapsed Time (days)[1]
3/3/2010	20.53	--	3/3/2010	19.38	--
3/23/2010	6.13	20	3/23/2010	6.13	20
4/6/2010	5.51	14	4/6/2010	5.52	14
4/18/2010	5.55	12	4/19/2010	5.50	13
4/26/2010	5.50	8	4/26/2010	5.50	7
5/18/2010	5.51	22	5/18/2010	5.60	22
5/27/2010	5.50	9	5/27/2010	5.52	9
6/8/2010	5.50	12	6/8/2010	5.50	12
6/17/2010	5.50	9	6/18/2010	5.50	10
6/28/2010	5.50	11	6/28/2010	5.50	10
7/6/2010	5.51	8	7/6/2010	5.50	8
7/14/2010	5.50	8	7/14/2010	6.96	8
7/26/2010	5.50	12	7/26/2010	5.50	12
8/2/2010	5.50	7	8/2/2010	5.50	7
8/10/2010	5.86	8	8/10/2010	5.50	8
8/20/2010	5.50	10	8/20/2010	5.50	10
8/31/2010	5.50	11	8/31/2010	5.50	11
9/10/2010	5.57	10	9/10/2010	5.44	10
9/20/2010	5.29	10	9/20/2010	5.73	10
10/4/2010	5.50	14	10/4/2010	5.50	14
10/28/2010	5.50	24	10/28/2010	5.50	24
Total Irrigation (cm)		131.46	Total Irrigation (cm)		131.79
Rainfall (cm)[2]		3.44	Rainfall (cm)		3.44
Estimated Reference Evapotranspiration (cm)[2]		213.28	Estimated Reference Evapotranspiration (cm)[2]		213.28
Irrigation and Precipitation/ET_0		0.63	Irrigation and Precipitation/ET_0		0.63

1 Days since previous irrigation event (rainfall not included).
2 Data from US Fish and Wildlife Service Cibola weather station, available: http://www.wrcc.dri.edu/cgi-bin/rawMAIN.pl?azACBL.

Table 3. Applied water summary for 2009 growing season, 2007 small-scale plots, B Blocks (deep, infrequent irrigation).

<table>
<tr><th colspan="3">Block B1</th><th colspan="3">Block B2</th></tr>
<tr><th>Date</th><th>Irrigation depth (cm)</th><th>Elapsed Time (days)[1]</th><th>Date</th><th>Irrigation depth (cm)</th><th>Elapsed Time (days)[1]</th></tr>
<tr><td>3/4/2010</td><td>19.87</td><td>--</td><td>3/4/2010</td><td>19.50</td><td>--</td></tr>
<tr><td>4/26/2010</td><td>22.00</td><td>53</td><td>4/26/2010</td><td>22.00</td><td>53</td></tr>
<tr><td>6/8/2010</td><td>22.00</td><td>43</td><td>6/8/2010</td><td>22.00</td><td>43</td></tr>
<tr><td>7/14/2010</td><td>22.02</td><td>36</td><td>7/14/2010</td><td>22.00</td><td>36</td></tr>
<tr><td>8/20/2010</td><td>5.72</td><td>37</td><td>8/20/2010</td><td>22.01</td><td>37</td></tr>
<tr><td>8/23/2010</td><td>16.52</td><td>3</td><td rowspan="2">10/4/2010</td><td rowspan="2">22.00</td><td rowspan="2">45</td></tr>
<tr><td>10/4/2010</td><td>22.00</td><td>42</td></tr>
<tr><td colspan="2">Total Irrigation (cm)</td><td>130.13</td><td colspan="2">Total Irrigation (cm)</td><td>129.51</td></tr>
<tr><td colspan="2">Rainfall (cm)[2]</td><td>3.44</td><td colspan="2">Rainfall (cm)[2]</td><td>3.44</td></tr>
<tr><td colspan="2">Estimated Reference Evapotranspiration (cm)[2]</td><td>213.28</td><td colspan="2">Estimated Reference Evapotranspiration (cm)[2]</td><td>213.28</td></tr>
<tr><td colspan="2">Irrigation and Precipitation/ET_0</td><td>0.63</td><td colspan="2">Irrigation and Precipitation/ET_0</td><td>0.62</td></tr>
</table>

1 Days since previous irrigation event (rainfall not included).
2 Data from US Fish and Wildlife Service Cibola weather station, available: http://www.wrcc.dri.edu/cgi-bin/rawMAIN.pl?azACBL.

Table 4. ANOVA linear modeling results after four growing seasons (October 2010 survey) for seeded riparian species in 2007 Plots.

Results		POFR[1] Crown Cover[2]	POFR Canopy Cover[3]	SAGO Canopy Cover	POFR Stems/m[2]	POFR Average Height[4]
Main Effects		p Values[5]				
Sprinklers		<0.0001	<0.0001	0.634	0.493	0.875
Seed Treatment		0.832	0.791	0.524	0.075	0.122
Surface Irrigation Method		<0.001	<0.001	0.190	0.067	0.918
Plot Position		0.026	0.040	0.421	0.006	0.482
Seeding Rate PLS/m[2]		0.462	0.345	0.789	0.610	0.829
Interactions						
Sprinklers*Seed Treatment		0.720	0.740	0.579	0.953	0.566
Sprinklers*Surface Irrigation Method		0.072	0.095	0.449	0.163	0.340
Seed Treatment* Surface Irrigation Method		0.999	0.967	0.380	0.873	0.412
Sprinklers*Seed Treatment*Surface Irrigation Method		0.557	0.509	0.521	0.337	0.242
		Means and Significant Differences[6]				
Sprinklers	No Sprinklers	0.889 A	0.912 A	0.003A	13.1 A	359 A
	Sprinklers	0. 619 B	0.633 B	0.005 A	11.0 A	366 A
Seed Treatment	Un-cleaned Hydroseed	0.784 A	0.801 A	0.001 A	17.2 A	309 B
	Cleaned Hydroseed	0.747 A	0.760 A	0.007 A	9.7 AB	424 A
	Cleaned Broadcast	0.874 A	0.756 A	0.003 A	9.3 B	354 AB
Surface Irrigation Method	Border-strip	0.644 B	0.656 B	0.006 A	9.2 A	360 A
	Furrow	0.806 A	0.889 A	0.001 A	15.0 A	365 A
Plot Position	Block 1	0.630 B	0.651 B	0.008 A	6.0 B	390 A
	Block 2	0.816 A	0.822 A	0.002 A	11.1 B	374 A
	Block 3	0.831 A	0.844 A	0.001 A	19.2 A	324 A
Seeding Rate, PLS/m[2]						
Correlation Relationship[7]	direct					
	inverse	0.462	0.345	0.789	0.610	0.828

1 Codes are for Fremont cottonwood (POFR) and Goodding's willow (SAGO).
2 Crown cover is the first cover type below a transect point; canopy cover is the ratio of the cover type to the total number of counting points (63) examined.
3 Canopy cover is the total canopy cover of the given vegetation type, including crown cover.
4 Height is the shoot length (cm).
5 Tests were run using JMP V 6.0.0 (SAS Institute, Cary, NC).
6 Numbers denote least-squared means. Significant differences were detected at p=0.05 within each main effect column according to Least-squared Means Differences Student's t-test; the same letters indicate that the difference between means is not significant and different letters indicate that the means are statistically significant. Means are compared within a result (column), not between them.
7 Relationships denote a direct (increasing-increasing) or inverse (increasing-decreasing) correlation between results and seeding rates.

Table 5. ANOVA linear modeling results after four growing seasons (October 2010 survey) for unseeded species in 2007 Plots.

Results		TARA[1] Crown Cover[2]	G/S Crown Cover	S/F Crown Cover	TARA Canopy Cover[3]	G/S Canopy Cover	S/F Canopy Cover	TARA Stems/ m^2	TARA Average Height[4]
Main Effects		p Values[5]							
Sprinklers		0.030	<0.001	0.154	0.054	0.003	0.200	<0.0001	0.521
Seed Treatment		0.758	0.081	0.888	0.740	0.768	0.951	0.210	0.854
Surface Irrigation Method		0.247	<0.001	0.218	0.624	0.016	0.625	0.873	0.338
Plot Position		0.019	0.843	0.359	0.048	<0.001	0.150	0.485	0.002
Seeding Rate, PLS/m^2		0.739	0.401	0.931	0.879	0.838	0.962	0.898	0.482
Interactions									
Sprinklers*Seed Treatment		0.523	0.139	0.546	0.423	0.431	0.697	0.953	0.933
Sprinklers*Surface Irrigation Method		0.262	0.221	0.945	0.363	0.117	0.317	0.454	0.052
Seed Treatment* Surface Irrigation Method		0.216	0.259	0.932	0.474	0.337	0.902	0.369	0.633
Sprinklers*Seed Treatment*Surface Irrigation Method		0.455	0.028	0.989	0.087	0.190	0.890	0.790	0.167
		Means and Significant Differences[6]							
Sprinklers	No Sprinklers	0.039 B	0.049 B	0.007 A	0.350 A	0.390 B	0.033 A	18.0 A	69 A
	Sprinklers	0.143 A	0.159 A	0.020 A	0.242 A	0.597 A	0.061 A	5.7 B	75 A
Seed Treatment	Un-cleaned Hydroseed	0.112 A	0.062 B	0.016 A	0.311 A	0.464 A	0.051 A	11.3 A	75 A
	Cleaned Hydroseed	0.071 A	0.113 AB	0.011 A	0.310 A	0.500 A	0.045 A	14.8 A	72 A
	Cleaned Broadcast	0.090 A	0.137 A	0.015 A	0.267 A	0.518 A	0.044 A	9.5 A	69 A
Surface Irrigation Method	Border-Strip	0.118 A	0.166 A	0.019 A	0.310 A	0.575 A	0.052 A	12.1 A	77 A
	Furrow	0.064 A	0.042 B	0.008 A	0.283 A	0.413 B	0.041 A	11.7 A	68 A
Plot Position	Block 1	0.195 A	0.114 A	0.024 A	0.402 A	0.687 A	0.072 A	13.7 A	95 A
	Block 2	0.047 B	0.104 A	0.009 A	0.244 B	0.457 B	0.049 A	11.8 A	74 AB
	Block 3	0.032 B	0.094 A	0.008 A	0.242 B	0.338 B	0.019 A	10.0 A	51 B
Seeding Rate, PLS/m^2									
Correlation Relationship[7]	direct	0.739	0.401	0.931	0.879	0.838	0.962		0.482
	inverse							0.898	

1 Codes are for Tamarix ramosissima (TARA), combined grasses and sedges (G/S), and combined shrubs and forbs (S/F) excluding TARA.
2 Crown cover is the first cover type below a transect point; cover percentage is the ratio of the cover type to the total number of counting points (63) examined.
3 Canopy cover is the total canopy cover of the given vegetation type, including crown cover.
4 Height is the shoot length (cm).
5 Tests were run using JMP V 6.0.0 (SAS Institute, Cary, NC).
6 Numbers denote least-squared means, letters denote significant differences at p=0.05 within each main effect column according to Least-squared Means Differences Student's t-test; the same letters indicate that the difference between means is not significant, and different letters indicate that the means are statistically significant. Means are compared within a result (column), not between them.
7 Relationships denote a direct (increasing-increasing) or inverse (increasing-decreasing) correlation between results and seeding rates.

Table 6. ANOVA modeling results for Fremont cottonwood and saltcedar in 2007 small-scale field study plots between October 2009 and October 2010.

Results		POFR[1] Growth[2], cm	TARA Growth, cm
Main Effects		**p Values[3]**	
Irrigation Treatment		0.611	0.791
Surface Irrigation Method		0.098	0.306
Fremont Cottonwood Crown Cover[5]		<0.0001	0.727
Fremont Cottonwood Stem Density		<0.0001	0.057
Saltcedar Crown Cover		0.954	0.020
Saltcedar Stem Density		0.031	0.270
Initial Tree Height[6]		<0.0001	0.004
Irrigation Treatment[7]		**Means and Significant Differences[4]**	
	A	35.4 A	7.1 A
	B	36.6 A	7.6 A
Surface Irrigation Method			
	Border-Strip	38.0 A	6.3 A
	Furrow	34.0 A	8.4 A
POFR Crown Cover			
	0-25	63.9 A	8.2 A
	25.1-50	45.6 A	5.4 A
	50.1-75	20.6 B	6.7 A
	75.1-100	13.9 C	9.1 A
POFR Density, stems/m^2			
	0-10	36.5 B	2.9 B
	10.1-20	32.2 B	5.1 B
	20.1-30	30.1 B	4.3 B
	30.1-40	45.1 A	17.0 A
TARA Crown Cover			
	0-25%	36.2 A	-2.2 B
	25.1-50%	35.8 A	2.6 B
	50.1-75%	--	21.6 A
TARA Density, stems/m^2			
	0-8	30.6 B	7.9 AB
	8.1-16	34.1 B	7.1 AB
	16.1-24	43.2 A	5.0 B
	24.1-32	36.1 AB	9.4 A
Initial Tree Height, cm			
Correlation Relationship[8]	direct	<0.0001	
	inverse		0.004

1 Codes are for Fremont cottonwood (POFR) and saltcedar (TARA).
2 Growth between October 2009 and October 2010 surveys.
3 Tests were run using JMP V 6.0.0 (SAS Institute, Cary, NC).
4 Numbers denote least-squared means, letters denote significant differences at p=0.05 within each main effect column according to Least-squared Means Differences Student's t-test; the same letters indicate that the difference between means is not significant, and different letters indicate that the means are statistically significant. Means are compared within a result (column), not between them.
5 Crown cover is the first cover type below a transect point; cover percentage is the ratio of the cover type to the total number of counting points (63) examined.
6 Height as measured during May 2009 surveys.
7 Codes indicated shallow, frequent irrigation (A) or deep, infrequent irrigation (B).
8 Relationships denote a direct (increasing-increasing) or inverse (increasing-decreasing) correlation between growth rates and initial (October 2009) tree heights.

Table 7. Fremont cottonwood and saltcedar mortality between October 2009 and October 2010 in 2007 small-scale study plots. Letters indicate significant differences across all values (t-test on proportions, $\alpha=0.05$).

Height Class	Irrigation Treatment	Fremont Cottonwood		Saltcedar	
		Mortality and Significant Differences	n	Mortality and Significant Differences	n
0-50	A	25% ABCD	4	14% AB	134
	B	43% A	7	12% BC	113
50.5-100	A	3% D	32	1% D	110
	B	6% CD	36	1% D	75
100.5-200	A	1% D	86	1% D	102
	B	0% D	105	0% D	31
200.5-300	A	0% D	84	0% D	24
	B	0% D	64	0% D	4
300.5-400	A	0% D	42	0% D	3
	B	0% D	47	--	0
400+	A	6% BCD	18	--	0
	B	0% D	32	--	0

Table 8. Applied water summary for 2009 growing season, 2008 plots, Block A3.

Block A3		
Date	Irrigation Depth (cm)	Elapsed Time (days)[1]
3/3/2010	19.19	--
3/23/2010	8.12	20
4/6/2010	7.01	14
4/19/2010	7.01	13
4/26/2010	7.00	7
5/18/2010	7.00	22
5/27/2010	7.02	9
6/8/2010	7.04	12
6/17/2010	7.00	9
6/27/2010	6.98	10
7/6/2010	7.00	9
7/14/2010	7.00	8
7/26/2010	7.00	12
8/2/2010	7.00	7
8/10/2010	7.00	8
8/20/2010	7.00	10
8/31/2010	7.00	11
9/10/2010	7.06	10
9/20/2010	7.00	10
10/29/2010	7.00	39
Total Irrigation (cm)		153.44
Rainfall (cm)[2]		3.44
Estimated Reference Evapotranspiration (cm)[2]		213.28
Irrigation and Precipitation/ET_0		0.74

1 Days since previous irrigation event (rainfall not included).
2 Data from US Fish and Wildlife Service Cibola weather station, available: http://www.wrcc.dri.edu/cgi-bin/rawMAIN.pl?azACBL.

Table 9. Applied water summary for 2009 growing season, 2008 plots blocks B3W and B3E.

Block B3W			Block B3E		
Date	Irrigation depth (cm)	Elapsed Time (days)[1]	Date	Irrigation depth (cm)	Elapsed Time (days)[1]
3/5/2010	21.11	--	3/4/2010	20.95	--
4/13/2010	21.00	39	4/14/2010	21.00	41
5/24/2010	21.11	41	5/24/2010	21.00	40
6/17/2010	21.25	24	6/17/2010	20.99	24
7/8/2010	21.00	21	7/8/2010	21.00	21
8/4/2010	21.40	27	8/4/2010	21.00	27
8/31/2010	21.11	27	9/1/2010	18.78	28
9/29/2010	25.68	29	9/29/2010	27.51	28
10/28/2010	21.11	29	10/28/2010	21.00	29
Total Irrigation (cm)		194.79	Total Irrigation (cm)		193.26
Rainfall (cm)[2]		3.44	Rainfall (cm)		3.44
Estimated Reference Evapotranspiration (cm)[2]		213.28	Estimated Reference Evapotranspiration (cm)[2]		213.28
Irrigation and Precipitation/ET_0		0.93	Irrigation and Precipitation/ET_0		0.92

1 Days since previous irrigation event (rainfall not included).
2 Data from US Fish and Wildlife Service Cibola weather station, available: http://www.wrcc.dri.edu/cgi-bin/rawMAIN.pl?azACBL.

Table 10. ANOVA linear modeling results for the 2008 Goodding's willow small-scale field study after three growing seasons (October 2010 survey).

Results	SAGO[1] Crown[2] Cover	SAGO Canopy[3] Cover	SAGO Stems/m^2	SAGO Average Height	TARA Crown Cover	G/S Crown Cover	S/F Crown Cover	TARA Canopy Cover	G/S Canopy Cover	S/F Canopy Cover	TARA Stems/m^2	TARA Average Height
Main Effects	**p Values[4]**											
Seed Treatment	0.500	0.092	0.053	0.824	0.340	0.783	0.953	0.539	0.482	0.576	0.628	0.591
Surface Irrigation Method	0.183	0.156	0.300	0.723	0.338	0.923	0.805	0.756	0.748	0.926	0.786	0.779
Seeding Rate PLS/m^2	0.896	0.649	0.768	0.156	0.732	0.642	0.797	0.317	0.249	0.983	0.406	0.455
Interaction												
Seed Treatment*Surface Irrigation Method	0.449	0.346	0.668	0.908	0.760	0.084	0.757	0.159	0.016	0.797	0.576	0.668
Seed Treatment	**Means and Significant Differences[5]**											
Uncleaned Hydroseed	0.087A	0.257A	4.78A	129A	0.192A	0.013A	0.576A	0.705A	0.143A	0.862A	27.28A	100A
Cleaned Broadcast	0.054A	0.115A	0.64B	136A	0.288A	0.017A	0.584A	0.776A	0.100A	0.826A	24.72A	88A
Surface Irrigation Method												
Border-strip	0.039A	0.132A	1.75A	127A	0.284A	0.016A	0.594A	0.757A	0.113A	0.841A	26.66A	97A
Furrow	0.101A	0.240A	3.67A	138A	0.196A	0.014A	0.565A	0.724A	0.130A	0.847A	25.34A	91A
Interactions												
Broadcast, Border	0.006A	0.026B	0.08B	132A	0.318A	0.033A	0.614A	0.714A	0.168 AB	0.815A	24.00A	87A
Broadcast, Furrow	0.102A	0.204AB	1.19AB	139A	0.257A	0.002A	0.553A	0.609A	0.032B	0.836A	25.43A	90A
Hydroseed, Border	0.073A	0.238AB	3.42AB	121A	0.250A	-0.001A	0.573A	0.800A	0.057B	0.867A	29.31A	108A
Hydroseed, Furrow	0.100A	0.276A	6.14A	136A	0.134A	0.002A	0.580A	0.609A	0.229A	0.857A	25.26A	93A
Seeding Rate, PLS/m^2												
Correlation Relationship[6] – direct	0.896	0.649			0.241		0.797	0.159			0.406	0.455
Correlation Relationship[6] – inverse			0.768	0.156		0.642			0.249	0.983		

1 Codes are for Goodding's willow (SAGO), saltcedar (TARA), combined grasses and sedges (G/S), and shrubs and forbs excluding saltcedar (S/F).
2 Crown cover is the first cover type below a transect point; cover percentage is the ratio of the cover type to the total number of counting points (63) examined.
3 Canopy cover is the total canopy cover of the given vegetation type, including crown cover.
4 Tests were run using JMP V 6.0.0 (SAS Institute, Cary, NC).
5 Numbers denote least-squared means, letters denote significant differences at p=0.05 within each main effect column according to Least-squared Means Differences Student's t-test; the same letters indicate that the difference between means is not significant, and different letters indicate that the means are statistically significant. Means are compared within a result (column), not between them.
6 Relationships denote a direct (increasing-increasing) or inverse (increasing-decreasing) correlation between results and seeding rates.

Table 11. ANOVA modeling results for Gooding's willow and saltcedar in 2008 small-scale field study plots between October 2009 and October 2010.

Results		SAGO[1] Growth[2], cm	TARA Growth, cm
Main Effects		**p Values[3]**	
Irrigation Treatment		0.571	0.332
Surface Irrigation Method		0.323	0.588
Saltcedar Crown Cover[5]		0.484	0.024
Shrub and Forb Crown Cover		0.188	0.373
Initial Tree Height[6]		0.016	0.310
Irrigation Treatment[7]		**Means and Significant Differences[4]**	
	A	1.16 A	-19.3 A
	B	-6.87 A	-13.4 A
Surface Irrigation Method			
	Border-strip	-7.83 A	-14.9 A
	Furrow	2.12 A	-17.8 A
Saltcedar Crown Cover			
	20-40%	-14.4 A	-28.4 B
	40.1-60%	8.1 A	-10.6 A
	60.1-80%	-2.3 A	-10.1 AB
Shrub and Forb Crown Cover			
	0-17%	5.7 AB	-9.2 A
	17.1-34%	-43.7 B	-21.5 A
	34.1-51%	6.4A B	-15.4 A
	51.1-68%	20.2 A	-19.2 A
Initial Tree Height, cm		**p Values**	
Correlation Relationship[8]	direct	0.016	0.310
	inverse		

1 Codes are for Goodding's willow (SAGO) and saltcedar (TARA).
2 Growth between October 2009 and October 2010 surveys.
3 Tests were run using JMP V 6.0.0 (SAS Institute, Cary, NC).
4 Numbers denote least-squared means, letters denote significant differences at p=0.05 within each main effect column according to Least-squared Means Differences Student's t-test; the same letters indicate that the difference between means is not significant, and different letters indicate that the means are statistically significant. Means are compared within a result (column), not between them.
5 Crown cover is the first cover type below a transect point; cover percentage is the ratio of the cover type to the total number of counting points (63) examined.
6 Height as measured during May 2008 surveys.
7 Codes indicated shallow, frequent irrigation (A) or deep, infrequent irrigation (B).
8 Relationships denote a direct (increasing-increasing) or inverse (increasing-decreasing) correlation between growth rates and initial (October, 2009) tree heights.

Table 12. Goodding's willow and saltcedar mortality between October 2009 and October 2010 in 2008 small-scale study plots. Letters indicate significant differences across all values (t-test on proportions, α=0.05).

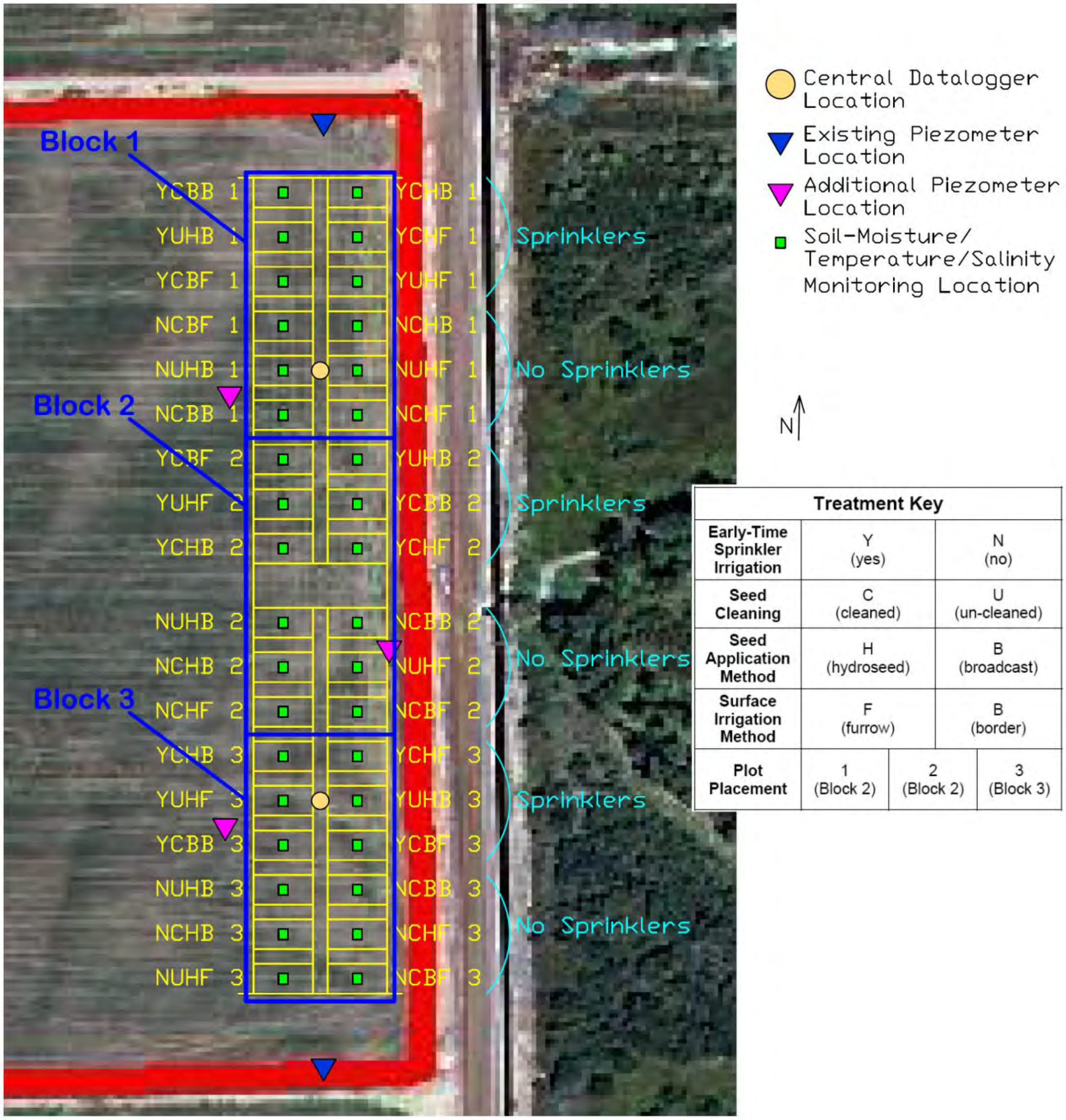
Height Category	Irrigation Treatment	Goodding's Willow		Saltcedar	
		Mortality and Significant Differences	n	Mortality and Significant Differences	n
0-100	A	58% B	26	40% BC	84
	B	95% A	65	20% C	114
100.5-200	A	0% F	20	3% EF	74
	B	32% CD	34	6% E	53
200-300	A	--	0	0% F	23
	B	0% F	9	0% F	13
300-400	A	--	0	0% F	2
	B	--	0	--	0

Table 13. 2009 Goodding's willow small-scale study result averages and significant differences for Goodding's willow (SAGO), saltcedar (TARA), grasses and sedges (G/S), and shrubs and forbs (S/F) per plot.

Seeding Rate, PLS/m^2	Crown Cover[1]				Canopy Cover				Tree Density, Stems/m^2	
	SAGO	TARA	G/S	S/F	SAGO	TARA	G/S	S/F	SAGO	TARA
579	0.07 G	0.16 F	0.01 H	0.68 A	0.16 G	0.35 E	0.06 H	0.88 A	6.0 A	3.0 A
1150	0.10 G	0.22 E	0.02 H	0.57 B	0.23 F	0.42 D	0.06 H	0.83 B	7.2 A	3.6 A
1685	0.32 D	0.18 EF	0.02 H	0.42 C	0.53 C	0.40 DE	0.11 G	0.86 AB	14.8 A	4.3 A

1 Numbers show arithmetic means, letters denote significant differences at p=0.05 for all values for a given result.

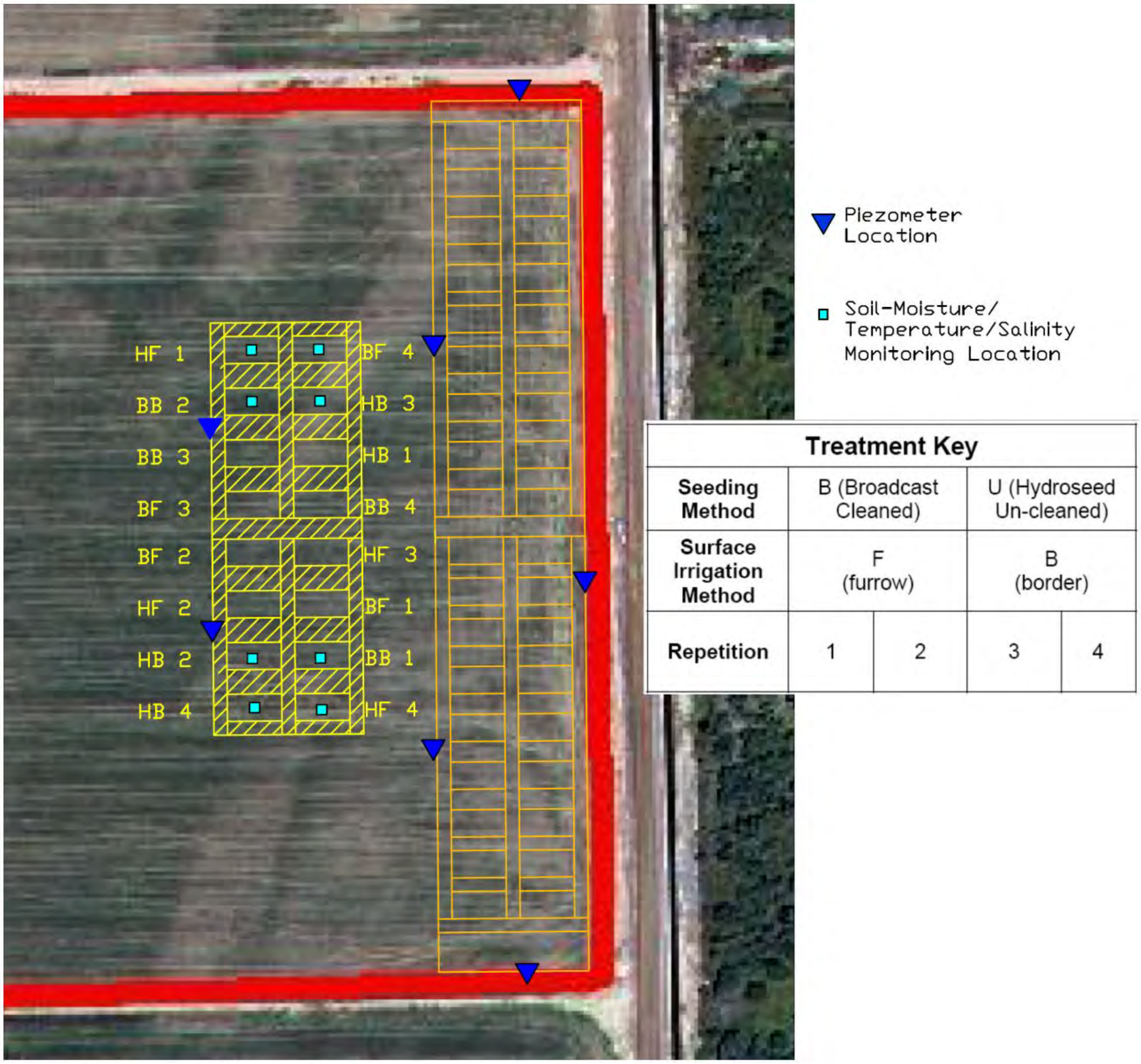
FIGURES



Treatment Key

Early-Time Sprinkler Irrigation	Y (yes)	N (no)	
Seed Cleaning	C (cleaned)	U (un-cleaned)	
Seed Application Method	H (hydroseed)	B (broadcast)	
Surface Irrigation Method	F (furrow)	B (border)	
Plot Placement	1 (Block 2)	2 (Block 2)	3 (Block 3)

Figure 1. Layout and treatments for 2007 small-scale field study plots at Cibola NWR Field 51.



Treatment Key				
Seeding Method	B (Broadcast Cleaned)		U (Hydroseed Un-cleaned)	
Surface Irrigation Method	F (furrow)		B (border)	
Repetition	1	2	3	4

Figure 2. Layout and treatments for 2008 small-scale field study plots at Cibola NWR Field 51.

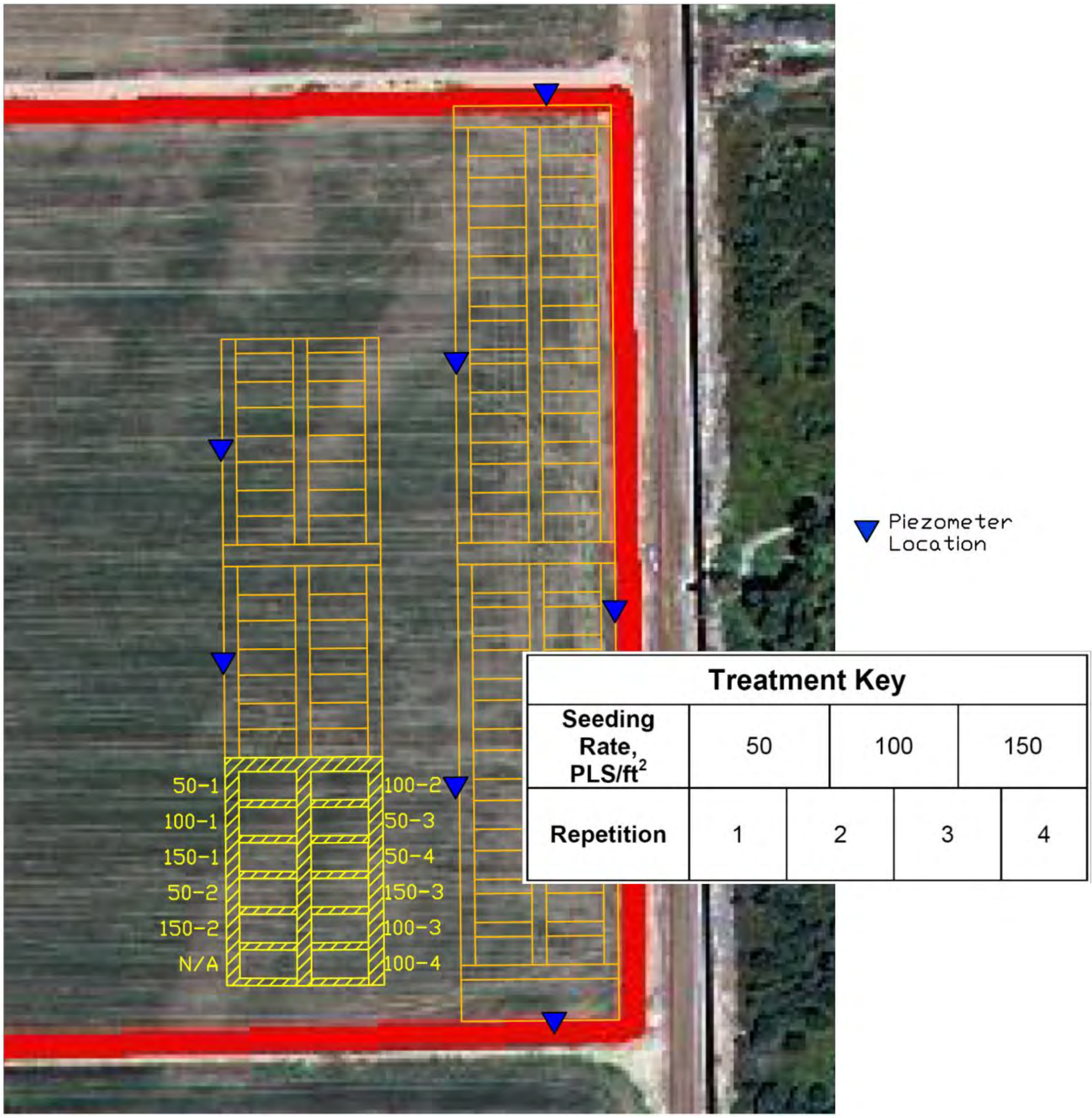


Figure 3. Layout and treatments for 2009 small-scale field study plots at Cibola NWR Field 51.

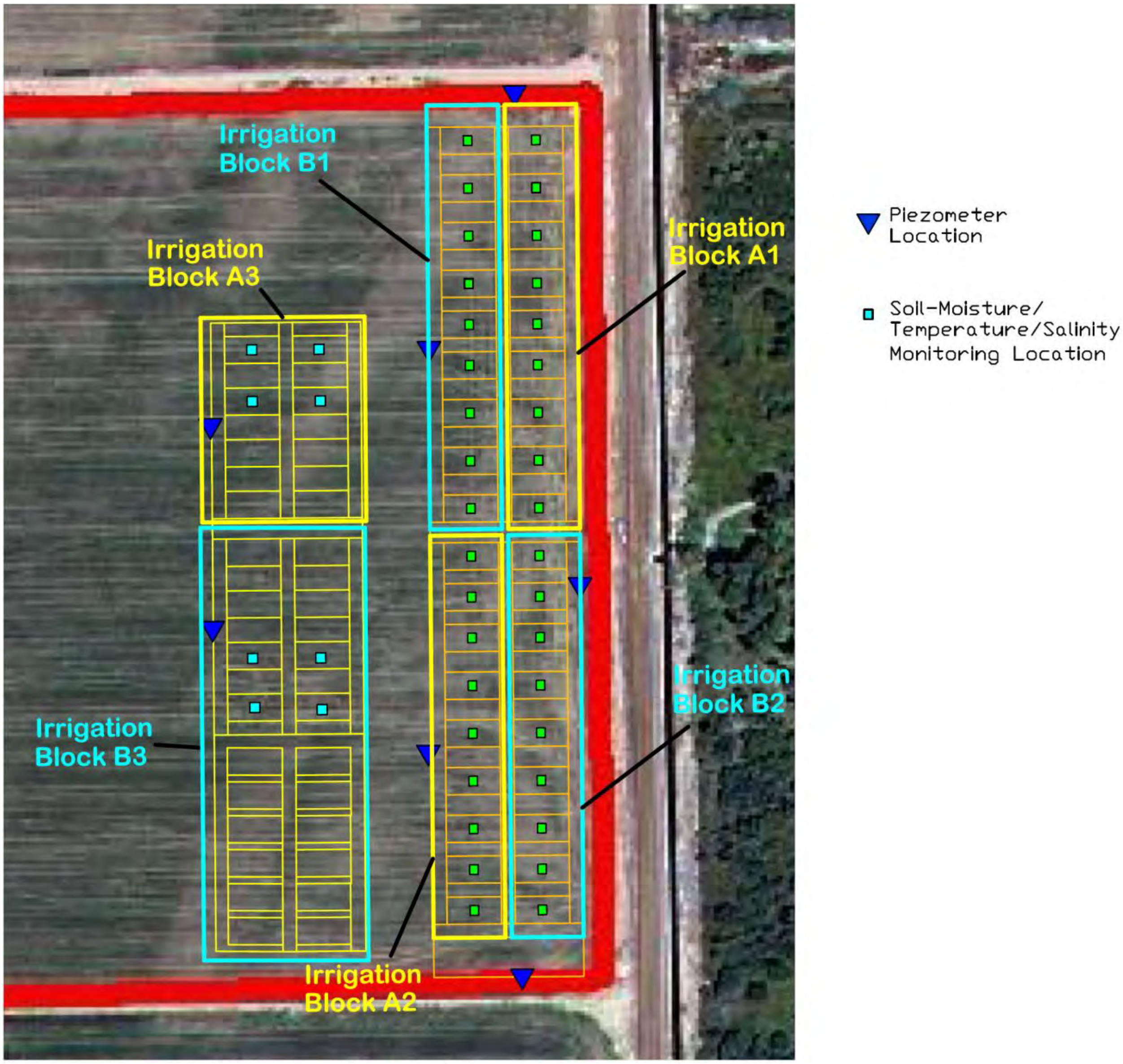


Figure 4. 2010 growing season irrigation block layout for small-scale field study plots at Cibola NWR Field 51.

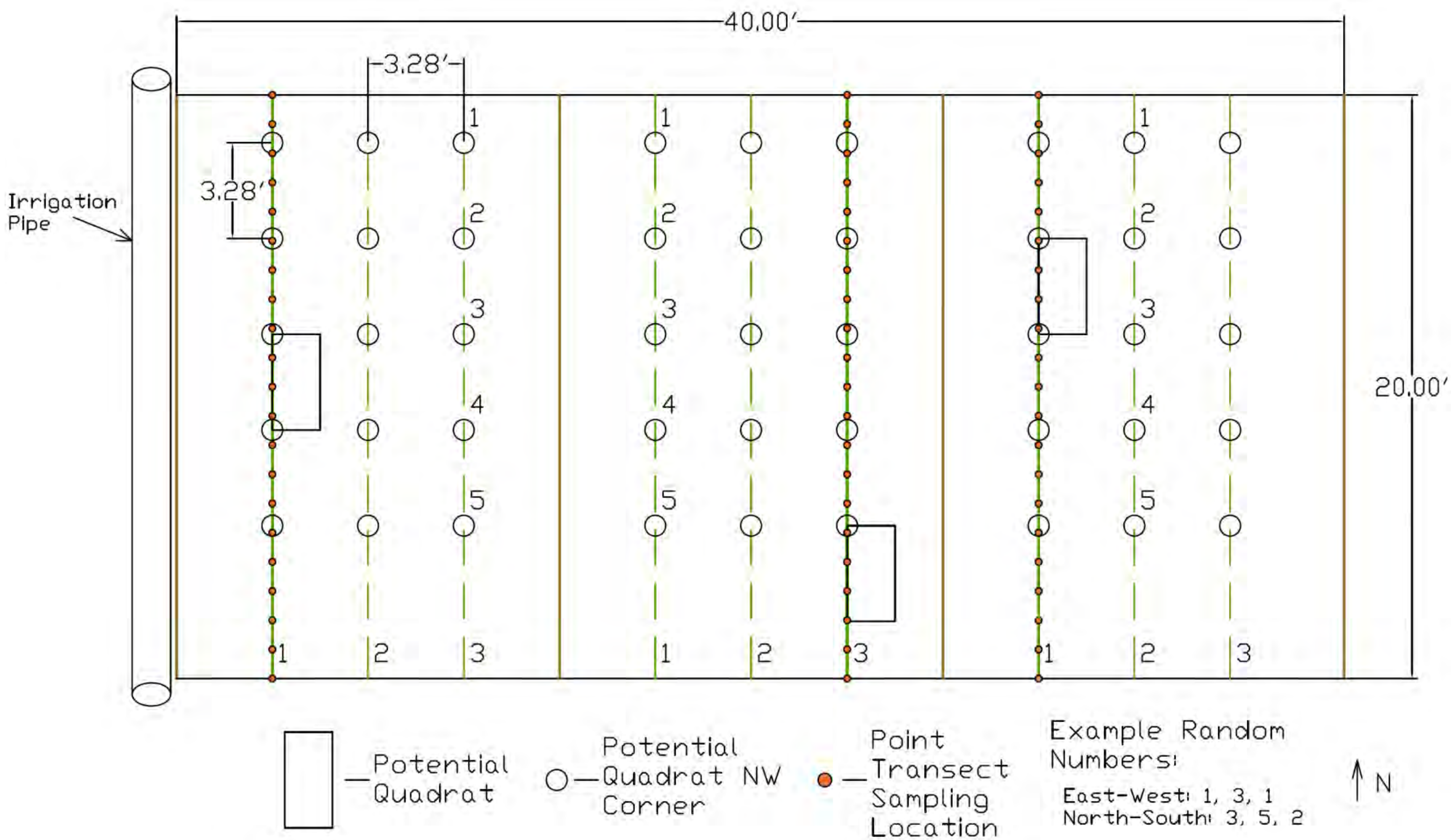


Figure 5. Example vegetation monitoring schematic for small-scale field study plots at Cibola NWR Field 51.

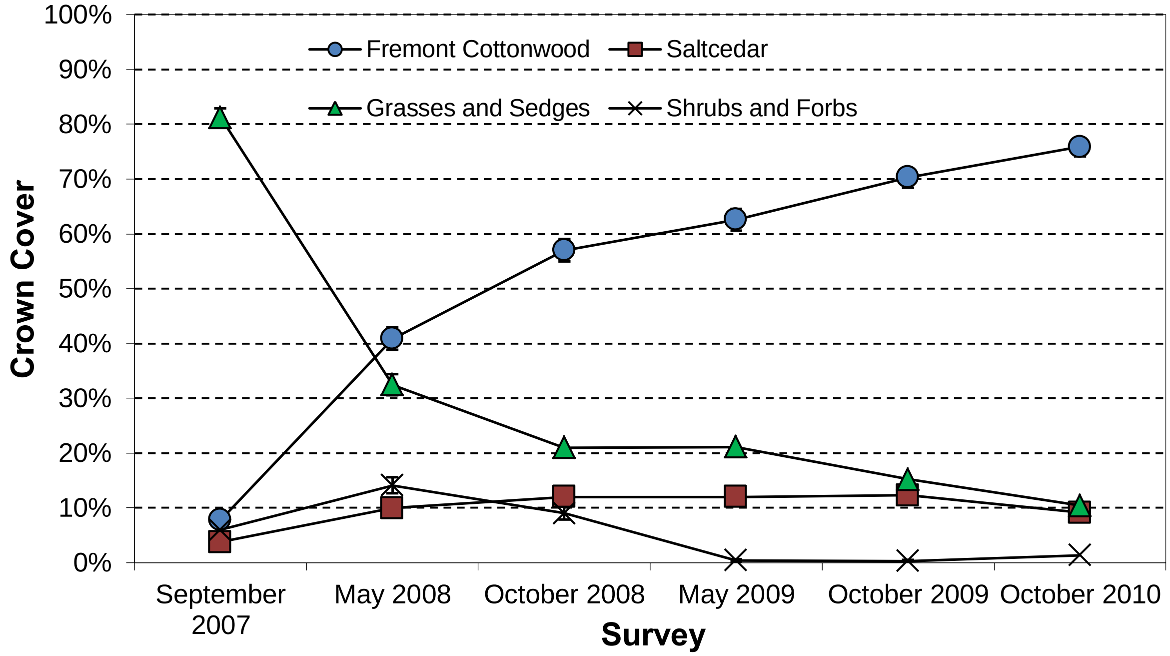


Figure 6. Vegetation crown cover trends for Fremont cottonwood (POFR), saltcedar (TARA), grasses and sedges (G/S), and shrubs and forbs (S/F) in 2007 study plots.

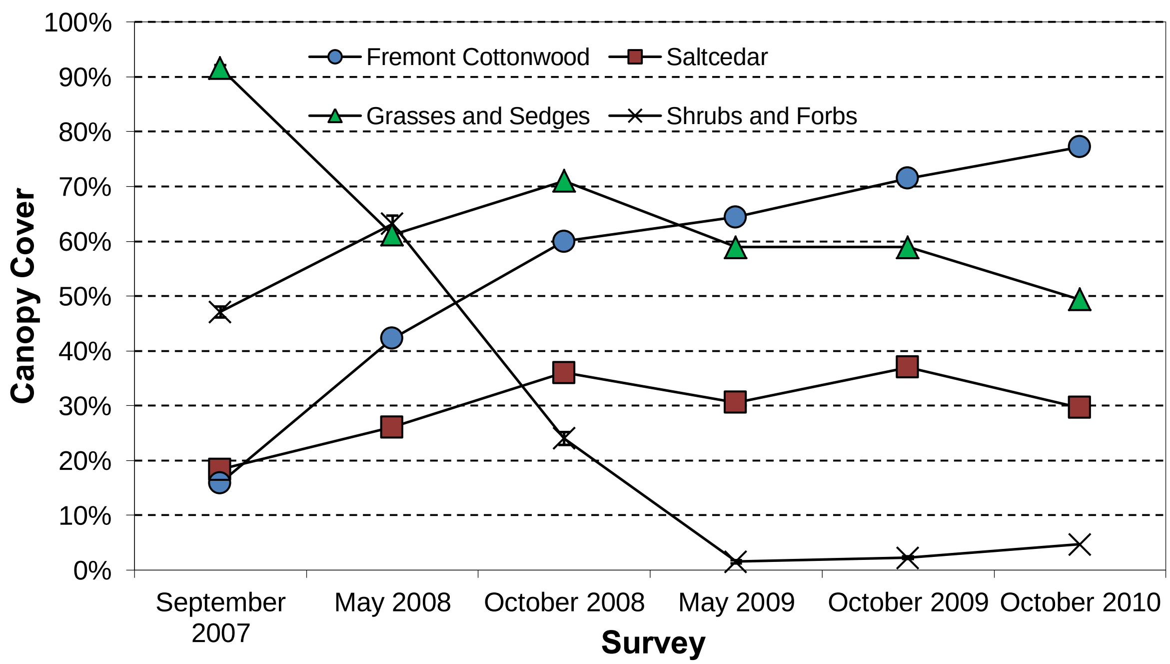


Figure 7. Vegetation canopy cover trends for Fremont cottonwood (POFR), saltcedar (TARA), grasses and sedges (G/S), and shrubs and forbs (S/F) in 2007 study plots.

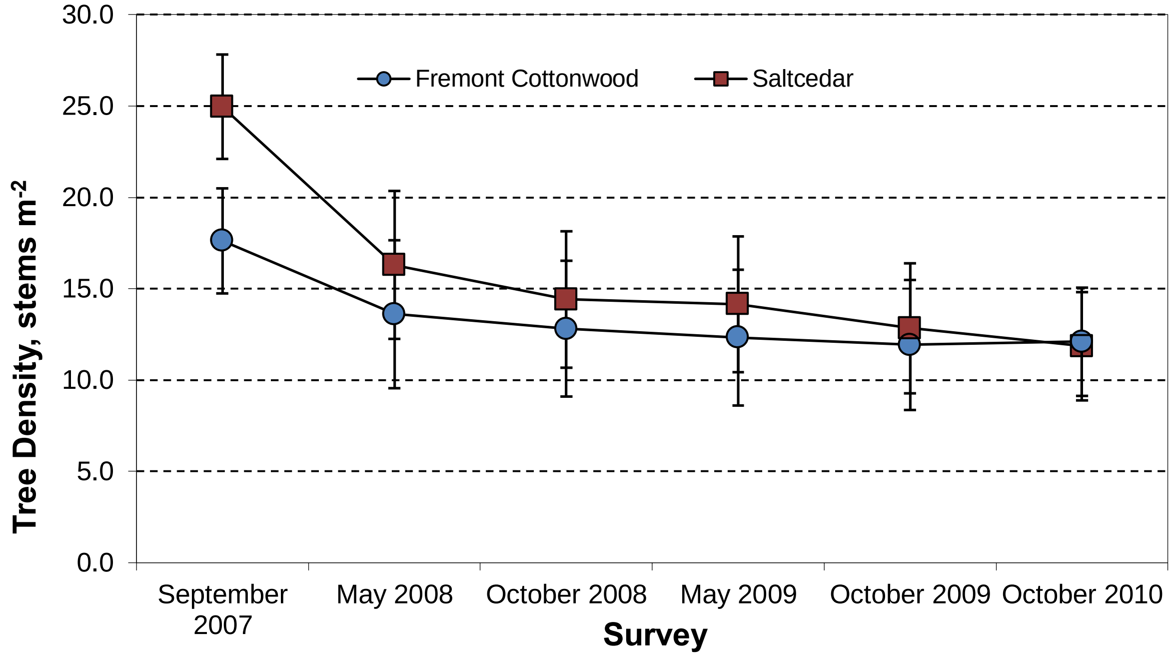


Figure 8. Fremont cottonwood (POFR) and saltcedar (TARA) tree density trends in 2007 small-scale study plots.

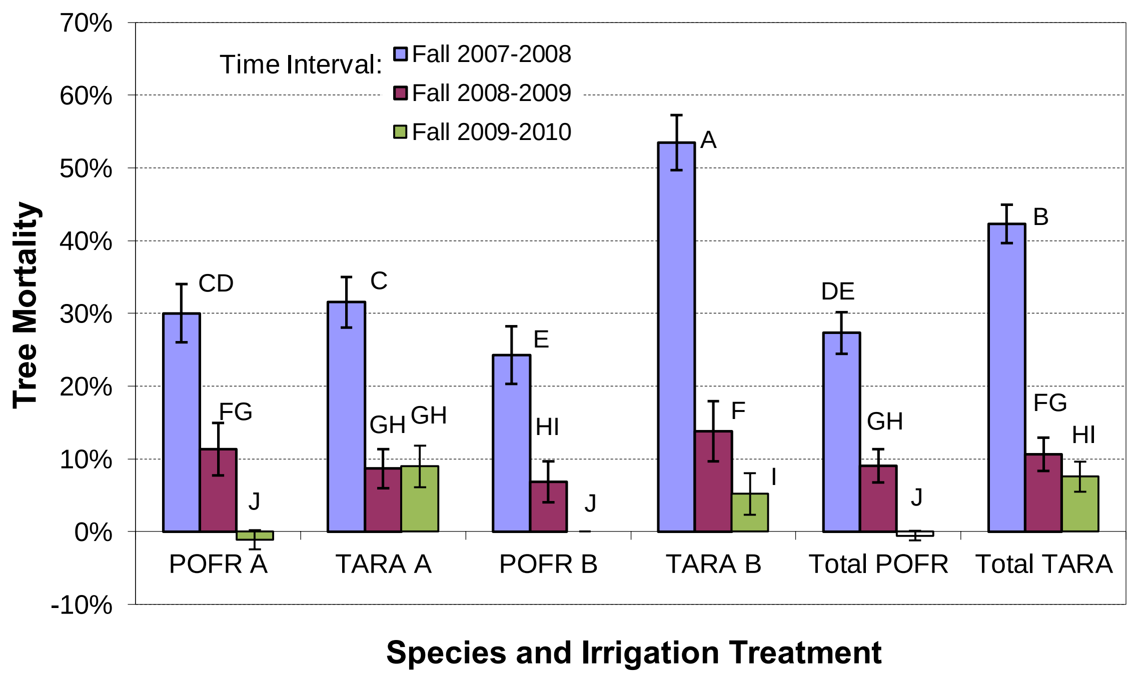


Figure 9. Fremont cottonwood (POFR) and saltcedar (TARA) mortality versus irrigation treatment (A: shallow, frequent; B: deep, infrequent) and growing season in 2007 study plots for all heights combined based on quadrat data. Letters indicate significant differences across all columns (t-test on proportions, α=0.05).

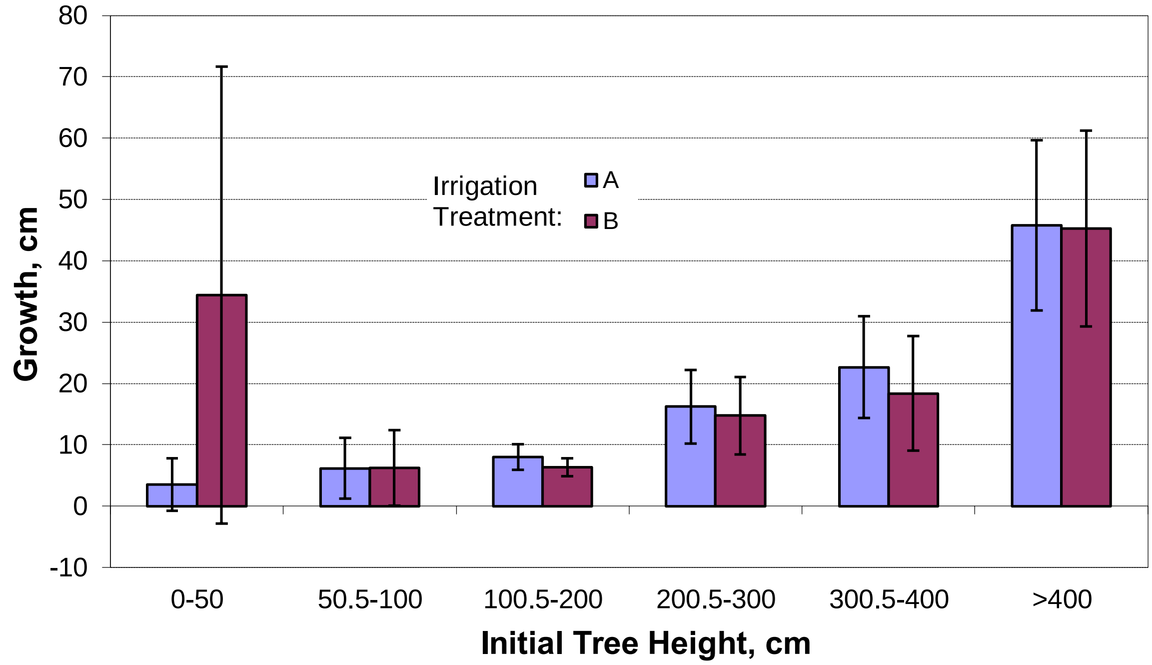


Figure 10. Fremont cottonwood growth versus initial height (October 2009) and irrigation treatment in 2007 study plots between October 2009 and October 2010. No significant differences were observed between paired columns (Student's t-test, α=0.05).

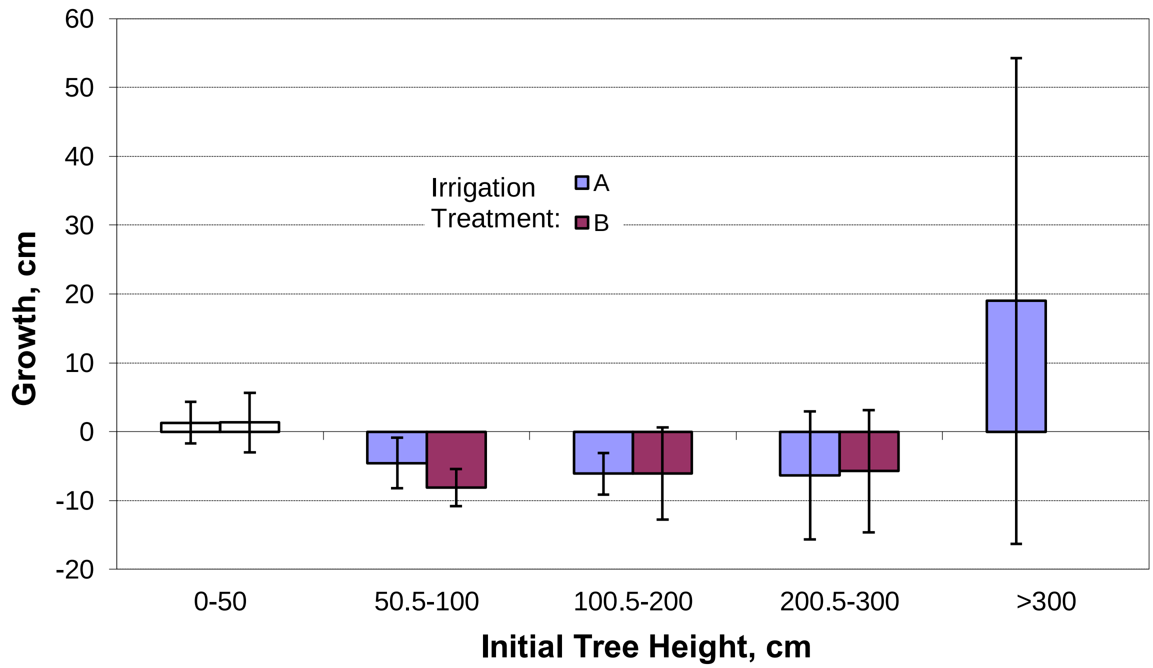


Figure 11. Saltcedar growth versus initial height (October 2009) and irrigation method in 2007 study plots between October 2009 and October 2010. * indicates significant differences between paired columns (Student's t-test, α=0.05).

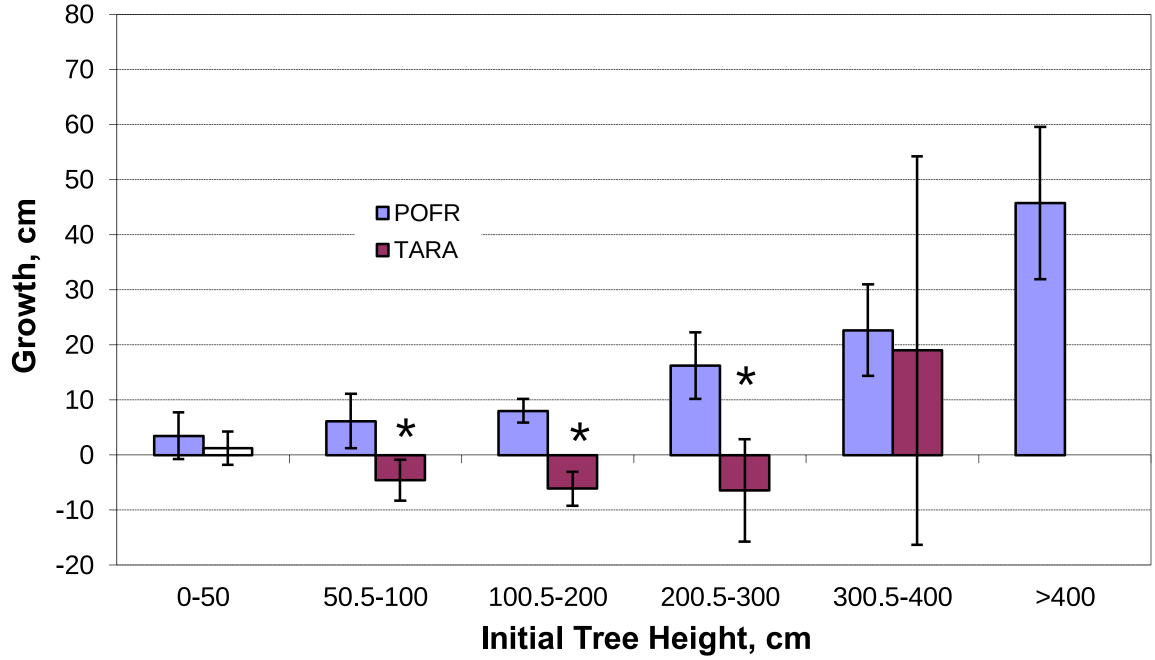


Figure 12. Fremont cottonwood (POFR) and saltcedar (TARA) growth versus initial height (October 2009) in 2007 study plots between October 2009 and October 2010 surveys, A blocks only. * indicates significant differences between paired columns (Student's t-test, α=0.05).

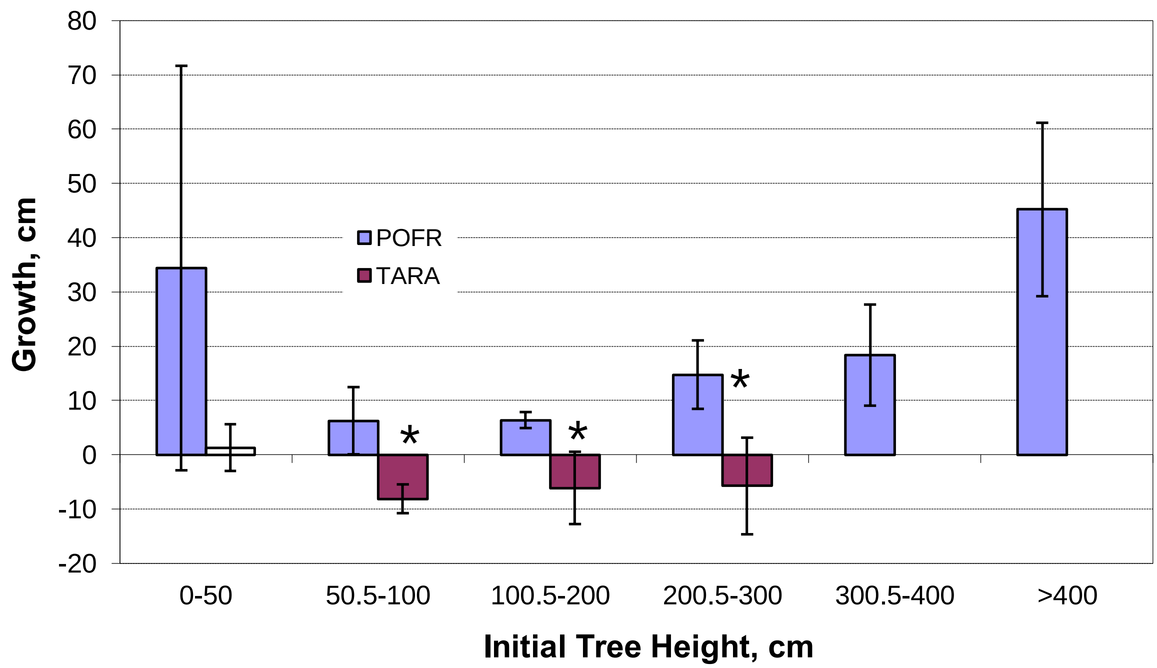


Figure 13. Fremont cottonwood (POFR) and saltcedar (TARA) growth versus initial height (October 2009) in 2007 study plots between October 2009 and October 2010 surveys, B blocks only. * indicates significant differences between paired columns (Student's t-test, α=0.05).

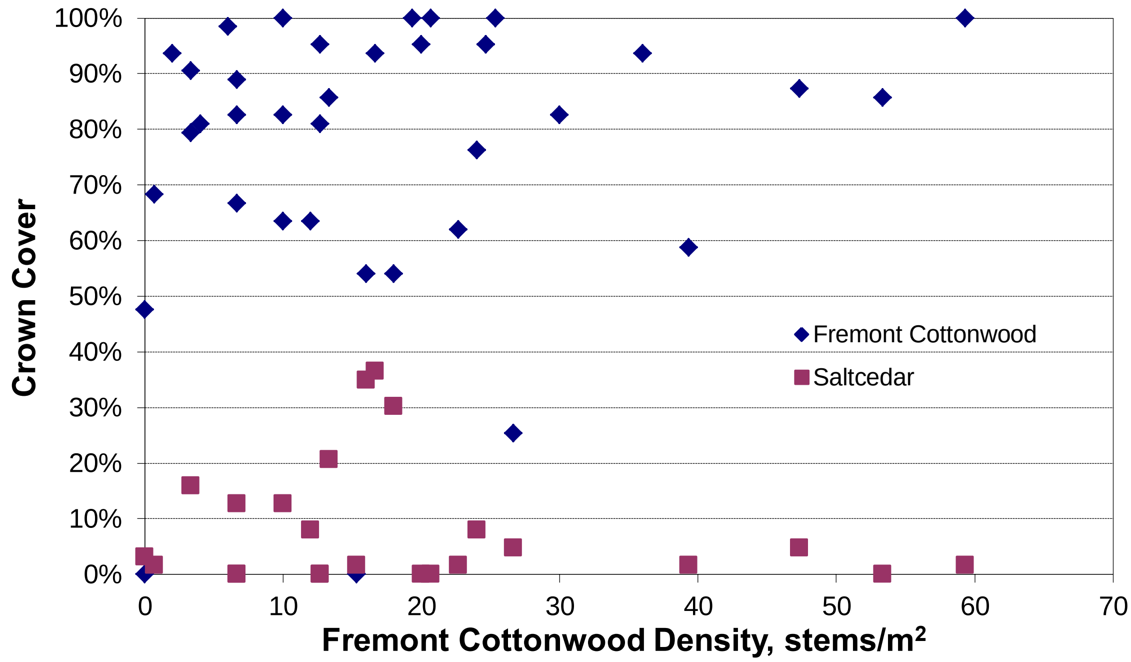


Figure 14. Fremont cottonwood and saltcedar crown cover after four growing seasons (October 2009) versus Fremont cottonwood stem density after the first growing season (September 2007).

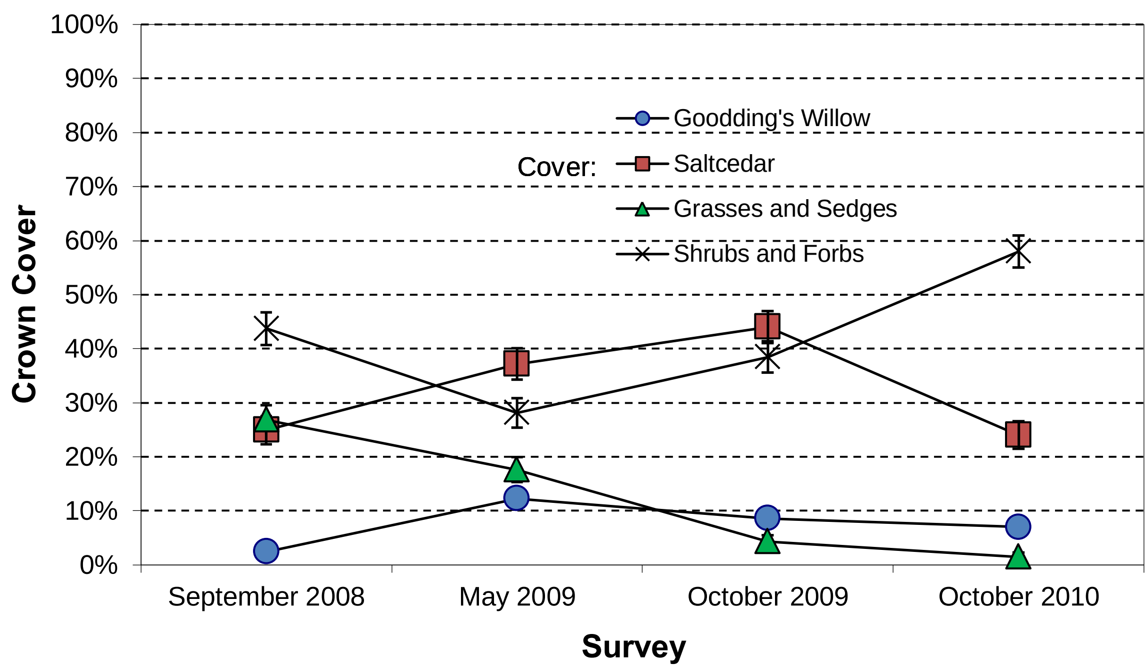


Figure 15. Vegetation crown cover trends for Goodding's willow (SAGO), saltcedar (TARA), grasses and sedges (G/S), and shrubs and forbs (S/F) in 2008 study plots.

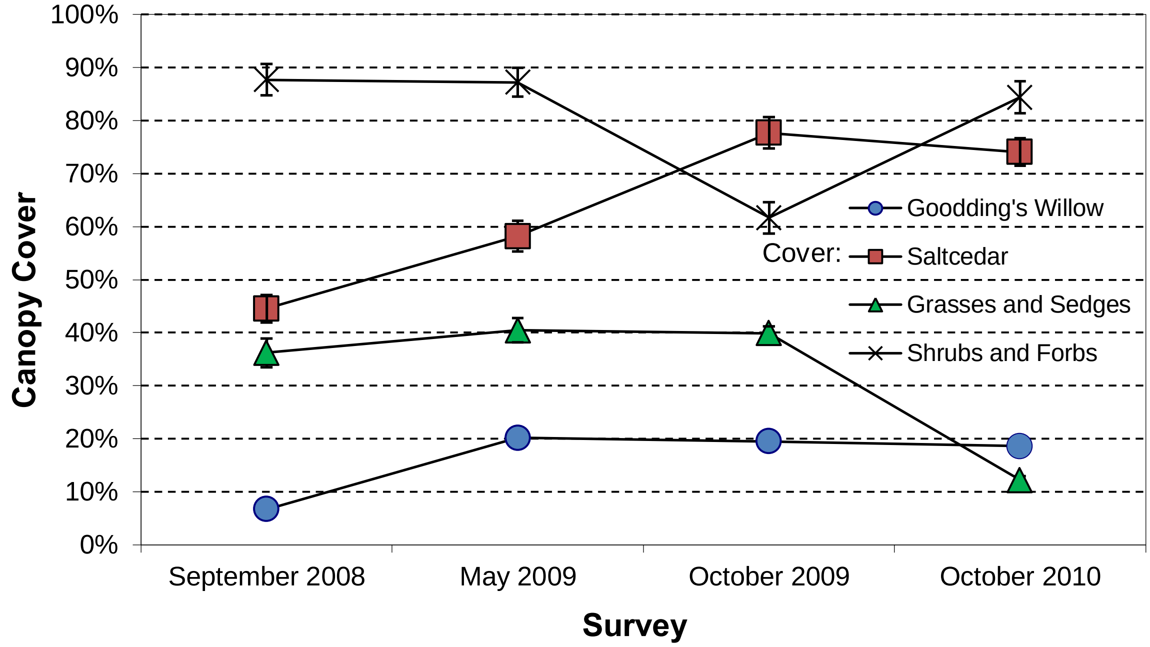


Figure 16. Vegetation canopy cover trends for Goodding's willow (SAGO), saltcedar (TARA), grasses and sedges (G/S), and shrubs and forbs (S/F) in 2008 study plots.

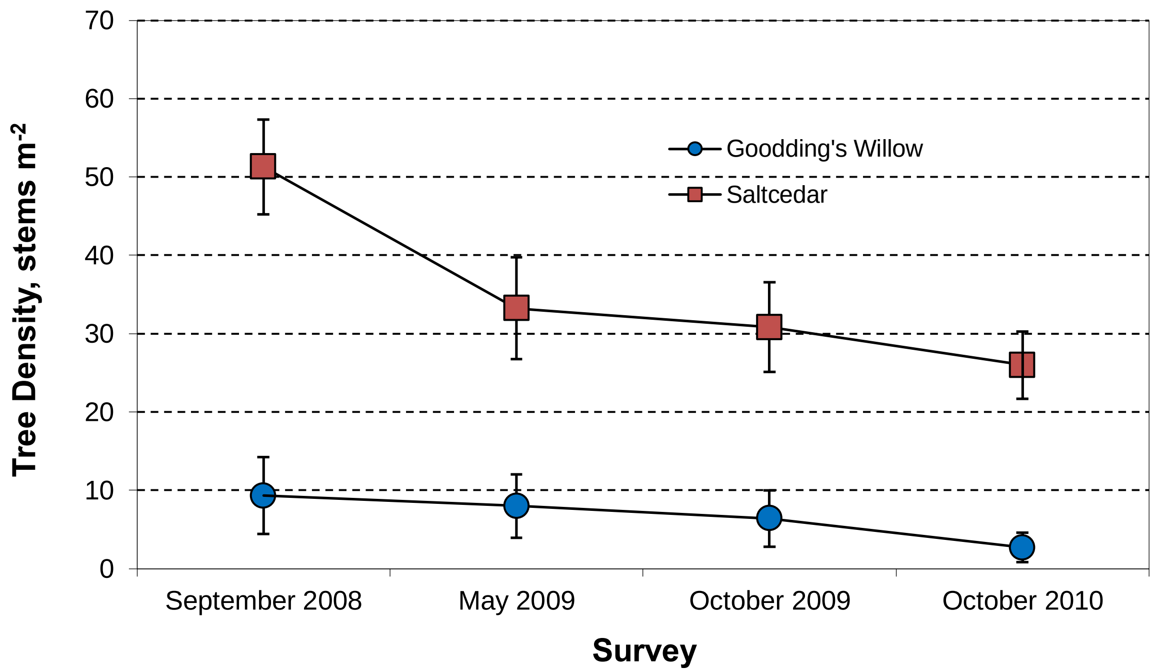


Figure 17. Goodding's willow and saltcedar tree density trends in 2008 small-scale study plots.

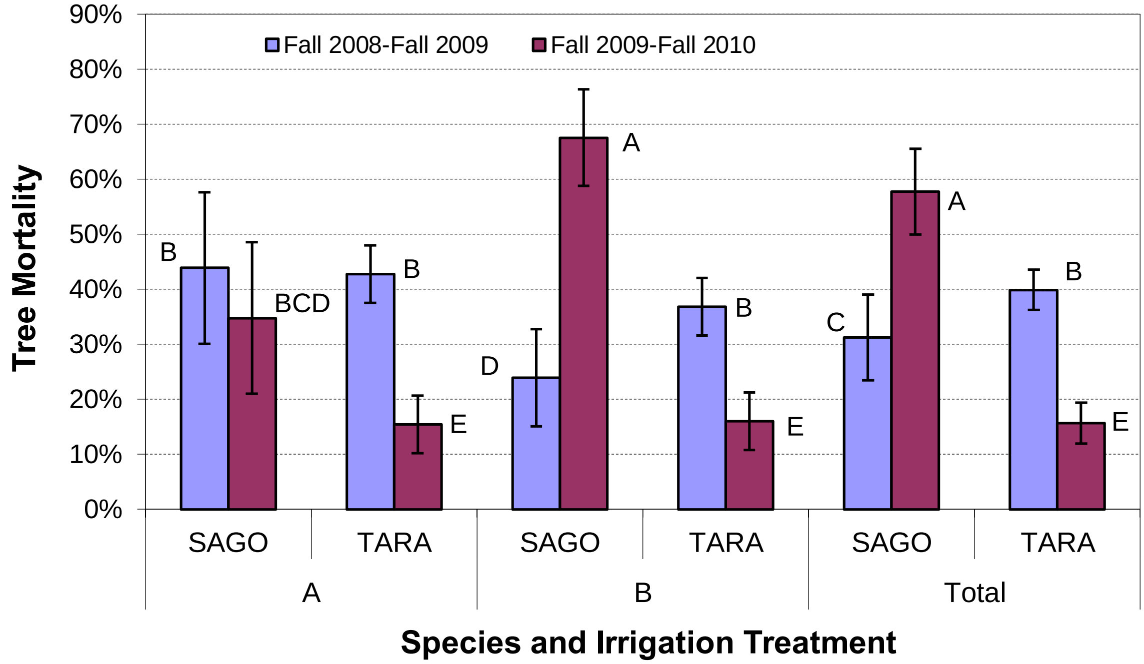


Figure 18. Goodding's willow (SAGO) and saltcedar (TARA) mortality rates versus irrigation method in 2008 study plots between the fall 2009 and fall 2010 surveys for all heights combined using quadrat data. Letters indicate significant differences across all columns (Student's t-test, α=0.05).

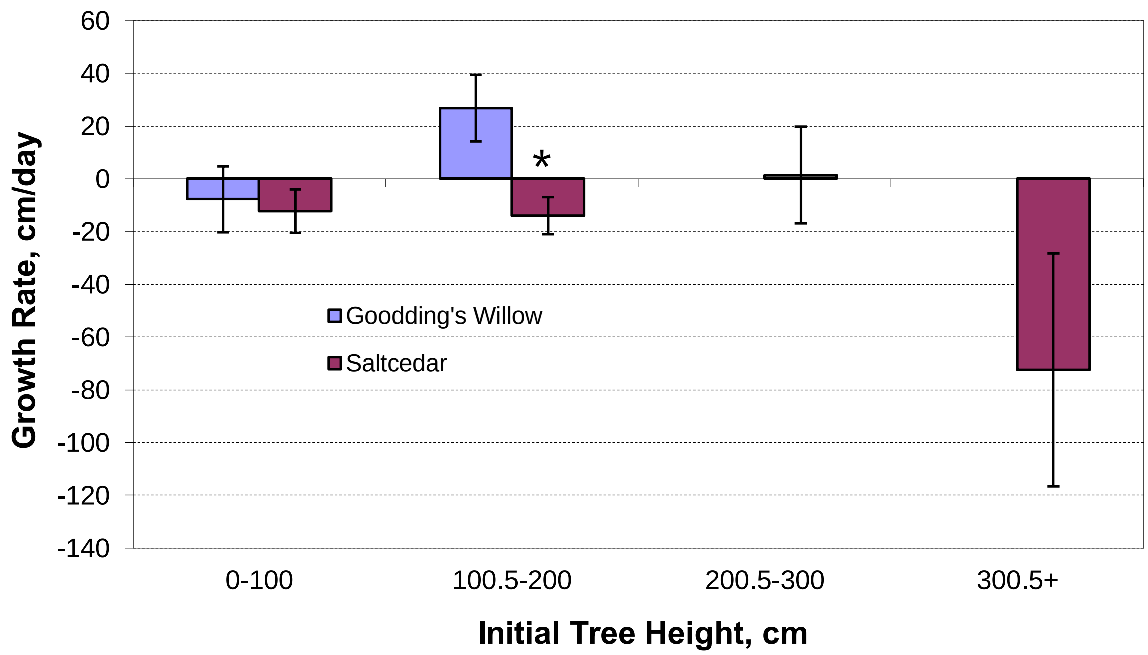


Figure 19. Goodding's willow and saltcedar growth rate versus initial height (October 2009) in 2008 study plots during the 2010 growing season, A blocks only. * indicates significant differences between paired columns (Student's t-test, α=0.05).

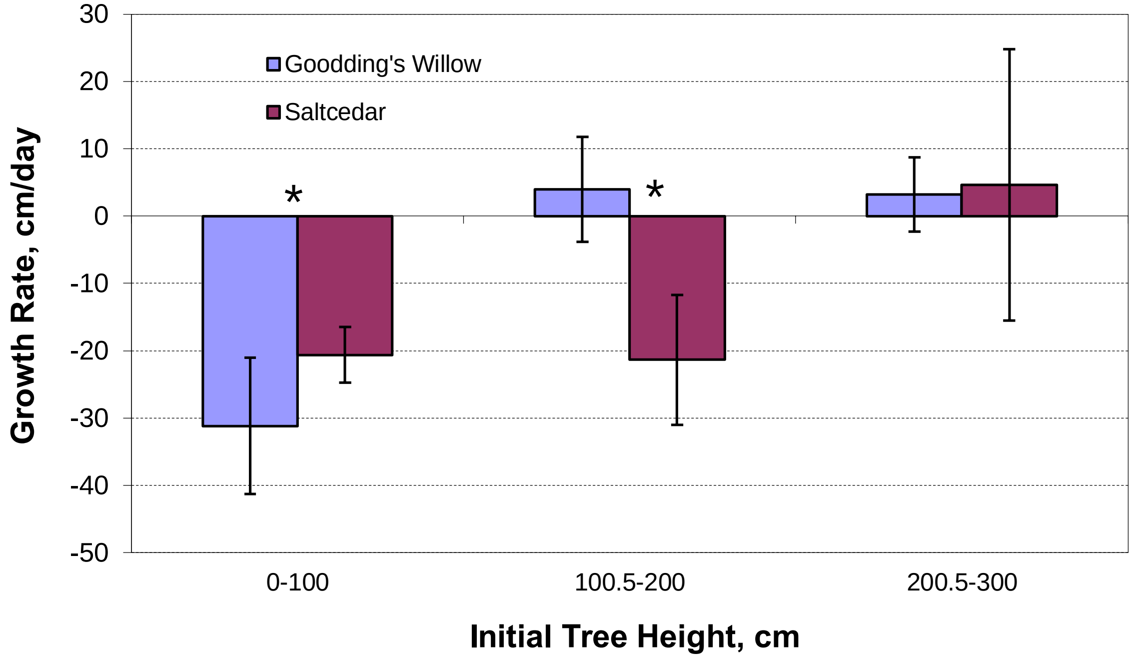


Figure 20. Goodding's willow and saltcedar growth rate versus initial height (October 2009) in 2008 study plots during the 2010 growing season, B blocks only. * indicates significant differences between paired columns (Student's t-test, α=0.05).

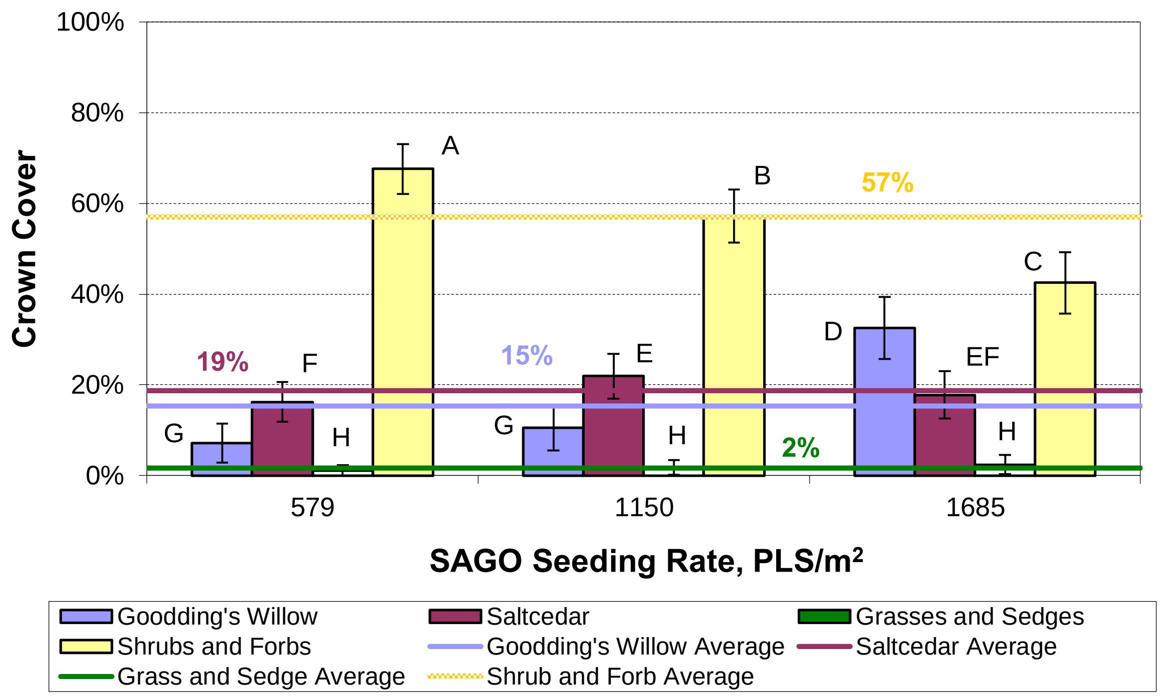


Figure 21. Average crown cover of Goodding's willow, saltcedar, grasses and sedges, and shrubs and forbs in 2009 Goodding's willow small-scale field study plots through two growing seasons. Letters indicate significant across all columns (Student's paired t-test, α=0.05).

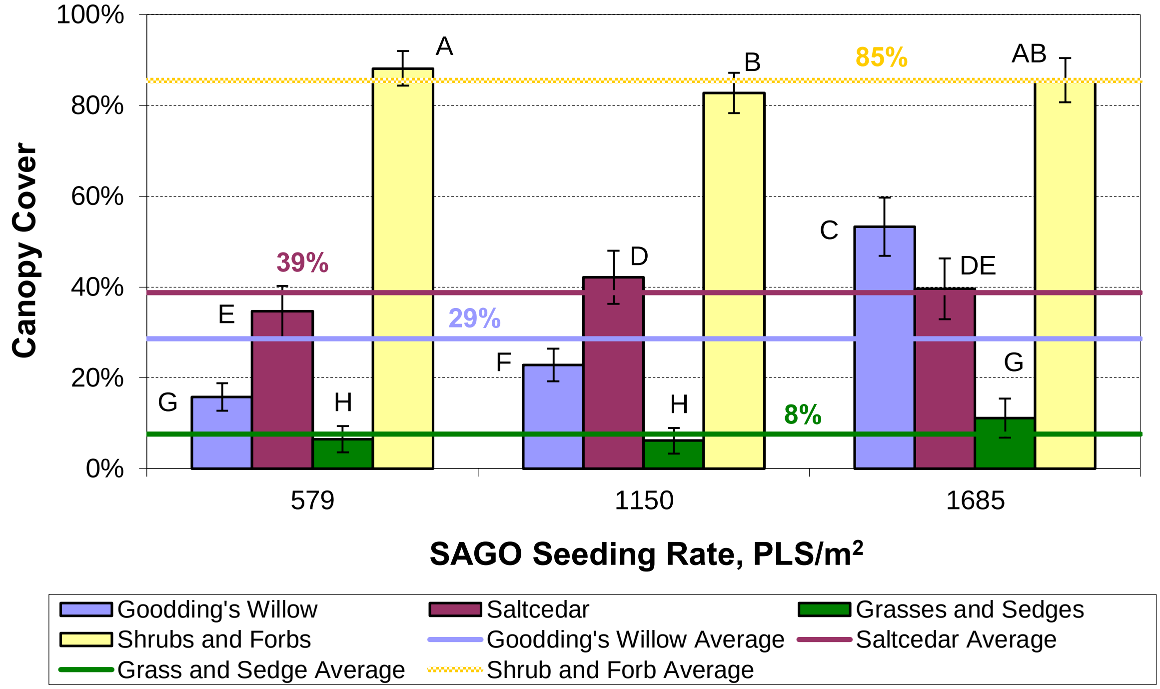


Figure 22. Average canopy cover of Goodding's willow, saltcedar, grasses and sedges, and shrubs and forbs in 2009 Goodding's willow small-scale field study plots through two growing seasons. Letters indicate significant across all columns (Student's paired t-test, α=0.05).

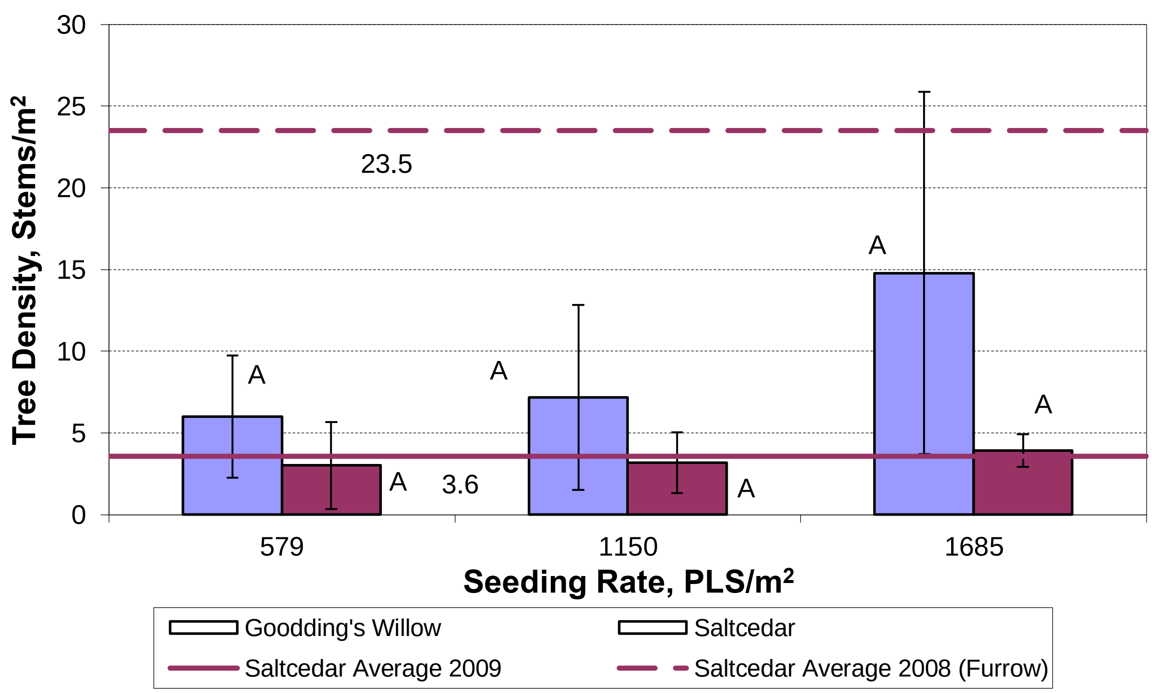


Figure 23. Average (per treatment) tree density of Goodding's willow and saltcedar in 2009 Goodding's willow small-scale field study plots over two growing seasons. Letters indicate significant differences across all columns (Student's t-test, α=0.05).

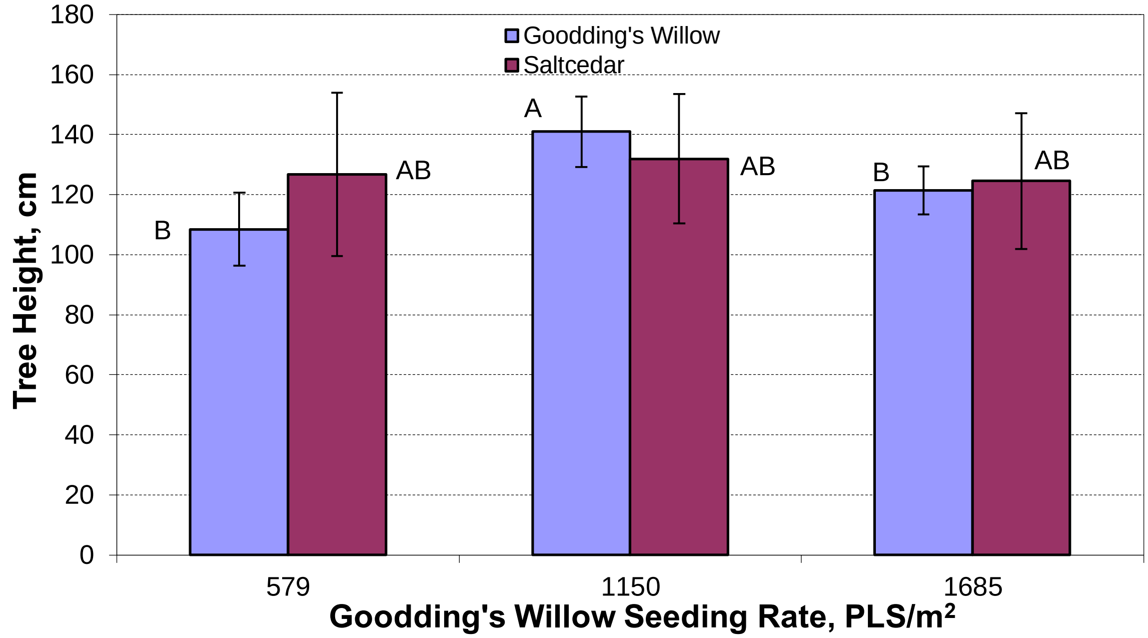


Figure 24. Average (per treatment) height of Goodding's willow and saltcedar in 2009 Goodding's willow small-scale field study plots after two growing seasons. Letters indicate significant differences across all columns at α=0.05.

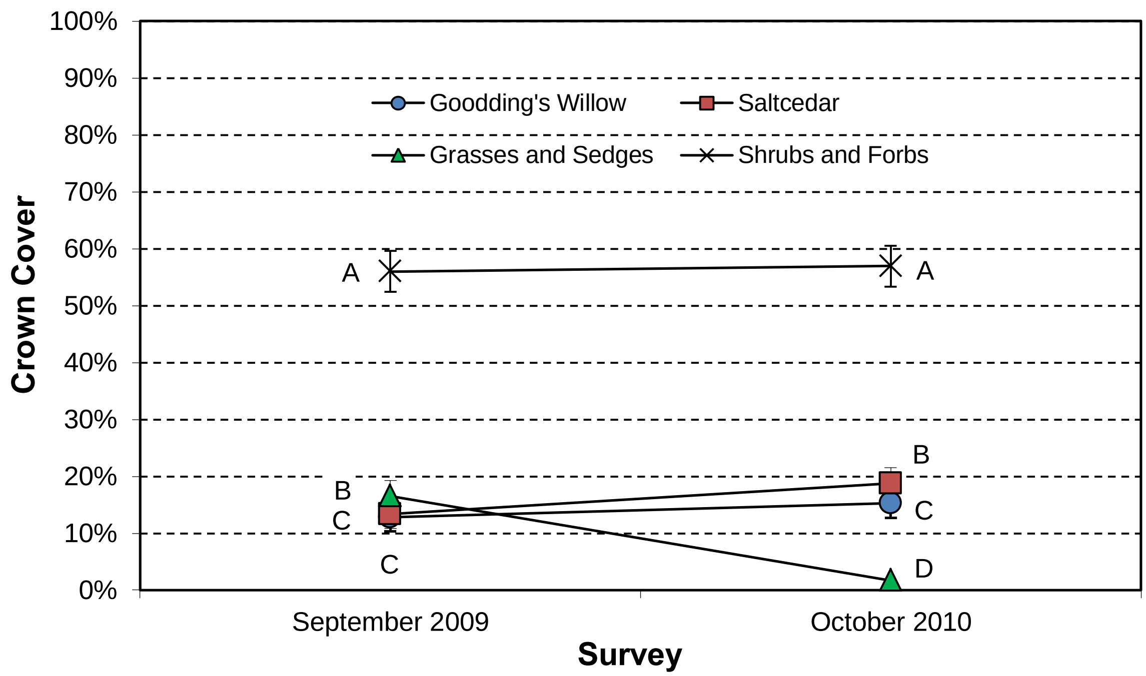


Figure 25. Vegetation crown cover trends in 2009 study plots for two growing seasons. Letters indicate significant differences for a given survey (Student's t-test, α=0.05).

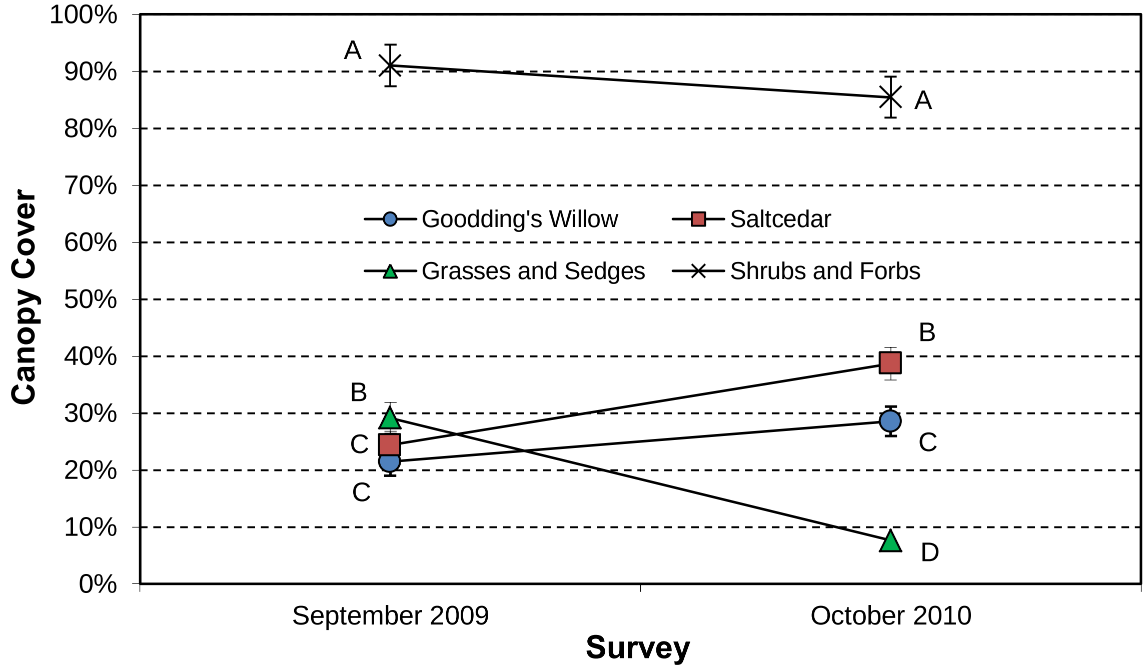


Figure 26. Vegetation crown cover trends in 2009 study plots for two growing seasons. Letters indicate significant differences for a given survey (Student's t-test, α=0.05).

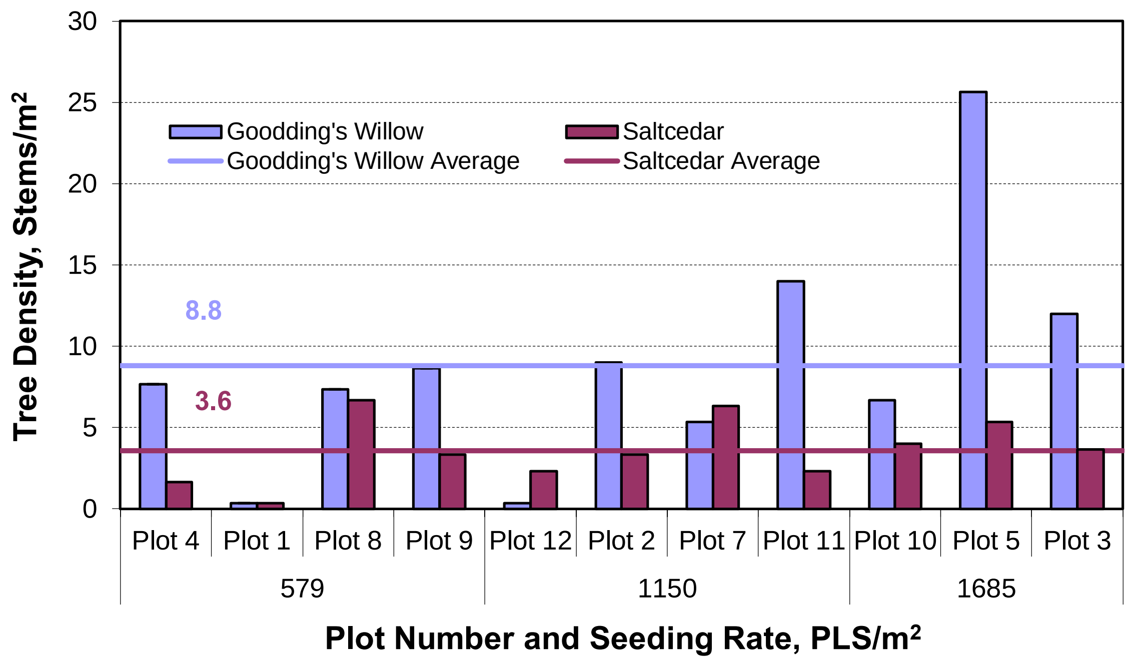


Figure 27. Average (per plot) stem density of Goodding's willow and saltcedar in 2009 Goodding's willow small-scale field study plots after two growing seasons.

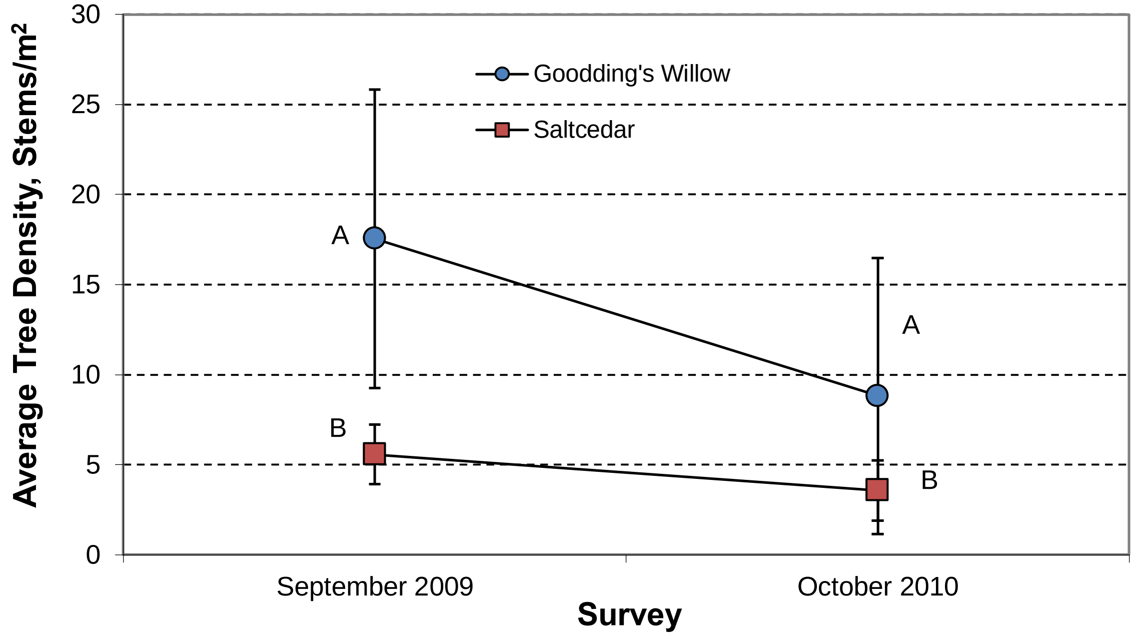


Figure 28. Overall average stem density of Goodding's willow and saltcedar in 2009 Goodding's willow small-scale field study plots through two growing seasons. Letters indicate significant differences for a given survey (Student's paired t-test, α=0.05).

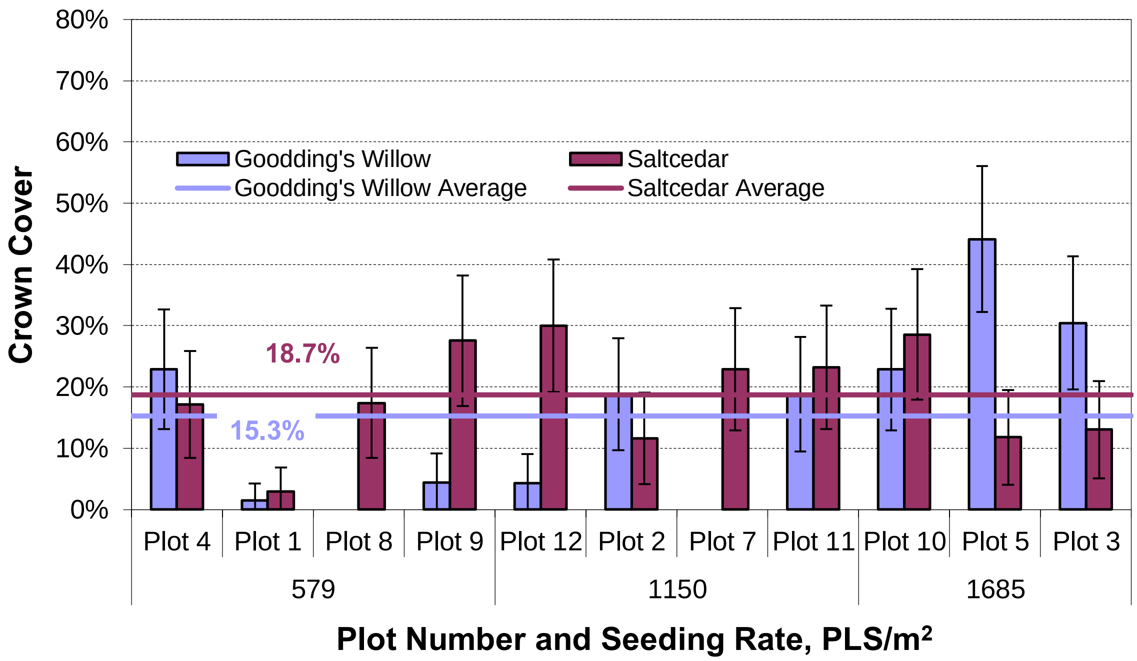


Figure 29. Average (per plot) crown cover of Goodding's willow and saltcedar in 2009 Goodding's willow small-scale field study plots after two growing seasons.

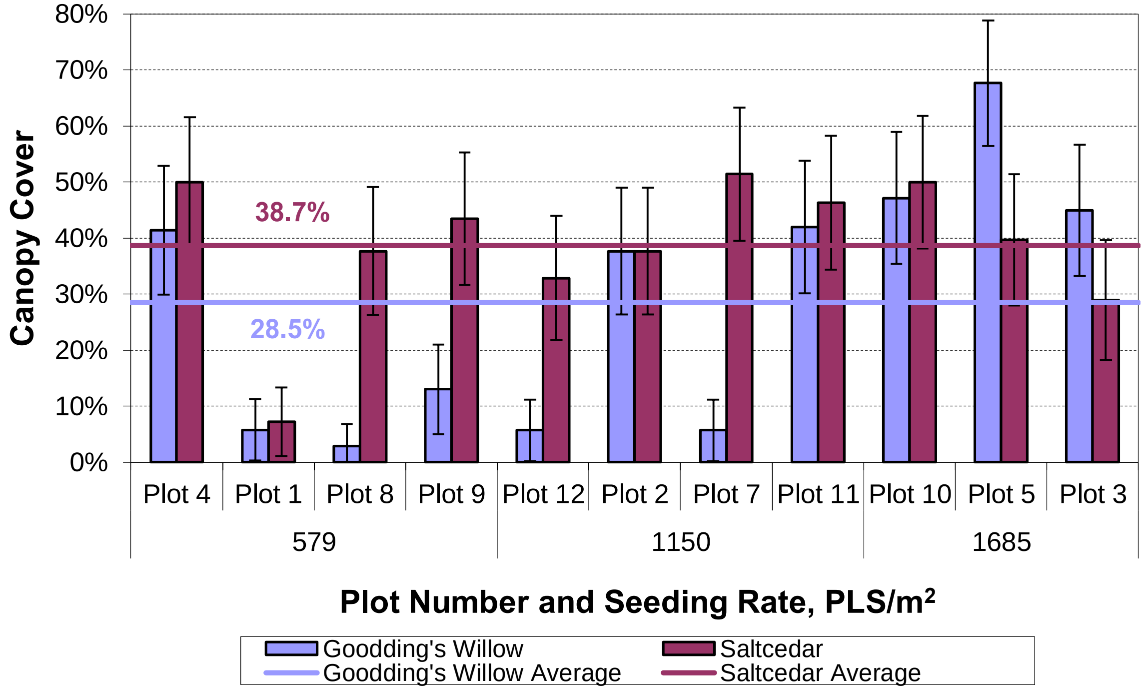


Figure 30. Average (per plot) canopy cover of Goodding's willow and saltcedar in 2009 Goodding's willow small-scale field study plots after two growing seasons.